QLK5-CT-2002-01270 PLYBIOTESTREPORT for the period 01/01/2003 – 31/12/2006(finalized 10/11/2008)

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QLK5-CT-2002-01270

PLYBIOTEST

Biological performance testing methodology to evaluate the durability of plywood as an indicator for exterior construction purposes

REPORT for the period 01/01/2003 – 31/12/2006 (finalized 10/11/2008)

Project progress summary

Section 2: Project Progress Report **NOT CONFIDENTIAL**

Objectives:

Plywood as example wood panel product is well-defined on mechanical and physical quality requirements for usage under moist construction conditions. The biological durability however is only defined in a very limited way. Recent developments in improving knowledge on the durability of solid wood in relation to applications out of ground contact should be transferable to wood panel products. Direct application of such methods leads to clear underestimation of the potential of plywood mainly consisting of non-durable wood species. The main objective is to develop a fit for purpose tool to determine the expected service life of plywood produced for a specific application. Such a quality evaluation system will bring the biodegradable plywood up to a level of full comparability with alternative products and provide the end-user with clearer decision tools. More accurate knowledge on the interaction between biological and physico-mechanical durability is needed to establish this fit-for-purpose methodology. Using explicit biological hazard/use classes and expected service life, different plywood types could this way be fully assessed on their relevant biological durability, which finally can lead to relevant quality labelling.

Results and Milestones:

During the first working year, the industrial partners produced a selection of adequate plywood for the project. This set of reference material was sampled and distributed to the different laboratories and has been used to perform work that contributes to the overall objectives:

1. The laboratory test method ENV 12038 is being fine-tuned for quality prediction: biological durability in relation to service-life.
2. Laboratory fungal testing using mechanical assessment alongside traditional mass loss determination is assessed in order to develop clear interaction systems for common identification of physico-mechanical durability and biological durability.
3. Both plywood composition and moisture content over time resulting in guaranteeing stability for exterior constructions are being identified.
4. Plywood either coated or not-coated will be classified on suitability for specific exterior end uses based on reliable criteria for biological durability.
5. Alongside the laboratory test method specific field test methods will be developed mimicking specific end uses covering the variation under exterior circumstances out of ground contact.

Some major achievements by the end of year 3:

- The standard laboratory fungal test ENV 12038 is very hard to relate to real performance unless worst case scenarios are involved.
- The performance of coated plywood or other protective measures not related to intrinsic biocidal efficacy is hard to detect by means of testing according to ENV 12038
- Several examples could be documented of plywood constructions performing adequately after several years of outdoor service. No biological degradation was observed although no preservative treatment was included.
- Observations on moisture behaviour under different outdoor exposure systems pointed out that wetting – drying phenomena could contribute significantly to the

overall biological performance of plywood.

- Full preservative efficacy or high durability according to ENV 12038 could not be achieved at economic levels of glue line additive concentrations, nor by a built up based on thin veneers combined neither with PF glue, nor by including a percentage of durable veneers.
- Some non destructive methods could be used to evaluate the feature or the performance of plywood before the use and to control it during its service life.
- Coated birch plywoods are performing well in the outdoor test situation in Finland. The moisture condition level of coated plywood products is more stable during the 1.5 years' test period than that of uncoated plywood, and moisture level of coated plywood products is lower than the critical moisture needed for decay development (wood moisture content above 25 - 30 %). Key factors for the performance is the edge sealing. According to limited test, the protection of duct bolt or other fixing points is also very important factor for the service life of plywood manufactured from the wood species of durability class 4 and 5 (spruce and birch).
- Test methods for biological durability have been tested for coated plywood. According to the test results, ENV 12038 seemed to work to test the resistance of plywood products against decay fungi when preceding outdoor weathering is used. Mould test at high humidity (RH 100%) did not seem to work so well.
- Coated plywood has been used for different applications. According to Finnish experience, paint base film coated and painted / colour film coated traffic signs are performing very well. The most critical factor for the use of these products seems to be the service life of the reflecting cover or the film, not the durability of birch plywood itself. Edge sealing and protection of duct bolt or other fixing points is very important factor for the service life of coated plywood manufactured from the wood species of durability class 4 and 5 (spruce and birch).
- Test fungi for assessing decay resistance of plywood are showing a different impact of wood species and glue type used indicating at least two test fungi are required to obtain reliable results on fungal Basidiomycetes testing of plywood.
- A fungi-resistant sealant has been selected providing options for improved and more realistic testing of coated and uncoated plywood.
- Freely hanging plywood outdoor testing proved that such exposure requires no enhanced biological durability for sufficient performance.

The extra results by the end of year 4 can be summarized as follows:

Results on performance

All plywood types under test are provided mainly by the industrial partners. Besides reference material produced at the beginning of the project additionally optimised panels were included during year 3 of the project. These plywood products were used in year 4 to verify the main parameters inducing adequate performance. The different hypotheses on the level of biological performance that can be expected from a plywood type were both evaluated in lab and outdoor testing. The tests using ENV 12038 are mainly focussing on improvements and additional assessment systems. This includes reproducibility, glue dependency, edge sealing, and moisture relationships…not only using reference material but now also optimised plywood.

The outdoor exposure testing has been fully established and was further examined both on biological degradation of the plywood and the moisture behaviour under a range of local climatic and construction conditions.

Results on non-destructive testing

Promising non-destructive testing techniques were further evaluated on their potential to be included in laboratory testing, field testing and evaluation of performance in practice. In particular the use of physical diagnostic methods is useful for field plywood testing and to correlate its results with those obtained from laboratory.

Results on the survey

Specific survey work that started in France to identify plywood performance in practice was complemented for other European regions. The field survey of structures made of coated plywood products was continued. Fit for purpose of coated plywood products in different targets were focused on.

In year 4 of the project all different results on performance testing (lab and outdoor) exposure needed to be combined with the survey results to identify critical parameters identifying different levels of fit for purpose suitability.

Results on coated plywood

Closely linked to the Finnish industrial partners specific work was initiated for coated plywood. This work will include a combination of different weathering tests and biological durability tests.

Coated birch plywood performed well in the outdoor test situation in Finland: moisture condition level of coated plywood products was more stabile during the 2 years' test period than that of uncoated plywood, and moisture level of coated plywood products is lower than the critical moisture needed for decay development (wood moisture content above 25 - 30 %). The condition of coated spruce sapwood has been worse as compared with coated birch plywood. The plywood made from durable top veneer did not perform well against weathering and discolouring. When coated, these products performed well during the short exposure time used. Integrated weathering and test methods for biological durability have been also tested for coated plywood. According to the test results, ENV 12038 seemed to work in order to test the resistance of coated plywood products against decay fungi when using preceding outdoor weathering. Mould test at high humidity (RH 100%) did not seem to work so well. Decay resistance of sound coated birch plywood was good as tested according to EN 12038 using different pre-weathering systems. The performance of coated spruce plywood against decay using this procedure was not satisfactory. For the test, edge sealing is required. Even the acrylate edge sealing paint performed well in the tests. Coated plywood products have been used for different target applications: formwork, claddings, racks, fences, footing in trailers, traffic signs. Most often these products are performed very well in Finland. Key factors for the performance are the edge sealing and protection against damages/injuries. The protection of duct bolt or other fixing points is very important factor for the performance and service life of plywood manufactured from the wood species of durability class 4 and 5 (e.g. spruce and birch). The performance of durability classification of coated plywood products should however not be based on the wood species only. For coated products, the performance of the whole system is most important.

Benefits and Beneficiaries:

The overall objective to come to a test methodology to underpin CE marking in respect of biological durability performance for plywood in exterior applications is regarded as an important element for the future of the European plywood industry. The collaboration of industrial partners using different plywood types is promising in this respect.

The ongoing project has been discussed both in meetings (twice a year) at CEN TC38 WG23 and via FEIC-meetings (Fédération Européeene de l'Industrie du Contreplaqué). This way both Standardisation Committees and the industrial platform are involved in the process of implementation of the results.

Future Action:

Further work was needed by the end of year 4. During the period 2007-2008 extra effort was dedicated to come to a full implementation of the results and methodology for standardisation related to the objectives of the plywood industry involved.

Status summary table

A. Total person months planned

Partner	Workpackage						Σ
	1	2	3	4	5	6	
1	3 + *2*	24 + *2*	10	3	5	3	48 + *4*
2	1 + *2*	20 + *8*	-	-	1 + *2*	2 + *2*	24 + *14*
3	-	14	-	11	-	-	25 + *0*
4	-	6 + *6*	29 + *6*	-	-	1	36 + *12*
5	1	-	-	16	2	3	22 + *0*
6	-	-	-	-	15	-	15 + *0*
7-13	each 2	-	-	-	-	0.5(7&9)	15 + *0*
Total	19 + *4*	64 + *16*	39 + *6*	30 + *0*	23 + *2*	10 + *2*	185 + *30*

B. Total devoted person months reported

Partner	Workpackage						Σ
	1	2	3	4	5	6	
1	3 + *2*	23 + *2*	9	2	3	2	42 + *4*
2	1 + *2*	23 + *8*	-	-	1 + *2*	3 + *2*	28 + *14*
3	-	14	-	12	-	-	26 + *0*
4	-	12	34 + *2*	-	-	0	46 + *2*
5	1	-	-	17	2	3	23 + *0*
6	-	-	-	-	12	-	12 + *0*
7-13	1 – 1.5	-	-	-	-	2x0.5	11 + *0*
Total	15 + *4*	72 + *10*	43 + *2*	31	18 + *2*	9 + *2*	188 + *20*

Progress report
year 1 to 4

Progress Report

Biological performance testing methodology to evaluate the durability of plywood as an indicator for exterior construction purposes			
PLYBIOTEST			
SHARED COST RTD			**Total project cost** (in euro) 1776062 €
Contract number **QLK5-CT-2002-01270**	**Duration** 48 Months		**EU contribution** (in euro) 1321140 €
Commencement date 1 January 2003		**Period covered by the progress report** 1 January 2003 – 31 December 2006	
<u>PROJECT COORDINATOR</u>			
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Key words Plywood, Fungal testing, Durability, CE-marking, Construction Products Directive			
World wide web address **http://allserv.ugent.be/~jvacker/index.htm or www.plybiotest.be**			

List of participants

Partner 1. Universiteit Gent (UGent) – contractor
Partner 2. Università di Torino (UNITO) – contractor
Partner 3. CIRAD Forêt – contractor
Partner 4. Bundesforschungsanstalt für Forst- und Holzwirtshaft (BFH) – contractor
Partner 5. VTT Building and Transport – contractor
Partner 6. Centre Technique du Bois et de l'Ameublement (CTBA) – contractor
Partner 7. PANGUANETA s.n.c. (PNG) – assistant contractor to UNITO (Partner 2)
Partner 8. COBLO n.v. – assistant contractor to Ugent (Partner 1)
Partner 9. FINNFOREST Oyj – assistant contractor to VTT (Partner 5)
Partner 10. KOSKISEN Oy – assistant contractor to VTT (Partner 5)
Partner 11. UPM-Kymmene Wood Oy – assistant contractor to VTT (Partner 5)
Partner 12. ALLIN – assistant contractor to UGent (Partner 1)
Partner 13. SMURFIT ROL PIN – assistant contractor to UGent (Partner 1)

1. OBJECTIVES AND EXPECTED ACHIEVEMENTS

Technical and scientific objectives and the innovative aspects

Plywood as example wood panel product is well-defined on mechanical and physical quality requirements for usage under moist construction conditions. The biological durability however is only defined in a very limited way. Recent developments in improving knowledge on the durability of solid wood in relation to applications out of ground contact should be transferable to wood panel products. Direct application of such methods leads to clear underestimation of the potential of plywood mainly consisting of non-durable wood species. The main objective is to develop a fit for purpose tool to determine the expected service life of plywood produced for a specific application. Such a quality evaluation system will bring the biodegradable plywood up to a level of full comparability with alternative products and provide the end-user with clearer decision tools.

Justification of the selected scientific and technological approach

The Construction Products Directive (CPD) requires the products used guarantee stability of the construction. Appropriate physico-mechanical durability for exterior applications in construction or transportation systems can be guaranteed by assessment of the glue bond quality and mechanical characteristics. However, due to the fact that non-durable wood species are used for plywood production the biological durability should also be concerned. A very reliable decay test ENV 12038 has been developed. This lab test seems suitable for assessment of the quality level of biological durability. Both the impact of moisture content and interrelated to the time factor indicates a more precise and explicit description of different end uses and biological hazard classes. More accurate knowledge on the interaction between biological and physico-mechanical durability is needed to establish a fit-for-purpose methodology. Using explicit biological hazard classes and expected service life, different plywood types could this way be fully assessed on their relevant biological durability, which finally can lead to relevant quality labelling.

Scientific and technological research objectives and the expected technical achievements

- The laboratory test method ENV 12038 will be fine-tuned for quality prediction: biological durability in relation to service-life.
- Laboratory fungal testing using mechanical assessment alongside traditional mass loss determination will allow to develop clear interaction systems for common identification of physico-mechanical durability and biological durability.
- Both plywood composition and moisture content over time resulting in guaranteeing stability for exterior constructions will be identified.
- Plywood either coated or not will be classified on suitability for specific exterior end uses based on reliable criteria for biological durability.
- Alongside the laboratory test method specific field test methods will be developed mimicking specific end uses covering the variation under exterior circumstances out of ground contact.

2. PROJECT WORKPLAN

2.1 Introduction

Plywood is the wood based panel product showing the best physical and mechanical properties for application in constructions. This is even more valid when moist circumstances are considered. Plywood is the only wood-based panel that should be used in load-bearing applications under the highest biodegradation risk in exterior conditions. The mechanical and physical criteria to be met for construction purposes in general and more specifically for outdoor applications are well defined. The required biological durability however is not totally clear. Suitable laboratory fungal test methods have been developed giving reproducible results in line with testing of the biological durability of solid wood and the test methods used for efficacy determination of wood preservatives. The standard test method according to ENV 12038 needs to be validated as a method to predict actual suitability of plywood products in applications under hazard class 3 conditions according to EN 335, meaning exterior usage out of ground contact. Input from plywood performance in existing constructions as well as field testing of boards will provide details on the relationship between laboratory durability testing of plywood and the service life of the products in practice. The use of coated plywood both for covered and not covered exterior conditions enhances the plywood performance. The increased service life should also be reflected by the laboratory fungal test or at least be based on an alteration in the relationship between performance under laboratory testing and reality performance.

2.2 Project structure, planning and timetable

2.2.1 <u>Progress during the first reporting period</u>

No changes on the technical work, milestones and deliverables have been adopted. The original content as follows has been maintained.

Hereafter the Workpackage list (Table 1), the list of milestones (Table 2) and the list of deliverables (Table 3) are included.

Table 1 Workpackage list

Work-package No	Workpackage title	Responsible participant No	Person-months*	Startmonth	Endmonth	Deliverable(s) No
WP1	Development and production of exterior quality plywood	2	19 + *4*	0	36	D1, D5, D6, D7, D8
WP2	Quality laboratory testing of biological plywood durability	1	64 + *16*	6	48	D9, D12, D13, D14
WP3	Accelerated outdoor testing of plywood	4	39 + *6*	6	48	D10, D15, D16
WP4	Impact evaluation of plywood coatings	5	30 + *0*	6	48	D2, D3, D11, D17, D18
WP5	Survey on outdoor performance of plywood	6	23 + *2*	0	48	D4, D19, D20, D22
WP6	Fit for purpose concept for quality marking of plywood	1	10 + *2*	24	48	D21, D23, D24
	TOTAL		185 + *30*			

* person months added as + in italic are staff not paid on the project for the Additional Costs partners

Table 2 List of milestones

M1. Month 12 (WP 1): All adequate test plywood developed

M2. Month 24 (WP 2 - 4): Data sufficient to produce optimised products (input for WP 1.3)

M3. Month 30 (WP 5): Identification of suitable plywood (input for WP 6)

M4. Month 30 (WP 2 - 5): Data sets available to interrelate lab results, field test results and survey results

M5 Month 36 (WP 4): Factors defined to predict positive impact of coatings

M6. Month 42 (WP 1 - 4): All optimised products under test

M7. Month 42 (WP 6): Rough fit-for-purpose concept and test methodology defined

M8. Month 48 (WP 2 - 6): All data processed to fine-tune overall result

Table 3 List of deliverables

Deliverable No	Deliverable title	Delivery month	Nature	Dessimination level
D1	Coated and uncoated birch and spruce plywood ...	6	Material	RE
D2	Preliminary test protocol to test coated plywood ...	12	Report	PU
D3	Results from the accelerated laboratory ...	12	Report	RE
D4	Identification of specific exposure systems	12	Report	PU
D5	Technical quality of different coating systems ...	18	Report	RE
D6	Core data of different coating systems prio to ...	18	Report	RE
D7	Experimental validation and realisation of ...	18	Report	RE
D8	All plywood available for testing	24	Material	RE
D9	Fast test method, based on non destructive ...	24	Report	PU
D10	Test protocol for modified ENV 12037	24	Report	PU
D11	A proposal for a new accelerated test method ...	24	Report	PU
D12	The relationship established between the loss ...	36	Report	PU
D13	Proper information on plywood characteristics ...	36	Report	RE
D14	Better evaluation of ENV 12038 by selecting ...	36	Report	PU
D15	Factors defined affecting degree of decay ...	36	Report	PU
D16	Difference between covered and non covered ...	36	Report	PU
D17	Results on coated plywood from the exterior ...	36	Report	RE
D18	Final results from the laboratory tests and from ...	36	Report	RE
D19	Survey results on service-life of different ...	36	Report	PU
D20	Estimation of time to failure for specific applications	36	Report	RE
D21	Critical plywood characteristics influencing ...	42	Report	RE
D22	Specifications for critical characteristics for ...	48	Report	RE
D23	Evaluation criteria using methodology based on ...	48	Report	PU
D24	Full definition of degree of exposure in relation to ...	48	Report	PU

Partner 1 is responsible for coordination including meeting related organisation, planning of the material flow, maintaining the web site (in total 3 mm on the project + 1 mm permanent staff).

Selection of adequate plywoods for both laboratory and field testing was performed. The sampling and test specimen preparation followed by distribution of this material allowed all testing partners to start with project specific material.

During the first working year partner 1 included work on ENV 12038 testing in order to map all weaknesses and strengths of the method in predicting performance of exterior plywood.

During this first reporting period, partner 2 (UNITO) also included a study on the production, market (consumption and current use) and the latest developments in the European plywood sector, with special attention to the exterior quality panels and to the new EN standards implemented for plywood and LVL, particularly those concerning the CE marking. P2 has been also charged of the coordination of the industrial partners in order to give indications about technical parameters for the panels to be produced in the project and to prepare technical sheets for the samples to be tested by laboratories.

Partner 3 completed the development of some non-destructive mechanical testing which will allow a better evaluation of the performance of plywoods after biological degradation. Mixed plywoods made from non durable and durable timbers have been manufactured and the evaluation of their properties could allow the use and up-grading of some timber resource, usually not used for such wood-based products.

Partner 4 focused mainly on the test protocol for ENV 12037 and the potential to be used as basis for plywood field testing. Both test set up (exposure scenarios) and the incorporation of underpinning data were main activities during the first working period.

Partner 5 focused on workpackage 4, the main goal of this workpackage is to define the performance of the coated birch and spruce plywood in hazard class 3 using different modified methods. The effect of coating types on the performance of plywood will be tested using accelerated weathering test methods developed for coated wood and the performance will also be tested using biological tests prior and after the weathering.

The coated and uncoated birch and spruce plywood were manufactured by partners 9 - 11. The test material has been selected for tests. Test sample size has been fixed and the test material for the tests has been performed. The laboratory weathering tests have been planned and preliminary tests series performed using a part of the test material using the water immersion (floating-freezing-drying cycles) and UV-ageing (modified EN927-6). The outdoor weathering test system has been planned and a preliminary test has been started at Otaniemi, Espoo. The effect of durable top veneer has not yet been studied. Preliminary tests on the effect of edge sealing against rot and water penetration has been started and performed. The preliminary test on durability against soft rot test has been started and finished.

Partner 6 is responsible for the link to performance of plywood in practice concerning exterior application. As such entire information was gathered on the survey set up as well as on the exposure scenarios for field testing.

All industrial partners (P7 – P13) produced plywood relevant for the concept of the project both for laboratory and field exposure.

2.2.1.1 Discussion-Conclusion

Although the period for selection of adequate plywood for the project and the production, sampling and distribution of this material required some more time than expected no significant delay is expected in the execution of the project. None of the tasks or sub tasks ended at month 12 but related milestones (M1) and deliverables (D1 up to D3) are adequately met.

The interaction between laboratories (institutes/universities) partners (P1 –P6) with the industrial partners (P7 – P13) has been very good and constructive. The overall objective to come to a test methodology to underpin CE marking in respect of biological durability performance for plywood in exterior applications is regarded as an important element for the future of the European plywood industry. The collaboration of industrial partners from different typology is promising in this respect.

2.2.1.2 Future action

The upcoming working period work will be performed in workpackages 1 up to 5, WP6 activities start in working year 3. Under WP1 extra plywood material will be provided both coated and non-coated. This involves all industrial partners (7 up to 13).

All materials provided under workpackage 1 will be included for testing under workpackages 2 up to 4. Partners 1, 2 and 3 focus on the ENV 12038 test system as such looking for improvements and additional assessment systems. Partner 4 is focusing on outdoor testing (WP3) and will be assisted on this by partner 1. For workpackage 4 partner 5 is the main actor and is also providing close links to the Finnish industrial partners in this respect. The workpackage 5 is managed by partner 6 and from month 12 on specific survey work will be started.

There was a clear need for extra coordination between partners 2 and 3. As such the following paragraphs are important information on the agreement.

Partner 2 (UNITO) and partner 3 (CIRAD) organized a meeting in Montpellier in November 2003 in order to define the measurement modalities to be used in laboratory and to determine a common protocol for non-destructive testing.

The measurements will consist of ultrasound wave propagation and on electrical properties. In the case of ultrasound, the signal will be recorded and analysed to calculate the first arrival time, the velocity and the amplitude. On the same specimens, the electrical measurements will be performed by plate electrodes on the whole surface of each test pieces. The resistivity, the dielectric constant and the loss angle will be calculated.

According to the decisions from the meeting of Montpellier, UNITO and CIRAD will perform biological tests on the bases of ENV 12038. With the purpose to realise a data bank on the behaviour of the electric and elastic properties of decayed wood, some experiment will be carried out on all reference plywood. In particular, test pieces of beech and poplar solid wood (dimensions 50x25x15 mm) and specimens extracted from the panels of plywood produced by the industrial partners (dimensions 50x50xthickness) will be used.

All the test pieces will be exposed to the degradation of two fungi: *Coniophora puteana* BAM Ebw. 15 (brown rot) and *Coriolus versicolor* CTB 863A (white rot).

The controls of mass loss will be done after 2, 4, 8 and 16 weeks. From each panel, 48 specimens will be obtained, for a total of above of 2,500 test pieces over the test control. The electric properties (in a range of frequencies between 1 Hz and 1 MHz) and ultrasonic properties (with frequency 1 MHz) will be performed by UNITO. CIRAD will realize ultrasonic measures (at the same frequencies) and “indentation test” on the decayed samples conditioned at 20°C and 35% RH.

UNITO and CIRAD will meet during the first half of 2004 with the aim to compare the first NDE results obtained from the specimens of durability tests.

Differently from what declared in the WP 5.2 and according to the decision taken during the meeting of Montpellier, for the outside controls CIRAD and UNITO propose to perform the ultrasonic measures and the “indentation test” but not the electrical measurements. The electrical analysis will not be done because the too low moisture content expected from the test pieces would invalidate the analysis. The measures will be carried out on the healthy part and on the decayed area of each test pieces at least on 5 panels (from buildings) and 5 windows from field testing. The results will be compared with the values measured in laboratory.
These testing are not yet done because the degradation of the samples extracted from the plywood has not already begun.
Moreover, UNITO will participate to the definition of specific exposure systems and to the indication of the environments where to program and realize future in field sampling and survey performance controls of plywood in exterior conditions use. Referring to the participation of P2 in WP5, the assessment on exterior performance of plywood will be carried out in the Alpine Climate.
In the following months, the main action of partner 3 will be the biological testing of the plywoods provided by the Plybiotest partners, as well as the evaluation of the residual mechanical performances after decay. The work on mixed plywoods will be carried on, as well as the testing of panels on hazard class 3 situation.

2.2.1.3 Action requested from the Commission

No specific actions requested

2.2.2. Progress during the second reporting period

The work indicated in the Technical Annex is being performed as indicated in Tables 1-3 of the reporting on the first period.

Partner 1 (UGENT) performed coordination tasks related to organizing meetings, compiling minutes, planning of material flow and maintaining a website (in total 2,5 mm + 1 mm permanent staff).

A lab formulated glue-line protection of poplar/beech plywood was lab tested in view of evaluating the potential of such protective measures.
Testing of all reference plywood according to ENV 12038 was set up as well as evaluation of end sealing systems for both weathering tests and to prevent fungal penetration.
Partner 1 has established 3 levels of exterior exposure by means of exposure scenarios with increasing impact of moisture and decay risk (free hanging, a covered gutter system, accelerated including sponge wetting).

Partner 2 (UNITO) evaluated the availability of commercial waterborne preservative compounds in order to improve plywood durability through their addition in the adhesive system.
The work included a study on the market in the European plywood sector with special attention to the preservatives developed for being used with the thermosetting adhesives suitable for gluing wood-based panels.
Different types of optimised poplar plywood with preservatives added in the glue mix, originally not indicated in the Technical Annex, have been produced.
Also, some experimental plywood has been produced with different wood species (paulownia, mix composition of okoumé-hornbeam, douglas veneers).
Partner 2 is now doing the evaluation of the resistance to decay of these optimised plywood according to the ENV 12038 test method.

In the meantime, partner 2 performed biological tests on some of the reference plywoods.
For this activity, test pieces of beech and pine solid wood and specimens of references plywood were used. For each type of panel, 96 samples were extracted for a total of more than 2500 samples. Half of the samples were cut at 90°(A) and the others at 45° (B). These cutting directions have been choosen in order to study the effects of the fiber direction on the propagation of the elastic waves (WP 2.2).
All the test pieces were exposed to the degradation of two fungi. In particular, for every panel, 48 samples have been exposed to the action of *C. puteana* and the others have been decayed by *C. versicolor*. The controls of weight loss have been done after 2, 4, and 8 weeks.

The non destructive analyses by ultrasonic and electric measurements have been carried out on test (not decayed) and decayed samples for every type of references plywood.
Purposes of this first phase of the research were above all to establish a scale of comparable values: level of degradation / ultrasonic velocities – electric parameters.

Data concerning the physico-mechanical properties included in the technical sheets have been completed and integrated with physic and mechanical testing on small test pieces in order to obtain an harmonise framework that could describe and compare on the same basis the plywood made by the industrial partners.
The work carried out during this period also included the searching and evaluation of different testing methods for the determination of hardness on wood-based products. This has required the selection of commercially available portable device for making the above measurement by a non destructive method aimed to establish a relationship between plywood decay and panel's hardness.
This last property is directly related to wood mass value and so its determination may constitute a way to detect and estimate decay surface of plywood in service. Different measurements of hardness have been done on the reference plywood to select the best portable device for wood surface hardness with a good accuracy and repeatability of results.

Partner 2 then studied the current external use of plywood in Italian continental climate through a network of contacts in the national building sector. In this context, partner 2 has investigated some among the more interesting national plywood constructions, collected all the available indications about the sites (photos, reports etc...) and select some cases for field inspection according to CTBA protocol.

Partner 3 (CIRAD) received all the plywood panels from industry. They were cut in samples (as decided with partner 2), pre-conditioned and conditioned in order to be tested according to ENV 12038. Sampling was done randomly and ultrasonic measurements were started prior to biological testing using the same sampling protocol as partner 2.
In the case of the experimental mixed plywoods (with durable coatings), all the biological tests were completed. The decayed panels were reconditioned and ultrasonic measurements were performed in order to compare with the original data (obtained for the same sample). Indentation tests were also done afterwards.
Some plywood samples for outdoor exposure in hazard class 3 were received from CTBA (partner 6). These samples were conditioned in order to make ultrasonic measurements before outdoor exposure. The ultrasonic device used for the plywood samples mentioned before has to be adapted to this test material.

Partner 4 (BFH) performed field tests as well as additional tests (moisture monitoring, mechanical strength).
A draft of the test protocol (Material and Methods) for ENV 12037 is included in the Technical Report. First series of supplementory ENV 12038 tests (after 12 weeks conditioning) were finished. First tendencies on the moisture uptake were observed by the monitoring of the moisture content. Initial values of mechanical strength were recorded.

Partner 5 (VTT) focused on workpackage 4. The main goal of this workpackage is to define the performance of the coated birch and spruce plywood in hazard class 3 using different modified methods. The effect of coating types on the performance of plywood will be tested using accelerated weathering test methods developed for coated wood and the performance will also be tested using biological tests prior and after the weathering.

The core data on studied coated and uncoated plywood material was collected. Main optimised products were already included. The water permeability and thickness deformation of material prior the weathering was measured using the modified method (EN 927-5). The thickness of coating layer was analysed under microscopy and the colour of surface of samples was measured using the Spectrofotometer Minolta 525 I device. The out door weathering tests to study the effect of coating types on the performance of plywood started at Otaniemi, Finland in May 2004. UV aging (modified EN 927-6) started in September 2004. The first results on the performance of coated and uncoated products were obtained in December 2004. The effect of surface injuries, edge sealing and follow-through was studied using the water immersion (floating-freezing-drying cycles). The outdoor weathering tests to study the effect of durable top veneer started in September 2004. The reference samples for tests on biological durability were prepared. Co-operation with the partners 1, 4 and 6 started on the tests of out door performance tests on coated plywood products. Buildings having coated plywood products were collected and preliminary detection of plywood structure was done.

Partner 6 (CTBA) initiated the survey and compiled an extended overview of plywood in exterior constructions mainly in France and Switzerland. This concept was checked with the other partners and will be used in a slightly modified version by the other partners involved.

All industrial partners (P7 – P13) produced plywood relevant for the concept of the project both for laboratory and field exposure. All were participating in the discussion to develop and produce optimised products for the project.

2.2.2.1. Discussion-Conclusion

Partner 1 (UGENT) proved that addition of fungicide in the glue-line is not a straight forward concept to enhance the durability of plywood.
The concept of different exposure scenarios for field testing was successfully implemented for all reference plywood types. Those materials are also under test according to ENV 12038. These tests have been aligned with the work of other partners in order to link results.

The study made by partner 2 (UNITO) on the available preservative has allowed selecting two active substances: quebracho tannin extract and a commercial compound named “Wolsit F-SP”.
Some types of optimised experimental plywood originally not indicated in the Technical Annex, with different types of glue mix and wood species, have been produced using the above compounds. This approach has been discussed between partners during the 3rd Project Co-ordinating Committee (PCC) meeting in Hamburg.
The aim of this work is to verify the efficacy of the preservatives selected and to establish a possible relationship between preservatives concentration in the glue mix and the decay resistance of plywood.
A set of experimental uncoated panels made in laboratory with different wood species of potential interest, combined in non homogeneous lay-up and veneer’s thickness has been also produced and tested in order to increase base information for the development of optimised product.

Concerning the evaluation of the resistance to decay of the reference plywoods according to the ENV 12038 test method, the results of the first group of samples, up to 8 weeks of degradation, show the greater values of mass loss for Panguaneta and Coblo poplar plywood. The MC are higher for the poplar plywood too. Only the Rolpin plywood doesn't show mass loss.
C. puteana was the most aggressive, decaying beyond the 20%, in terms of mass loss, after 8 weeks.

For the non-destructive testing, the research seems to confirm the diagnostic effectiveness of ultrasounds. Ultrasonic velocities result sensitive to degradation: a negative trend is always observed passing from the healthy samples to the decayed ones. The observed decreases are probably determined by fungal degradation.
Concerning the electrical properties, it was noted that there is a similar trend for all the panels and both the examined fungi. The resistivity decreases strongly in passing from the controls (not decayed), at normal MC, to the decayed samples. The permettivity has the opposite trend: it increases in passing from the controls to the decayed samples.
We must consider that these are only partial results. For this reason a complete and exhaustive discussion is not yet possible.

According to the decisions from the 3rd meeting of Hamburg, partner 2 has completed the research and evaluation of different methods of hardness measurement on wood-based products.

Different testing has been done on the reference plywood to select the best portable device for measurement of wood hardness with an adequate accuracy and repeatability. Five samples for each reference plywood have been selected and a double series of four shore hardness measurements on each test pieces were made with two handle device: shore A and D. The hardness resulted into a range from 23.5 and 41.0 shore. On the basis of the results obtained it was chosen a shore D portable digital hardness tester (Mitutoyo Hardmatic HH-300) supplied with external data output. The software device allows the direct acquisition of the hardness data through the link to a computer by USB door. The shore test is cheap, portable, and easily applied, rapid and definite for materials for which it is suitable. The shore methods need a certain practice to guarantee good repeatability in the measurements.

The work carried out included a study on the current external use of plywood in Italian continental climate through a network of contacts in the national building sector. The results showed that, at least for the time being, in Italy do not exist a lot of examples of exterior plywood used in building applications.

Partner 3 (CIRAD) tested some experimental plywood made of non durable timbers according to the protocol of ENV 12038 but for different exposure times to *Coriolus versicolor* and *Coniophora puteana*. Ultrasonic measurements were done on the samples before and after the fungal attack, when possible. In the case of a fungal attack leading to mass losses above 18-20%, the plywoods were far too degraded to allow ultrasonic measurements. Nevertheless, for lower mass loss, the decrease of ultrasonic velocity is rather well correlated to the mass loss/exposure time parameters. This protocol was then applied to the plywoods obtained from the industry partners.

The experimental plywoods made of non durable timber with durable top veneers (different patterns studied) have all been tested according to the ENV 12038. The durability of the timber used as top veneer, as well as the pattern used for the plywood has an impact on the global durability of the plywood. The decrease of the ultrasonic velocity (measured before and after the fungal exposure) can be correlated to the mass loss, but only to a certain extend.

Conclusions from field tests could not be drawn yet by partner 4 (BFH) due to the status of the tests (running). Results after 14 weeks of the monitoring of the moisture content confirmed, that the different set ups induce humidity regimes as expected. First tendencies indicate influence of panel type, its preparation and the way of exposure. In first laboratory tests according to ENV 12038 most of the panel types as well as the corresponding solid wood showed higher massloss than the virulences and the controls. Actually this means, that the samples are not durable. These values have to be set into relation to the results of the field test in the future as well as to the results of the other partners.

Partner 5 (VTT) started weathering tests using the method developed during the first year. Different coating systems were included, and after 7 month's exposure, all coatings were performed well. Water absorption to the samples varies, but no significant mould growth or biological damage was found. On the untreated plywood samples, however, significant mould growth and blue stain was found, but no decay. Used UV aging seemed not be very effective to produce cracks in coated plywood products. The effect of UV light was focused on the colour change of phenol film coated products.

Partner 6 (CTBA) could already conclude from the input on the survey up to now that little or no decay problems were found in the plywood evaluated. Most frequent moisture related problems were delamination and deformation.

Partners 7-13 (industrial partners) discussed with the other partners their views on what are critical parameters for exterior plywood. Based on input from the university institute partners optimised products were identified.

2.2.2.2. Future action

During year 3 the results on ENV 12038 testing by partner 1 (UGENT) for all reference plywood will become available. An additional test will be set up using edge sealing. In order to establish critical parameters for performance of exterior plywood in relation to fungal decay wood-moisture relationships will be studied in more detail. This will include monitoring moisture content of all plywood under field testing as well as measuring water uptake and release under lab test conditions. Work on the survey (task 5) will be started in 2005.

Biological tests by partner 2 (UNITO) are in progress to verify the efficacy of the addition of water-base preservatives in the glue mix (TUMF and WUMF). The poplar plywood samples, laboratory produced by partner 2, will be decayed by four reference fungi according to ENV 12038: *Coniophora puteana*, *Gloeophyllum trabeum*, *Coriolus versicolor* and *Pleurotus ostreatus*. In order to evaluate the biocidal effects of the preservative compounds chosen, the reaction of each fungus against the quebracho tannin extract and the Wolsit F-SP will be assessed. Cellulose disks impregnated with

different concentrations of active substance, the same used in the TUMF and WUMF glue mix, will also be put on the mycelium grown on Petri dishes.
All the plywood samples will be analysed after 16 weeks of degradation by ultrasonic and electrical measurements and assessed in terms of mass loss.
The most performing results obtained from this experimental optimised plywood will be validate by the production and testing of a set of industrial panels (in cooperation with partner 7).

Non destructive analyses by ultrasonic and electric measurements will be completed on the reference plywood. In order to evaluate the non destructive testing made on the reference plywood submitted to ENV 12038, partner 2 is conditioning some test samples above FSP (fibre saturation point) for each panel typology. Electric and ultrasonic parameters will then be measured. In this way the potential effect of moisture content on the above measurements could be calculated and removed from results.

The hardness portable device Shore D will be used in field and in laboratory testing. The measurements of the hardness will be made on the samples of reference plywood, before and after exposure to the ENV 12038 conditions, in correspondence of the four corners of each sample.

Survey on the more interesting exterior use of plywood in national constructions will start in spring 2005 according to CTBA inspection protocol. The possibility of using the portable hardness device shore D will be validated in field testing.

Partner 3 (CIRAD) is due to perform non-destructive tests after the biological trials are finished for the plywood received from industry.
Concerning the experimental plywoods with durable top veneers, the indentation tests are finished and they now have to be discussed. For the samples from the CTBA, some changes on the ultrasonic measurement device have to be realised in order to perform this test before the outdoor exposure.

Partner 4 (BFH) will perform during the coming working period work in workpackages 2 and 3. According to the workplan the field test samples will be assessed in August (including also bending test). The second series of the laboratory test according to ENV 12038 (after 6 months natural weathering) will start in April 2005 as well as microscopical investigations on the structure of materials tested. Moisture monitoring will be continued.

The original colour of coatings was measured by partner 5 (VTT) using Spectrofotometer methods, and additional measure will be performed during the out door and UV weathering tests. In the spring 2005, the condition of samples after one year outdoor weathering will be studied and samples for biological tests will be taken. The biological tests will be: mould and blue stain tests in high humidity (chamber test), brown rot test (modified ENV 12038) and soft rot tests (modified EN 807). Additional UV aging will be performed and mixed water-floating, UV aging and natural out door weathering will be performed. The comparison of the effect of different test methods on the condition of plywood products will be analysed.

The analysis of the condition of different buildings or products (age around 5 – 25 years) with coated plywood products will be performed using the system developed by partner 6. The condition of 5 different coated plywood structures in Finland will be analysed.

Partner 6 (CTBA) will coordinate survey work in order to improve the database including different climatic zones and outdoor exposure systems in Europe.

2.2.2.3. Action requested from the Commission

No specific actions requested

2.2.3 <u>Progress during the third reporting period</u>

The work indicated in the Technical Annex is being performed as indicated in Tables 1-3 of the reporting on the first period.

During working year three partner 1 (UGENT) dealt with coordination tasks related to the organisation of Project Co-ordinating Committee meetings, the compilation of minutes, the planning of material flow and the maintenance of the website (in total 2,5 mm + 1 mm permanent staff).

Partner 1 received, processed and redistributed the optimized plywood panels produced by the industrial partners according to the sampling scheme as agreed upon during working year 1.

The outdoor field testing of reference plywood specimens was continued by partner 1. A visual assessment was performed, evaluating the performance of all reference plywood types after 18 months of outdoor exposure. The accelerated weathering set up including sponge wetting was finished and the samples were prepared for analysis.

ENV 12038 testing of all reference plywood types was completed with test fungi *Coniophora* and *Pleurotus*. A new ENV 12038 test set up including edge sealed specimens is started.

Partner 1 developed a floating test method to investigate the moisture related behaviour of the different reference panels. Absorption and desorption curves were established.

With the aim to protect poplar plywood with preservative added in the glue mix, partner 2 (UNITO) did some study on this matter.
In order to evaluate the biocidal effects of the preservative compounds chosen, the reaction of each fungus against the quebracho tannin extract and the Wolsit F-SP was assessed. Cellulose disks impregnated with different concentrations of active substance, the same to be used in the TUMF and WMUF glue mix, were put on the mycelium grown on Petri dishes. Using minimal inhibition concentration test results, different types of optimised poplar plywood with preservatives added in the glue mix (Wolsit and Tannin, four concentrations for each product), originally not indicated in the Technical Annex, were produced at laboratory level by partner 2 and tested using 4 decay fungi according to ENV 12038.

All the plywood samples were analysed after 16 weeks of degradation by ultrasonic and electrical measurements and assessed in terms of mass loss.
The most performing results obtained from this experimental optimised plywood have allowed the production of a set of industrial panels (in cooperation with partner 7).
Also, some experimental plywood with different wood species (paulownia, mix composition of okoumé-hornbeam, douglas veneers) has been tested in order to evaluate their performance against decay fungi and to realize an industrial production.

Therefore different types of industrial optimised plywood, proposed in the meeting of Hämeenlinna (May 2005), were produced by Unito with partner 7 (Panguaneta), in order to test the new products in cooperation whit other partners.
The final optimized plywood produced at industrial level is showed in the following table:

Code	Coating	Wood species	Glue	Thickness	Plies	Veneers
U1	non-coated	maritime pine	UMF	17 mm	7	2.5 mm
U2	non-coated	paulownia	UMF	18 mm	9	2.1 mm
U3	non-coated	oak	UMF	15 mm	9	1.8 mm
U4	non-coated	poplar	PF	18 mm	9	2.1 mm
U5	phenolic film	poplar	PF	18 mm	9	2.1 mm
U6	non-coated	poplar	UMF	15 mm	11	1.4 mm
U7	phenolic film	poplar	UMF	15 mm	11	1.4 mm
P4	non-coated	poplar	Resorcinol UMF	18 mm	9	2.1 mm
P5	non-coated	poplar	Wolsit UMF	18 mm	9	2.1 mm
P6	non-coated	poplar	Tannin UMF	18 mm	9	2.1 mm

Partner 2 completed biological tests on 22 reference plywoods.
For this activity, test pieces of beech and pine solid wood and specimens of references plywood were used. For every reference plywood, 96 samples were extracted for a total of more than 2500 samples. All test pieces were exposed to two decay fungi: *C. puteana* and *C. versicolor*. The controls of mass loss have been done after 2, 4, 8 and 16 weeks.
The non destructive analyses by ultrasonic and electric measurements were carried out on test (not decayed), decayed samples for every kind of references plywood and beech and pine solid wood. Also hardness measurements have been carried out after each degradation period on each plywood/solid wood type.
In order to evaluate the reliability of the non destructive measurements, partner 2 carried out electric and ultrasonic measurements on some test samples conditioned above FSP (fiber saturation point). In this way the potential effect of moisture content on the measurements can be considered.

On the basis of the information collected through a network of contacts in the national building sector about the current external use of plywood in the Italian continental climate, UNITO has selected some more cases for inspection according to CTBA protocol. As planned, survey on the above examples of exterior applications was started in May 2005. For each case UNITO has selected all the information about the sites (photo, reports etc., according to CTBA check list). The moisture content of plywood was measured using a digital moisture meter based on the principle of non-destructive measurements by means of dielectric constant measurements

Partner 3 has still to do most of the biological tests on the industrial plywoods.
Indentation tests were done on non durable plywoods, before and after biological degradation. In this case, biological attack was stopped at regular intervals.
Optimized 5 plies plywoods were produced with : (i) pure cypress heartwood, (ii) poplar with cypress heartwood top veneer.
Concerning the experimental plywoods with durable top veneers, all indentation tests and shearing tests were done after biological attack. Correlations were found between mass losses and mechanical results.
The ultrasonic measurements could not be done on the samples received from partner 6, due to the size and geometry of the samples. Indentation tests were performed. The samples were put in outdoor exposure. So far, no decay was observed.

Laboratory tests performed by partner 4 according to ENV 12038 were completed (after 12 weeks pre-conditioning and 6 months natural weathering). Further ENV 12038 tests were carried out with additional panels produced at BFH laboratory (PF/MUF-glued, with wood preservatives) as well as with selected reference panels after application of edge sealing (Sigmadur HB).

The field test samples were assessed according to ENV 12037 after 6 months exposure (February 2005) and 12 months exposure (August 2005). The first bending test was taken out directly after the second assessment in August 2005. Selected specimens were investigated microscopically. Further panels produced at BFH laboratory (same as added in lab test, see above) were included in the field tests in march 2005. The bending test series that started in 2004 in order to identify the influence of exposure time, water storage and natural weathering on mechanical strength was continued. Further values from moisture monitoring were obtained. Optimised panels delivered in 2005 by Partner 1 were prepared for field test in the Double layer set up (not sealed) and the Hanging set up (sealed). Conditioning at 20°C/65%RH of optimised panels started in December 2005.

Partner 5 (VTT) focused on workpackage 4. The effect of coating types on the performance of plywood after accelerated weathering test have been assessed. Moisture content samples as well as surface condition of coatings have been measured. Different coating condition index have been noted: e.g. cracking, peeling off, colour change, mould and blue stain on surface and water permeability. Samples from weathered and un-weathered plywood have been exposed to biological tests ENV 12038 and mould tests at high humidity (RH 100%). Water penetration through the different type of fixing of different coated plywood types have been studied using water immersion method and modified Cobb's method. Survey of different structures made of coated plywood products have been continued in WB 5. I n the WP 6, the evaluation of the impact of coatings on the use and service life of plywood has been started.

Partner 6 (CTBA) continued the survey and compiled the information on plywood in exterior constructions in a database. Plywood constructions described until now are mainly situated in France and Switzerland. The other partners are using this concept in a slightly modified version for their inventory.

All industrial partners (P7 – P13) produced optimized plywood plywood types as agreed upon during PCC-meetings. This optimized plywood is delivered to partner 1 (UGENT) and redistributed. All industrial partners were participating in the discussion on how to include the optimized plywood in the project.

2.2.3.1. Discussion-Conclusion

Tests performed by partner 1 (UGENT) according to ENV 12038 revealed a difference in decay preference by *Coniophora* and *Pleurotus* for birch and poplar plywood. The latter fungus is rather glue-indifferent and attacks both plywood types easily, while the presence of PF-glue seems to be a restricting factor for decay by *Coniophora*, even after 12 weeks of preconditioning in a ventilated room. No difference between soft and hardwoods can be made based on type of test fungi since spruce plywood is showing high mass losses for *Pleurotus* while pine plywood is not, and spruce plywood is not consistently decayed by *Coniophora*.

Sigmadur HB Finish proved to be a good edge sealant for application as a fungi-resistant sealant in fungal decay testing.

No fungal decay was detected during a visual assessment of the freely hanging and the covered outdoor field tests at the Ghent University. All plywood specimens were rated for the occurrence of blue stain, moulds and wood destroying fungi, panel deformations (cup and twist) and weathering signals (crack formation, defibrillation, damage by insects and erosion). Staining was present on most samples. Spruce plywood showed severe crack formation while only starting surface degradation was present for the other plywood types.

Preliminary processing of the floating test results suggest the importance of glue-type on the absorption and desorption properties of plywood. PF-glue is more permeable then UMF-glue, thus allowing the PF-glued plywood types to reach higher moisture contents. A coating prevents the uptake of water.

In lab tests conducted by partner 2 (UNITO), Wolsit showed a biocide effect above 5% concentration (m/m) while tannin quebracho composite only showed a preliminary inhibiting effect on the mycelium growing. These results were confirmed by the tests on the experimental optimized poplar plywood: Wolsit toxic threshold value was 5-10% concentration (m/m) in the glue mix while tannin quebracho composite showed no biocidal effect.

The results obtained on the experimental uncoated panels made with different wood species suggested no resistance against decay fungi, with a mass loss near to 30%. Only paulownia plywood showed the lowest mass loss of, 9.9% with *Coriolus versicolor* critical fungus test.

Concerning the reference plywoods resistance against two decay fungi (*Coniophora puteana* and *Coriolus versicolor*), the results showed that all the 22 tested panels did not exceed the decay tests according to ENV 12038 procedure except plywood named with A2 and A4 code which feautures are showed in the following table.

Partner	Code	Coating	Wood species	Glue	Thickness	Plies	Veneers
ALLIN	A2	non-coated	top veneers okoumé, inner veneers poplar	PF	15 mm	7 plies	1.0 / 3.0 / 2.0 mm
	A4	non-coated	top veneers moabi, inner veneers poplar	PF	15 mm	7 plies	1.0 / 3.0 / 2.0 mm

Concerning non-destructive testing, the research seems to confirm the diagnostic effectiveness of the ultrasounds. Ultrasonic velocities are sensitive to degradation; in fact a negative trend is always observed passing from the healthy samples to the decayed ones. The observed decreases are probably determined by fungal degradation but samples moisture content has an important role in ultrasonic velocity setting. The potential effect of samples moisture content on the measurements was determined using the ultrasonic device with samples impregnated with water in order to obtain different levels of moisture contents.
However, there were some problems in reading the ultrasonic measurements on the Finnforest panels because of the difficulties on the first arrival time reading.

Concerning the electrical properties, it was noted that there is a similar trend for all panels and the examined fungi. The resistivity strongly decreases in passing from the controls (not decayed), at conditioning (20/65) stage to the decayed samples. The permittivity shows the opposite trend: it increases in passing from the controls to the decayed samples.
The potential effect of samples moisture content was also determined evaluating electrical properties of samples impregnated with water in order to obtain different level of moisture contents.
Concerning the relationship between shore hardness and MC of wood, as expected, in the sound solid wood samples the shore hardness decreases with the increase of MC. As well, the shore hardness decreases with the increase of MC also in the references sound plywood samples.
However, the results show that it does not always exist a good correlation between shore hardness and MC of plywood (P3 and S4/S5 done $r^2 < 0.5$).
The results also showed clearly that shore hardness test values and its relationship with MC may be quite statistically reliable only for homogeneous groups of plywood (same wood specie, glue type and structure). The shore hardness values measured on decayed samples are always lower than the theoretical hardness values calculated on sound samples for the same level of MC. The hardness value calculated on the bases of the relationship shore/MC found are, generally, congruous with the hardness measured on the sound samples before the biological testing (C2 average experimental hardness of 53.2 versus a calculated value of 53.0 for 9% MC).Finally, the work carried out by UNITO included the evaluation of relationship between shore hardness and mass loss: generally, the analysis of the experimental results highlight that it does not exist an high level of correlation between shore hardness and mass loss: often the shore hardness shows irregular trend with the increasing of fungi attack and some reference plywood (C2) gave a low coefficient of regression ($r^2 < 0.58$).

The preliminary results obtained suggested does not exist a proportional correlation between shore hardness and mass loss of decayed samples.
Also, for different types of samples the results show a different level of decrease of the shore hardness at same mass loss which cannot be explained by the influence of different wood density and moisture content of the plywood (after ENV 12038 test for *Coriolus versicolor* F2 samples show a mass loss average of 4.2% against an average

decrease of shore hardness of 39%, while C2 samples shows a mass loss average of 26% versus an average shore hardness decrease of 52%). The analysis of the results obtained shows that, because of the irregular surface of decayed samples, the measurements of shore hardness may be affected by a non-systematic relevant error. The source of error is evident: the tip of the needle is of the same order of size of wood fibres and therefore one cannot expect an "absolute value of hardness". The results also are influenced by the friction in using the hardness device and by the surface characteristics of the sample. Nevertheless, the use of hardness as a non-destructive and/or handily test, especially for finished wood based-panels, remains attractive.
For the above considerations the shore hardness value calculated for every decayed reference plywood may be used only as "qualitative parameter" in order to predict a potential presence of decay by *in situ* measurement. In any case the use of shore test as a non-destructive method to estimate decay of plywood in service appears hardly reliable.

Partner 3 performed lab testing evaluating the use of indentation tests as rapid and non destructive (or very little destructive) tests. It was shown that the loss of indentation energy could be clearly correlated to the mass loss and this for different stages of decay. This is very true for the early stages of decay, as, on average, the loss of indentation energy is 2.5 times more sensitive than the mass loss.

Correlations were obtained between the results from the indentation tests and the mass losses for the experimental plywoods with durable top veneer. From these results, 2 models were drawn to explain the behaviour of the experimental plywoods.
Shearing tests were also performed on the experimental plywood samples, used previously for the indentation tests. This totally destructive test is very discerning to estimate the loss of mechanical integrity of the material. Nevertheless, shearing tests are time-consuming and heavy tests.

Considering these results indentation tests could be mechanical tests used as "routine" tests to evaluate the degradation state of the plywoods after biological degradation.
For all the experimental plywoods considered, the mix of durable plies with non durable plies always increased the resistance of the plywood. The use of durable top veneers is then a real "benefit" for the plywood resistance.

Lab test results obtained by partner 4 according to ENV 12038 revealed high mass losses for most panel types. Effects of 6 months natural weathering in comparison to 12 weeks pre-conditioning were visible but mostly had no significant consequence for the assessment of the durability according to ENV 12038. However, natural weathering induces higher mass losses in some PF-glued panels through *Coniophora puteana* and *Coriolus versicolor*. The application of edge sealing reduces mass loss in the lab test significantly. Wood preservatives did not show the protection expected in the lab test.

While the first field test assessment focussed on staining, in the second decay was detected in some cases. The field test assessment (including bending tests and microscopic investigations) and the lab tests were set into correlation. The moisture monitoring and the field test assessments clarify a close relationship between fungal attack and the construction of the sample setups which induce different humidity regimes in use class 3. As no significant discrepancies occurred, the results allow (roughly up to now) to identify plywood for external uses. Mass loss in the lab tests and the field test assessment indicate a better performance for those panels made of durable wood species compared with the non-durable ones. An influence of edge sealing in the field tests on the moisture content was remarkable, effects on fungal attack were not yet visible.

Partner 5 continued weathering tests using the method developed during the first year. Different coating systems and optimised plywood products were included. After 18 month's exposure, some coatings started to show mould growth and blue stain on surface. The average condition of coated plywood was good as compared to uncoated plywood. Coated birch and spruce plywood, however, performed well in the outdoor situation in Finland: moisture condition level of coated plywood products was more stable during the 1.5 years' test period than that of uncoated plywood, and moisture level of coated plywood products was lower than the critical moisture needed for decay development (wood moisture content above 25 - 30 %).

According to a limited number of water permeability tests, the protection of fixing point is also very important factor for the moisture content and durability of coated plywood. According to the test results ENV 12038 seemed to work also to determine the resistance of the plywood against decay fungi when preceding outdoor weathering is used. Mould test at high humidity (RH 100%) did not seem to work so well.

According to Finnish experience, coated plywood has been used for several targets: e.g. traffic signs made from paint base film and painted or coated reflecting film. The product is performing very well in Finland. The most critical factor for the use of these products seems to be the service life of the reflecting cover or the film, not the durability of birch plywood itself. Edge sealing and protection of duct bolt or other fixing points is very important factor for the service life of plywood manufactured from the wood species of durability class 4 and 5 (spruce and birch).

Partner 6 (CTBA) could already conclude from the input on the survey up to now that little or no decay problems were found in the plywood evaluated. Most frequent moisture related problems were delamination and deformation.

All industrial partners (P7-P13) were involved in the discussions on optimized plywood. The results on this were used to identify and select specific types. These optimized plywoods are produced and forwarded to the coordinator for further distribution.

2.2.3.2. Future action

Partner 1 has started several ENV 12038 test for which results will be obtained during 2006. They will allow comparison for all reference and optimized plywood between decay caused by *Coniophora*, *Pleurotus* and *Coriolus*, with or without edge sealant application. Solid wood is included in the test set up. The influence of pre-conditioning method will be investigated as well.

Partner 1 continues the outdoor field tests and has started a second accelerated weathering test including all optimized panels. A set of plywood specimens delivered at the tropical test site at Kourou (partner 3) will allow for comparison of the weathering intensity between a tropical situation and the accelerated weathering at the site of the Ghent University.

Further investigation of the moisture related behaviour of plywood will be intensified by continued processing of the floating test data and by development of a field test method allowing continuous water monitoring of outdoor exposed plywood specimens.

The survey related site visit program will be continued and interaction with partner 6 (CTBA) will be intensified.

Some optimised plywood will be tested by partner 2 (UNITO) according to ENV 12038, using four reference fungi: *Coniophora puteana*, *Gloeophyllum trabeum*, *Coriolus versicolor* and *Pleurotus ostreatus*. All the plywood samples will be analysed after 16 weeks of degradation by ultrasonic and electrical measurements and assessed in terms of mass loss.

Partner 2 (UNITO) will participate to the evaluation and comparison of results from the different tasks in order to find the foreseen solutions concerning the validation of the ENV 12038 and the definition of correlated and faster test methods for the evaluation of plywood durability performance in relation to service classes and exposure conditions.

Shore data analysis is still in progress in order to find possible relationships with other hardness test methods for wood-based panels.

UNITO continues the activity of survey of interesting cases of exterior use of plywood in national constructions, according to CTBA inspection protocol.

Partner 3 will do the biological tests and the non destructive mechanical tests (ultrasonic measurements and indentations) on the industrial plywoods. A choice of the optimized plywood types received will also be tested according to ENV 12038 and with indentation tests before and after biological testing. The plywood samples from partner 6 will be observed regularly in order to report decay if it is occurring. Identation tests will be performed afterwards.

Partner 4 will conduct the 3rd and 4th assessment of running field tests. The bending test and moisture monitoring will be continued as well as the determination of EMC of the optimised panels and exposure in the field.

The outdoor weathering trial of different coated and uncoated plywood products will be continued at the test site of partner 5 (VTT) in Otaniemi. Also laboratory tests on the biological durability will be continued, and the final results will be reported. The measurements on colour change during different weathering tests will be analysed and reported. The co-operation with CTBA and BFH will be continued and the field tests using different racks and lay-outs will be reported. Results on the survey of coated plywood structures will be finished and reported. Fit for purpose of coated plywood products in different targets will be focused.

Partner 6 still needs to integrate the material from other partners on the survey in order to provide input for WP6.

2.2.3.3. Action requested from the Commission

No specific actions requested.

2.2.4 Progress during the fourth reporting period

Partner 1 (UGENT) completed and analyzed all ENV 12038 testing of reference and optimized plywood types during working year 4.

The outdoor field exposure of reference plywood samples was continued. A second visual assessment was performed, evaluating the performance of all reference plywood types after 30 months of outdoor exposure. Still no fungal decay could be detected on specimens exposed in the freely hanging and the covered outdoor field tests. All plywood specimens were rated for the occurrence of blue stain, moulds and wood destroying fungi, panel deformations (cup and twist) and weathering signals (crack formation, defibrillation, damage by insects and erosion). Staining was present on most samples. Due to defibrillation and disappearance of the outer greyed surface layer, mould and blue stain fungi are more easily detected. This leads to higher scores for mould and blue stain presence for most plywood specimens.
Spruce and maritime pine plywood show severe crack formation while continuing surface degradation was present for the other plywood types.

The accelerated weathering set up including sponge wetting was finished and the samples were prepared for analysis. Results were partly presented at the annual IRG conference.

The Continuous Moisture Monitoring (CMM) test set up was constructed and its preliminary results on plywood moisture behaviour in outdoor exposure applications were analysed. Results are partly to be presented at the IPPS 2007 conference in Cardiff. This monitoring set up includes a fully equipped weather station consisting of a solar energy sensor, a tipping bucket rain gauge, a relative humidity probe, a thermometer, an anemometer and a wind vane. Every 5 minutes the weather data together with the signal of 56 load cells bearing an attached plywood specimen is logged and saved. Obtained time series allow comparison between plywood types on single shower level as well as on seasonal basis.

For WP4 coated reference plywood samples are included in all test set ups (ENV 12038 durability testing, outside test exposure systems, CMM...). The influence of a coating was assessed during floating tests allowing investigation of absorption and desorption parameters of plywood.

Testing of the impact of edge sealing was performed as well in the ENV 12038 testing by using a two component polyurethane sealant (Sigmadur HB Finish) as edge sealant for all reference plywood specimens.

Partner 1 (UGENT) conducted a survey of representative plywood constructions in the Benelux. Several cases including plywood in class 3 outdoor exposure situations were assessed. Results were compiled and delivered to partner 6 (CTBA) to be incorporated in the developed database.

As coordinator Partner 1 (UGENT) worked out a fir-for-purpose methodology and discussed this with industrial partners and the FEIC Technical Group.

Partner 2 (UNITO) completed ENV 12038 test on 10 optimised plywood chosen among those produced by the all partners during the previous years: none of these optimised plywood showed performance allowing classification as durable plywood.
Ultrasonic and electrical measurements were completed on tested optimised plywood and data processing was carried out and finished.

During the period considered, Partner 2 (UNITO) in order to evaluate the reliability of the non destructive measurements finished the analysis of shore hardness measurements done.
Partner 2 continued to collect information on the use of plywood in the Italian continental climate. Other examples were selected for inspection according to the CTBA protocol. As planned, for each case UNITO collected all the information about the sites (photo, reports etc., according to CTBA check list).

UNITO has contributed to the analysis and comparison of results from the different tasks. Obtained laboratory and field results were processed and linked in order to define the basic plywood parameters necessary for construction of a fit for purpose concept and proposal for quality marking of plywood. According to this target, Partner 2 defined a partial quantitative classification of plywood performances.

Finally, UNITO has defined some proposal of modification of the test ENV 12038 method.

Partner 3 (CIRAD): All the biological tests according to ENV 12038 have been done on industrial plywoods and for a fungal exposure of 2, 4, 8 and 16 weeks. From the obtained results, it is clear that the time of the fungal exposure can not be shortened under 8 weeks.
The ultrasonic measurements and the indentation tests were carried out for all samples when possible after fungal testing. When the fungal decay was too high, and when the shrinkage was important, ultrasonic and mechanical were impossible to be executed.
The non-destructive test results were highly correlated to the fungal decay (especially after 16 weeks of fungal attack).
Plywood samples for filed testing received by partner 3 were evaluated for the degradation after 27 months. For Maritime Pine as well as for Okoumé plywoods, discoloration, blue stain and mould on the outside, as well as rot in the inner plies were recorded.

Partner 4 (BFH) performed additional work related to moisture uptake, the influence of glue, number of plies, wood species and layout of the veneer sheets and visualization of moisture uptake of specimens used for lab testing. Field test material was evaluated after 1.5 and 2 years exposure using visual assessment, mechanical strength (bending) tests and moisture monitoring. This allowed differentiating between the filed test set ups used and their impact on identifying suitable plywood. This methodology could also be used for the optimised panels although only up to 6 months exposure.
Results from laboratory tests (WP 2), moisture monitoring and outdoor tests (WP 3) were used for correlation statistics in order to identify the optimum methodology for the simulation of use conditions.

Partner 5 (VTT) focused on workpackage 4, 5 and 6. The WP 4 was finished earlier. The effect of coating types on the performance of plywood after 2 years´ accelerated outdoor weathering test was assessed. Moisture content samples as well as surface condition of coatings were measured. Different coating condition index parameters were noted: e.g. cracking, peeling off, colour change, mould and blue stain on surface and water permeability. Water permeability prior to and after weathering tests has been measured. Samples from weathered and un-weathered plywood were then exposed to biological tests ENV 12038 using 3 different fungi. Soft rot tests were also completed. Survey of different structures made of coated plywood products were performed under WP 5. In the WP 6, the evaluation of the impact of coatings on the use and service life of plywood was covered.

During year 4 Partner 6 (CTBA) collected survey information from other partners and integrated the material with their own survey results to provide input for WP6.

Partners 7 and 9
Especially Panguaneta and Finnforest attributed as industrial partners extra time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

2.2.4.1. Discussion-Conclusion

The results on performance lab testing from Partner 1 (UGent) confirm *Pleurotus* to be rather glue-indifferent, attacking both UMF and PF glued plywood types easily, while the presence of PF-glue remains a restricting factor for decay by *Coniophora*, even after 12 weeks of preconditioning in a ventilated room. This glue-inhibitory effect can be reduced for *Coniophora* by implementation of an EN 84 leaching procedure prior to testing. However, for UMF-glued plywood material a leaching procedure has an adverse effect on plywood durability (due to removal of nutritious substances, making UMF-plywood less attractive to fungi).

When no edge-sealing is applied it is impossible to make a difference in durability between coated or not-coated plywood material. Edge-sealing is required for the evaluation of coating quality or the effect of a durable top veneer.

No difference between soft and hardwoods can be made based on type of test fungi since spruce plywood is showing high mass losses for *Pleurotus* while pine plywood is not, and spruce plywood is not consistently decayed by *Coniophora*.

Partner 1 (UGent), the coordinator used the input from all partners and of all other workpackages to come to an implementation document related to standardisation. A implementation document as well as a brainstorming document were used to interact with the FEIC Technical Group.

According to the durability test data of Partner 2 (UNITO), even if sometime they are limited to e.g. only 2 decay fungi only, it can be pointed out that not all coating improved enough the plywood performances. It can be concluded that coated plywood is not always suitable for severe exposure conditions.

Moreover the large standard deviations of mass losses hint a great data variability, which could be attributed not only to fungi biology but also to the reduced number of plywood samples used in the ENV 12038 test.
Finally, after a generic comparison between PF and UMF glued plywood, it was concluded that UMF plywood are more decayed by *C. puteana* and *C. versicolor* than for *G. trabeum* and *P. ostreatus*.
Concerning ultrasonic measurements, it was realized that the ultrasonic measurement system is not suitable to detect or to predict decay because ultrasonic velocity decrease is only significant when plywood decay is higher than 10% of mass loss.
Concerning electrical measurements, it can be pointed out that resistivity, permittivity and loss tangent are differently sensitive to decay for the 3 plywood features glue, wood species and coating. Decay for most of UMF glued plywood could be assessed using permittivity parameter while resistivity is suitable for most of PF glued plywood but it is not possible to use a single math function to assess or to predict decay of the all plywood. Consequently, electrical measurements could be suitable to use as non-destructive mechanical test because of electrical parameters sensitivity to many plywood decay: however some problems concerning the sensitivity absence to decay of some plywood have to be solved yet.
Although electrical parameters proved to be sensitive enough to assess decay of many plywood, it should be necessary to develop new studies taking into account the plywood features and increase the number of specimens.

The results obtained from shore hardness measurements using reference and optimised plywoods confirm that there is no clear relationship between hardness and mass loss: the test method is not sensitive enough for modest variations in the wood density. The results show that there is no definite discrimination in shore value for low wood density variation as is present within the same type of plywood.
Moreover, the following considerations can be underlined:

- because of the irregular surface of decayed specimens, the measure of shore hardness is affected by relevant errors: the shore value, related to indenter penetration under applied force, depends not only to the shape of indenter but also to the response to indentation. Phenomena of swelling and irregularity of the decayed surfaces of sample strongly affect the values measured;
- many error sources can affect the uncertainty of measurement of the shore test: if the difference on the shore scale is less than twenty hardness units, it is not sure that this is due to the effect of the mass loss of the decayed specimens;

On the basis of the results the use of standard shore D test as a non destructive method to estimate decay of plywood in service appears not to be adequate.

As planned, UNITO has continued to select examples of exterior applications of plywood in alpine climate. The results obtained during this inspection were not always comparable with ENV 12038 results. In some application the performance of not durable or less durable plywood was better than expected on the basis of the mass loss determined with ENV 12038 test method. Moreover, plywoods made of wood species of natural durability classified in class 3 - moderately durable (e.g. african mahogany), with expected service life of 10-15 years, show a service life shorter than expected, while, in the same exposure conditions, other plywoods with natural durability of class 4 – less durable after about 12 years do not show any trace of decay.

The monitored external applications show that structures made with plywood of moderately durable wood species (okoumé and maritime pine) can be used for 20 years only with periodic refinishing to restore or repair the eroded varnish coating.

On the basis of the results from biological test according to ENV12038 and the inspection conduced during the WP5, UNITO defined a partial quantitative classification of plywood performances which detailed for each class of service life related to the exposure conditions and estimated long-life (from 5 up to more than 20 years) the most performing plywood tested during the project.
Only for the use class 2 all types of plywood (wood species, lay-up, film, ect.) and / or adhesive are suitable: in this context the main critical factors are the glue bond quality of the plywood and its dimensional stability under MC variation due to temporary wetting. In these exposure conditions there is no risk of decay, and therefore no requirements are needed on mass loss. The situation is very different for the use class 3 where it is suggested to establish/increase the maximum level of mass loss to 6%.

Concerning the results obtained from laboratory test ENV 12038, UNITO suggest to modify the test method:

1. increase the number up to e.g. twenty five or thirty specimens;
2. select two different series of fungi related to different classes of resins: *C. puteana* and *C. versicolor* for UMF and MUF adhesive systems and *P. ostreatus* and *C. puteana* for the PF adhesive system.

Finally, it is also suggested to realize a guideline or to revise the ENV 1099 adding some examples (with photos or other practical examples) of different plywood adequate for the use in class 3.1 and 3.2.

Partner 3 (CIRAD) concluded with regard to fungal testing that for all the plywood tested, it appears that 8 weeks of fungal exposure is a crucial time. It seems that if the mass loss is below 3% at that time, this will not change at 16 weeks. This is shown for all panels, except for R1 when exposed to *Coniophora*. But in this case, the results were extremely different from one sample to another (very high standard deviation).
The ultra-sonic method is not relevant to be linked with the mass loss. For this non-destructive method, many problems were underlined.
The indentation tests were performed for the samples decayed by fungi for 2, 4, 8 and 16 weeks. So far, this method could not be sufficiently correlated with the mass losses, and as for the ultrasonic measurements, some drawbacks are found for this method too. The surface of the sample that has been submitted to fungal attack and to drying at 103°C, is usually no longer sufficiently flat. As long as the mass loss is low (roughly < 3-5%), this is not a problem.

Partner 4 (BFH) performed extra analyses on the moisture conditions of specimens exposed under different set ups. Result showed high moisture contents for the double layer test which allowed concluding that this was very much in line with lab testing while free hanging exposure did not allow differentiating between different specimens under test.

Partner 5 (VTT) continued and finished weathering tests using the method developed during the first year. Different coating systems and optimised plywood products were included. After 18 month's exposure, some coatings started to show mould growth and blue stain on the surface. After 24 months’ exposure, discolouring fungi were disappeared due to a dry and warm period. The general condition of coated birch plywood was as good as uncoated plywood. Coated birch and spruce plywood performed well in the outdoor situation in Finland. Moisture level of coated plywood products was more stable over the 2 years' test period than for uncoated plywood. The moisture level of coated plywood products was lower than the critical moisture needed for decay development (wood moisture content above 25 - 30 %). The plywood made from durable top veneer did not perform well against weathering and discolouring. When coated, this product performed a lot better.

Integrated weathering and test methods for biological durability were also tested for coated plywood. According to the test results, ENV 12038 seemed to work for testing resistance of coated plywood products against decay fungi when using preceding outdoor weathering. Mould test at high humidity (RH 100%) did not seem to work so well. Decay resistance of sound coated birch plywood was good when tested according to EN 12038 using different pre-weathering systems. The performance of coated spruce plywood against decay using this procedure was not satisfactory. This test requires edge sealing. Even the acrylate edge sealing paint performed. Coated plywood products have been used for different targeted applications: formwork, claddings, racks, fences, flooring in trailers, traffic signs. Most often these products are performing very well in Finland. Key factors for the performance of coated plywood products are the edge sealing and protection against damages. The protection of duct bolt or other fixing points is very important factor for the performance and service life of plywood manufactured from the wood species of durability class 4 and 5 (spruce and birch). The performance of durability classification of coated plywood products should not be based on the wood species only. For coated products, the performance of the whole system is most important.

Partner 6 (CTBA) continued the survey and compiled the information on plywood in exterior constructions in a database. Plywood constructions described are mainly situated in France and Switzerland.

In 2006 the site visit program was continued by Christiane Deval. A limited selection of building sites was assessed. The selection was done by the age of the panel. Building sites more than 10 years old were researched in priority.
Christiane Deval assessed a few others building sites, and compiled the information on plywood in exterior constructions in the database.

A survey template document in English was handed over to all partners.
The other partners used this concept in a slightly modified version for their inventory.

CTBA received data from Ghent University, UNITO and VTT and information was compiled in the data base.

Very interesting examples are assessed with 30 year old plywood in maritime pine and okoumé.
Also several buildings using spruce and birch plywood and spruce LVL in hazard class 3 have been assessed. All these façades in hazard class 3 are directly weather exposed. Some parts of the façades were even hazard/use class 4 situations.

Some “Non qualified Plywood” has been assessed too, Ghent University provided examples and CTBA integrated this assessment in the first part of the study.

2.2.4.2. Future action

Further work was needed by the end of year 4. During the period 2007-2008 extra effort was dedicated to come to a full implementation of the results and methodology for standardisation related to the objectives of the plywood industry involved.

2.2.4.3. Action requested from the Commission

No specific actions requested.

2.3 Description of the workpackages

No changes to the workpackages as described in the technical annex were needed.

WP 1. Development and production of exterior quality plywood

Workpackage number: **1**

Start date: Month 0
Completion date: Month 36

Partners responsible	**2**	1	5	7-13	Total
Planned person months per partner and total:	1 + *2*	3 + *2*	1	each 2	**19 + *4***
Devoted person months per partner and total:	1 + *2*	3 + *2*	1	1-1.5	**15 + *4***

Objectives

- Production of different panel types: MUF poplar plywood, poplar LVL and exotic plywood with different veneer thickness/lay-up; poplar plywood with treated glue lines.
- Control and measurement of the plywood panels and LVL selected for testing.
- Development of MUF glued poplar plywood with surface protection (overlaid by phenolic film, resin coated and/or edge painted) and with faces made of veneer of durable wood species or with mixed layers (combi).
- Production of plywood with durable top veneers.
- Production of optimised plywood types.

Methodology and study materials

1.1 Development and production of non-coated exterior quality hardwood plywood

This task is dealing with the screening and selection of data concerning the market and end-uses for the established types of commercial poplar plywood with regard to the available clones and the lay-ups representative of the full range of the products.
Plywood and LVL panels will be manufactured using veneers of at least one poplar clone and exotic wood species, glued together with a MUF (melamine-urea-formaldehyde) polycondensation resin adequate for gluing wood-based panels suitable for external use in humid conditions (bonding classes 2 and 3, in compliance with the standard EN 314).

1.2 Production of coated plywood

Coated birch plywood (ply thickness 1.5 mm) and spruce plywood (ply thickness 1.5 and 3 mm) will be manufactured to be assessed in other WPs. Part of the boards will be coated with phenol film or with painted craft liner. In addition new developments combining standard core plywood and durable or modified top veneers will be prepared. Choice of different edge sealing technologies will be studied. Partner 9 will focus on spruce plywood using different veneer thickness, LVL and plywood having durable top veneers. Partner 10 will produce coated birch plywood and plywood

partly based on heat treated top veneers. Partner 11 will concentrate on the production of painted craft liner coated plywood and different edge sealing systems.
Considering that the project is focussed on the plywood for the construction and transportation sector and for use in humid conditions, panels will be made with MUF glue and also with surface protection by partner 7. Film-faced poplar plywood is not usually manufactured but for this projects will be realised two types of surface protection: with phenolic film and with a resin coating. The edges of the above panels will be also protected (for instance, by a paint of acrylic resins dispersed in aqueous solution, with low toxicity for higher organisms). In order to obtain a comparison of the performance of different types of plywood suitable for outdoors conditions on the construction and transportation sector, other panels will be produced and checked.

1.3 Production optimised products

Based on the results obtained from the preliminary tests conduced on the commercially used plywood and on those with special lay-ups and surface protections, the industry will be able to realise optimised plywood with better performance for exterior use.

Progress during the first reporting period

P1: Partner 1 collected the plywood reference material produced by partners 7 to 13. The reference material was sampled according to a specific sampling scheme (see technical report P1) and sent to partners 1 to 6.

P2: Partner 2 has contributed to define the main criteria for the composition of the reference panels (selection of wood species – also combined in non homogeneous lay-up – veneer's thickness and appearance class, panel's lay-up, bonding type and quality, surface and edges protections) and also in the coordination of the industrial partners involved in the production of the coated and uncoated panels.
The above work has been agreed with the project coordinator and the industrial partners in order to include in the project a representative range of the European plywood production and also to verify the effects of the different lay-out/parameters of production of the panels selected on their durability in use.

Finally, on the bases of the harmonized standard EN 13986: 2002 "Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking", that defines the performance characteristics required by wood-based panels, including plywood, for use in construction applications, and where a set of tables lists the relevant performance characteristics for load bearing (structural) and non-structural applications in the three service conditions (dry, humid and exterior), partner 2 has prepared a technical sheet in order to have a common framework to describe and compare the plywood made by the industrial partners.
Data concerning the panels' properties have been obtained from factory quality controls done directly by each company or from results of testing made through national federations of plywood industries. Considering the above mentioned aim of the sheets, specific test to check the declared performance data of the different panels are not been done.

P5: The choice of plywood test material has been selected to tests and then manufactured.

P7: The test boards have been produced and delivered to Ghent University (P1).

P8: Two different types of plywood have been produced and delivered to Ghent University (P1).

P9: Finnforest Corporation has produced and delivered the plywood and LVL-panels to the laboratories UGENT and VTT building and Transport.

P10: The test boards have been made for testing laboratories VTT Building and Transport and University Gent.

P11: Basic birch and spruce plywood panels were produced in the production conditions. The panels were painted on the automatic painting line consisting the wood protection and/or primerisation and/or top coating). There was no edge-sealing in panels here.

P12: Four different types of plywood have been produced and delivered to Ghent University (P1).

P13: Manufacturing of maritime pine plywood uncoated panels for testing, sorting of various thickness maritime pine veneers. Manufacturing of panels glued with formo-phenolic glue. Control production parameters. Panels have been delivered to Ghent University during 4th quarter 2003

Progress during the second reporting period

P1: During the extra meeting between partners 1-6 in Montpellier (September 2004) and the third PCC meeting in Hamburg (November 2004), partner 1 together with the other partners discussed the subject of the production of optimized plywood panels. It was agreed for the industrial partners to produce several different types of optimized plywood, and send 6 panels of each to the Ghent University (P1). At the end of 2004 the first set of panels arrived in Ghent. They were processed according to the agreed sampling scheme and made ready for delivery to the other research partners.

P2: (UNITO) has done the evaluation of commercial waterborne preservative compounds in view of their possible use for improving plywood durability through the addition in the adhesive system.
A study was made on the market in the European plywood sector, with attention to the preservatives specially developed for being used with aminoplastic thermosetting adhesives.
Different types of optimised poplar plywood with different amount of preservatives added in the glue mix, originally not indicated in the Technical Annex, have been produced. Some experimental plywoods have also been produced using different veneers species (pawlonia, douglas, okoumé-hornbeam); they will be tested according to the methodology used for reference panels (after 2, 4, 8 and 16 weeks of degradation).
The above work has been agreed with the project coordinator and the industrial partners (P7) in order to planning the manufacturing of optimised product.

P5: Additional uncoated plywood products with faces from veneers of durable wood species and main optimised plywood products were included in the weathering tests for WP 4.

P7: Discussion and research performed on selection and production of optimized plywood.

P8: Discussion and research performed on selection and production of optimized plywood.

P9: Discussion and research performed on selection and production of optimized plywood. Finnforest, has delivered more reference material to partner 4 / BFH, Hamburg: sanded Finnforest Spruce softwood plywood 15mm/5 ply, spruce veneer 2,6 mm, spruce veneer 1,4 mm, spruce and birch peeler logs. Cooperation was intensified with some overlaying manufacturers intentionally to develop better overlays for exterior applications. New equipments were installed to produce more effectively plywood with glue additives for exterior applications like for scaffolding platforms.

P10: Discussion and research performed on selection and production of optimized plywood.

P11: Discussion and research performed on selection and production of optimized plywood. Participation in two national Meetings in Finland and one Technical Meeting in Hamburg.

P12: Discussion and research performed on selection and production of optimized plywood.

P13: Discussion and research performed on selection and production of optimized plywood. Four different optimised types of plywood have been produced and delivered to Ghent University.

Progress during the third reporting period

P1: As discussed during the 2004 meetings in Montpellier (September 2004) and Hamburg (November 2004), the industrial partners produced several different types of optimized plywood, and sent 6 panels of each to the Ghent University (P1). Partner 1 collected all panels, processed them according to the agreed sampling scheme and prepared and completed the delivery to the other research partners. At the end of 2005 all optimized panels were processed and redistributed.

On request of partner 1 (UGENT), partner 3 (CIRAD) produced in their laboratory 2 more panel types (throughout cypress plywood and a cypress/poplar combi plywood). Partner 1 received these panels and incorporated them in the different test set ups at the Ghent University.

Details on optimized panel types can be found in the 2005 technical report of partner 1.

P2: During July 2005 a first set of industrial optimised panels has been produced by Partner 2 (UNITO) and 7 (Panguaneta) using poplar clone "I 214" and different wood species, also combined in non homogeneous lay-up, coated with phenolic film or uncoated and veneer’s thickness:

- maritime pine plywood UMF glued, nominal thickness 17/7 mm made with veneers (from Smurfit-France) of 2.5 mm,
- paulownia plywood UMF glued, nominal thickness 18/9 mm made with veneers of 2.1 mm,
- oak plywood UMF glued, nominal thickness 15/9 mm made with veneers of 1.8 mm.
- poplar plywood (raw) PF glued (clone I-214), nominal thickness 18/9 mm made with veneers of 2.1 mm,
- poplar plywood as above but phenolic film faced,
- poplar plywood (raw) UMF glued (clone I-214), nominal thickness 15/11 mm made with veneers of 1.4 mm,
- poplar plywood as above but phenolic film faced.

These plywood panels were manufactured using industrial veneers supplied by partner 7 and bonded with a UMF (melamine-urea-formaldehyde) resin mixture suitable for gluing wood-based panel for use in humid conditions. Panels with size of 125x250 cm and nominal thickness between 15 and 18 mm were made according to the normal industrial process.
Furthermore, partner 2 (UNITO) and partner 7 (Panguaneta) has produced a second set of phenolic industrial optimised panels, as follows:

- poplar plywood (raw) PF (phenol formaldehyde) glued, nominal thickness 18/9 mm, made with veneers of 2.1 mm thick,
- poplar plywood as above but phenolic film faced.

A final set of industrial raw optimized panels made with poplar clone “I 214” bonded with standard UMF adhesive system added with different preservative selected from P2 (Fintan 737 and Wolsit® F-SP) was also produced, with the following characteristics:

- poplar I 214 plywood UMF + wolsit glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick,
- poplar I 214 plywood UMF + tannin glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick,
- poplar I 214 plywood UMF + resorcinol glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick.

The selected preservatives were used with a max concentration of 10% on the bases of laboratory results derived from experimental plywood made by UNITO. For Wolsit this concentration was necessary to determine a biocidal effect, while the commercial powder of modified quebracho tannin extract was the max threshold allowable with the characteristics of the UMF resin used by P7 and the environmental conditions in the mill. In this last case the addition of tannin to the glue mix doesn’t shows any biocidal effect but can be helpful for improving the bonding quality of the plywood.
Furthermore, and for the same aim as above, was produced a reference poplar plywood glued with an adhesive system based on UMF resin added with low percentage of resorcinol in powder (5%). For this reason, the bonding quality was tested for the second set of industrial optimised plywood produced according to the standard EN 314 after a 5.1.3 pre-treatment.

Table 3. List of the optimised poplar plywood produced by partner 2 with technical support of partner 7.

Code	Coating	Wood species	Glue	Thickness	Plies	Veneers
U1	Non-coated	maritime pine	UMF	17 mm	7	2.5 mm
U2	non-coated	pauwlonia	UMF	18 mm	9	2.1 mm
U3	non-coated	oak	UMF	15 mm	9	1.8 mm
U4	non-coated	poplar	PF	18 mm	9	2.1 mm
U5	phenolic film	poplar	PF	18 mm	9	2.1 mm
U6	non-coated	poplar	UMF	15 mm	11	1.4 mm
U7	phenolic film	poplar	UMF	15 mm	11	1.4 mm
P4	non-coated	poplar	Resorcinol UMF	18 mm	9	2.1 mm
P5	non-coated	poplar	Wolsit UMF	18 mm	9	2.1 mm
P6	non-coated	poplar	Tannin UMF	18 mm	9	2.1 mm

These panels will be tested by scientific partners in order to determine their decay resistance. Partner 2 will test U1, U3, U4, U5, U6, U7 and some optimised plywood proposed by other partners.

P5: Partner 5 assisted the Finnish industrial partners in the selection and production of optimized plywood.

P7: Partner 7 (Panguaneta) produced in collaboration with partner 2 (UNITO) 12 types of optimized plywood panels and delivered them to UGENT (see P2)

P8: Coblo has produced optimized UMF-glued poplar plywood and a UMF-glued poplar/beech combination. 6 panels per type are delivered to UGENT.

P9. Finnforest has delivered optimized plywood to partner 1 (UGent). In June Finnforest sent 6 panels of unsurfaced birch plywood, with 2.4 mm thick birch veneers for the tests in Ghent. Panel sizes are 1200 mm x 1200mm x 21mm/10ply panels and panels are glued with phenol-formaldehyde glue.

P10: Partner 10 (Koskisen) delivered 2 optimized birch plywood types to UGENT. Both panel types are coated and PF-glued.

P11: UPM-kymmene produced 8 types of optimized plywood. Wood species are birch and combination of spruce and birch. Panels are PF-glued, coated and not coated, untreated or treated with Xyligen.

P12: Allin delivered 2 more optimized panel types to UGENT (P1). The first type is a grooved okoumé plywood while the second is a okoumé plywood with a weatherproof paper overlay.

P13: Partner 13 (Smurfit Rol Pin) produced 4 types of optimized maritime pine plywood panels for testing. It concerns coated, heat treated, preservative treated and grooved maritime pine plywood. All panels are glued with formol-phenolic glue and have been delivered to Ghent University during 2005.

Progress during the fourth reporting period

Since all test panels were successfully processed and distributed to the partners involved and as a result of analysis of the test results on reference panel types optimized plywood types were produced, processed and redistributed as well during working year 3, no additional work was necessary for work package 1.

Deliverables

The following deliverables were covered:

D1. Coated and uncoated birch and spruce plywood samples for other WPs, month 6

During the period considered a total number of 130 uncoated and coated plywoods have been produced.

a) Uncoated reference panels:

- Poplar plywood (with the clones I-214 and Beaupré),
- Poplar plywood with okoumé faces,
- Poplar plywood with moabi faces,
- Mixed (combi) plywood with longitudinal grain veneers on okoumé and cross veneers on poplar (with okoumé faces)
- Maritime pine plywood
- Okoumé plywood
- Spruce plywood
- Birch plywood
- Spruce LVL.

In total 15 different types of uncoated panels have been produced for durability testing. Some of the above uncoated panels have been realized using veneers of different thickness/lay-up.

b) Coated reference panels, the following 7 different types of coated panels for durability testing:

- Birch plywood coated with phenolic film (with 2 basic weights)
- Birch plywood coated with melamine film
- Birch plywood coated with paint (2 types)
- Spruce plywood coated with paint
- Spruce LVL coated with paint.

Some of these were provided of special edge-sealing.

D5. Technical quality of different coatings systems, month 18

The water permeability and thickness deformation of plywood material prior the weathering was measured using the modified method (EN 927-5). The thickness of coating layer was analysed under microscopy and the colour of surface of samples was measured using the Spectrofotometer Minolta 525 I device.

D6. Core data of different coating systems prior to assessments

The core data on studied coated and uncoated plywood material was delivered by the industrial partners. Main optimised coated plywood products were already included.

D7. Experimental validation and realisation of optimised poplar plywood with better performance for exterior use (construction and transportation sector), month 18.

The following experimental uncoated plywood has been produced:

- Poplar clone I 214 plywood glued with standard UMF glue mix,
- poplar clone I 214 plywood glued with TUMF glue mix,
- Poplar clone I 214 plywood glued with WUMF glue mix,
- Plywood with different types of wood species (okoumé, hornbeam, douglas and paulownia).

In total 13 different types of uncoated panels have been produced for durability testing. Some of the above uncoated panels have been realized using veneers of different thickness / wood species.

The following optimised plywoods have been produced by July 2005:

- maritime pine plywood UMF glued, nominal thickness 17/7 mm made with veneers (from Smurfit-France) of 2.5 mm,
- paulownia plywood UMF glued, nominal thickness 18/9 mm made with veneers of 2.1 mm,
- oak plywood UMF glued, nominal thickness 15/9 mm made with veneers of 1.8 mm.
- poplar plywood (raw) PF glued (clone I-214), nominal thickness 18/9 mm made with veneers of 2.1 mm,
- poplar plywood as above but phenolic film faced,
- poplar plywood (raw) UMF glued (clone I-214), nominal thickness 15/11 mm made with veneers of 1.4 mm,
- poplar plywood as above but phenolic film faced,
- poplar I 214 plywood UMF + wolsit glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick
- poplar I 214 plywood UMF + tannin glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick
- poplar I 214 plywood UMF + resorcinol glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick

In total 13 different types of uncoated and film faced optimised plywoods have been produced for ENV 12038 durability testing.

D8. All plywood available for testing, month 24

For the outdoor weathering tests in WP 4, the following different types of plywood products were selected (main optimized plywood products were included):

- Uncoated birch plywood (edge sealed and non edge sealed)
- Edge sealed samples (3 times with Teknos JRM edge sealing paint):

- Birch plywood coated with phenolic film (with 2 basic weights)
- Birch plywood coated with melamine film
- Birch plywood coated with paint base film and paint (3 types)
- Birch plywood coated with paint (3 types)
- Spruce plywood coated with phenolic film (with 2 basic weights)
- Spruce plywood uncoated and coated with transparent paint
- Spruce LVL uncoated and coated with transparent paint
- Uncoated birch plywood with larch faces
- Uncoated spruce plywood with pine heart wood faces
- Uncoated poplar plywood (2 types)
- Uncoated poplar plywood with okoumé faces,
- Uncoated poplar plywood with moabi faces
- Uncoated okoumé plywood
- Uncoated moabi plywood

Milestones

The following milestones were covered:

M1. Month 12: All adequate test plywood developed.

Some reference plywood still needs delivering but all partners involved in producing test plywood have been planning production or have produced adequate test plywood. Optimized coated plywood products were also delivered.

M2. Month 24: Data sufficient to produce optimized products.

Discussions at the meeting in Montpellier (only research partners) and in Hamburg (all partners) allowed identifying a first series of optimized products. These are produced by the industrial partners from end 2004 to beginning 2005.

M6. Month 42: All optimised products under test

Optimised plywood produced by the industrial partners were delivered to all partner and submitted to the test.

WP 2. Quality laboratory testing of biological plywood durability

Workpackage number: **2**

Start date: Month 6
Completion date: Month 48

Partners responsible
Planned person months per partner and total:
Devoted person months per partner and total:

1	2	3	4	Total
24 + *2*	20 + *8*	14	6 + *6*	**64 + *16***
23 + *2*	23 + *8*	14	12	**72 + *10***

Objectives

- Improvement of the evaluation procedure for ENV 12038
- Development of non destructive mechanical tests to control mechanical properties
- Correlate mass loss and mechanical property loss at different decay stages, in order to estimate realistic durability of plywood and estimate if accelerated tests can be valid
- Non destructive testing and mechanical shear testing for the evaluation of the bonding quality of plywood and LVL.

Methodology and study materials

2.1 Durability testing according to ENV 12038

Biological tests according to the ENV 12038 will be performed on non-coated exterior quality plywood and on exterior quality plywood coated with durable top veneer. These trials will be replicated in order to be able to evaluate the decay at different stages (2, 4, 8,…16 weeks). Degradation of samples will be carried out on agar medium (with preconditioning) or on vermiculite (without preconditioning).
For comparison the plywood used in WP 3 will be tested according to ENV 12038 test by partner 4 (after 12 weeks conditioning and after 6 month of natural weathering at the field test site of partner 4).

2.2 Non-destructive mechanical testing

Non destructive mechanical tests will be developed. The mechanical tests envisaged should be able to be performed on plywood samples previously used for biological testing. Two methods will be investigated in order to assess decay through mechanical degradation of the panel: The use of ultrasound wave propagation through the panel (absolutely non- destructive) and mini indentation tests. The results of these experimental methods will be analysed through the use of simulation by 3D finite element methods of multi-layered materials considered as visco-elastic.
Furthermore most plywood will be assessed on technological characteristics (physical and mechanical properties) using non-destructive testing (stress-wave based by Bing) for the determination of stiffness on plywood and LVL. Partner 2 will perform commodity testing for measurement of the electric and ultrasonic properties of samples: Impedenzimeter with a shielded device for measurement by plated electrodes (frequency 10 Hz and 10 MHz) and ultrasonic indicating tester with piezoelectric transducers with an exponential or flat shape (Frequency 54 KHz).

2.3 Integrating biological and physico-mechanical testing

Mechanical shear test for the evaluation of the bonding quality of the plywood and LVL (before and after degradation). Both the mass loss and the decrease of residual bending and shear strength of the test pieces will be integrated. Partner 1 will focus on the Minnesota shear test for this integration. From the numerical analysis of the two non-destructive tests (simulation of the influence of mechanical evolution of each layer and glue line on the indentation curve and the ultra sound wave propagation), a selected set of descriptors for each test will be analysed in relation to mass loss and visual observation of internal decay of specimens. The most explicative regression equations will be proposed as possible indicators for decay.

Progress during the first reporting period

P1: UGENT performed laboratory fungal tests. The main focus of this first series of tests on a range of plywoods produced in the lab was to evaluate the influence of glue types in combination with veneer thicknesses ranging from 1 to 3 mm. These fungal tests were performed in accordance with the technical description for Basidiomycete fungal testing of board materials as described in the European standard ENV 12038.

P2: To prepare the degradation test, according to ENV 12038, UNITO obtained the following decay fungi: *Coniophora puteana* BAM Ebw 15, *Pleurotus ostreatus* FPRL 40C, *Gloeophyllum trabeum* BAM Ebw 109 and *Coriolus versicolor* CTB 863A. The strains were maintained on the PDA medium and were propagated for the degradation test. The culture vessels used have a capacity of 600 ml which conforms to the reference standard. According to ENV 12038, wood specimens for the control of virulence were prepared having the dimension of 50 + 0.5 mm x 25 + 0.5 mm x 15 + 0.5 mm. The wood species used were Scots pine (sapwood) for *C. puteana*, *G. trabeum* and beech for *P. ostreatus* and *C. versicolor*.
Test pieces were conditioned at 20 + 1 °C and 65 + 5 % R.H. in order to reach 12 % of wood moisture content. The degradation test lasted 16 weeks.
The loss in mass of the specimen used to control the virulence of each fungus was above the minimum value (20 %) required by ENV 12038.

The non-destructive mechanical testing is not yet done because the degradation of the samples extracted from the plywood has not already begun.
Partner 2 (UNITO) and partner 3 (CIRAD) organized a meeting in Montpellier in November 2003 in order to define the measurement modalities to be used in laboratory and to determine a common protocol.

P3: Fungal strains and biological materials are ready for the biological testing. Plywoods from the different partners are in a conditioned room, prior to cutting into samples. Ultrasonic measurements and indentation testing have been set up, and will be used as non destructive mechanical tests to qualify plywoods before and after biological decay. Shearing tests device has also been set up.

P4: The ENV 12038 – test with plywood used in WP 3 has been planned in detail. Cutting schemes for taking the samples have been developed and samples have been prepared. They are placed in conditioning chamber. 12 weeks conditioning is going to be finished in July 2004, 6 months natural weathering will be finished in October 2004.

Progress during the second reporting period

P1: Partner 1 performed several fungal decay tests according to the European standard ENV 12038.

A first test setup was focussed on testing the effectivity of incorporating glueline biocides. Two different propiconazole based glueline additives were added to the glue of laboratory produced beech, poplar and spruce plywood (UMF and PF glue). Samples of 50x50mm were subjected during 16 weeks to fungal attack in conditioned circumstances. The types of fungi used were *Pleurotus ostreatus*, *Coniophora puteana*, *Coriolus versicolor* and *Gloeophyllum trabeum*. A chosen set of decayed plywood samples was subjected to the Minnesota Shear Test in an attempt to link the mass loss to the loss in strength. The results of these tests were presented during the PCC meeting in Hamburg (November 2004).

Two different tests were set up during 2004. The first includes all plywood reference material using two fungi (*Pleurotus ostreatus* and *Coniophora puteana*). In the second test set up, beech and spruce plywood samples were edge sealed with an edge sealing product (Sigmadur HB Finish, a two component high build semigloss aliphatic acrylic polyurethane finish) in order to test the effectivity of the edge sealing product for use in fungal decay testing. The choice of edge sealing product was made after preliminary laboratory weathering tests. Results of these two tests will be presented during the spring 2005 PCC meeting in Hämeenlinna, Finland.

P2: According to the decisions taken during a special meeting in Montpellier with partner 3, CIRAD, partner 2 is now performing the biological tests on the bases of ENV 12038.
In particular, test pieces of beech and pine solid wood (dimensions 50x25x15 mm) and specimens of plywood (dimensions 50x50xthickness mm) were used. For each panel type, 96 test pieces were sampled according to the agreed cutting scheme. In total more than 2500 samples have been prepared. Because of the high numbers, partner 2 decided to subdivide them in 4 groups. In the 2004, 700 samples were decayed according to ENV 12038 and submitted to non-destructive measurements.
Half of the specimens have been cut at 90° (A) and the others at 45° (B). This solution has been chosen in order to study the effects of the fiber direction on the propagation of the elastic waves that are used for non-destructive evaluation (NDE) of panel decay. For every panel, 48 samples have been decayed from *C. puteana* and the others from *C. versicolor*.

The UNITO laboratory also performed non destructive mechanical tests. Different methods have been investigated in order to assess decay of the panel: electric and ultrasonic properties and measurements of shore D hardness.
Partner 2 has partially completed the measurements of the electric and ultrasonic properties on the available samples.
Partner 2 is now conditioning some test pieces above FSP (fibre saturation point) for each panel typology in order to calculate the potential effect of wood moisture content on the electric and ultrasonic measurements.

Partner 2 has tested and selected a shore D portable digital hardness device supplied with external data output to make in field and laboratory testing. The software device allows the direct acquisition of the hardness data through the link to a computer by USB door.

P3: The different plywoods have been cut by partner 3 and sampled according (the same protocol as Partner 2 was used, i.e. some samples have been cut at 90° and some at 45°). The samples have been pre-conditioned and conditioned according to ENV 12038. Ultrasonic measurements before the fungal exposure have started as well as the biological tests. They are still on going.
In the same time, plywoods made of non durable timbers have been tested against fungi, according to the protocol of ENV 12038, but for different exposure times. The ultrasonic measurements have been done before and after the biological test. Correlation between the mass losses obtained for different exposure times and decrease in ultrasonic velocity has been done. Nevertheless, when the mass loss is too high (above 18-20%), the ultrasonic measurement becomes impossible. It also appears that above 16%, the correlation becomes poorer.

P4: Partner 4 started the ENV 12038 – test with plywood included in WP 3 in week 25 to week 27 and ended it in week 41 to 43. Solid wood of Birch, Spruce Sapwood, Maritime Pine and Scots Pine heartwood were included additionally. Results were analyzed and presented at the 3rd project meeting in Hamburg in November 2004. Further panel types (from Allin) were included in the test simultaneously with the ENV 12038 testing after 6 months natural weathering. The natural weathering started delayed in August 2004. Subsequently the appropriate 12038 test starts 2005 in the weeks 13 to 15 (month 28)

Progress during the third reporting period

P1: ENV 12038 testing of all reference plywood types was completed with the compulsory test fungi *Coniophora* and *Pleurotus*. The test results revealed a difference in decay preference by *Coniophora* and *Pleurotus* for birch and poplar plywood. The latter fungus is rather glue-indifferent and attacks both plywood types (PF and UMF glued) easily, while the presence of PF-glue seems to be a restricting factor for decay by *Coniophora*, even after 12 weeks of preconditioning in a ventilated room. No difference between softwoods and hardwoods can be made based on type of test fungi since spruce plywood is showing high mass losses for *Pleurotus* while pine plywood is not, and spruce plywood is not consistently decayed by *Coniophora*.

A new ENV 12038 test set up including edge sealed specimens is started as well as a test set up including all optimized plywood specimens and solid birch, spruce and poplar wood (*Coniophora*, *Pleurotus* and *Coriolus*).

P2: Partner 2 (UNITO) completed biological tests on 22 reference plywoods. For this activity, test pieces of beech and pine solid wood and specimens of references plywood were used. For each type of panel, 96 samples were used for a total of more than 2500 samples. All the test pieces were exposed to the degradation of two fungi: *C. puteana* and *C. versicolor*. The controls of mass loss have been done after 2, 4, 8 and 16 weeks.

The non destructive analyses by ultrasonic and electric measurements have been carried out on test (not decayed) and decayed samples for every type of references plywood. Some hardness measurements have been also carried out on the reference plywood after each degradation period.
In order to evaluate the reliability of the non destructive measurements, partner 2 carried out electric and ultrasonic measurements on some test samples conditioned above FSP (fiber saturation point). In this way the potential effect of samples moisture content on the above measurements could be calculated and removed from results.
Concerning the reference plywoods resistance against two decay fungi (*Coniophora puteana* and *Coriolus versicolor*), the results showed that all the 22 tested panels did not exceed the decay tests according to ENV 12038 procedure except for plywood named with A2 and A4 code which feauture are showed in the following table.

Partner	Code	Coating	Wood species	Glue	Thickness	Plies	Veneers
ALLIN	A2	non-coated	top veneers okoumé, inner veneers poplar	PF	15 mm	7 plies	1.0 / 3.0 / 2.0 mm
	A4	non-coated	top veneers moabi, inner veneers poplar	PF	15 mm	7 plies	1.0 / 3.0 / 2.0 mm

With the aim to realize optimised panels, partner 2 evaluated the biocidal effects of two preservative compounds added to the glue mix: Wolsit F-SP and quebracho tannin extract. Preliminary *in vitro* tests were carried out: cellulose disks impregnated with different concentrations of active substance, the same used in the TUMF and WMUF glue mix, were put on the mycelium grown on Petri dishes. Wolsit showed a biocide effect above 5% while tannin quebracho composite only showed a preliminary inhibiting effect on the mycelium growing. Results from the lab-test were the guideline to realize the corresponding Wolsit/tannin plywood which were tested according to ENV 12038.
All the plywood samples were analysed after 16 weeks of degradation by ultrasonic and electrical measurements and assessed in terms of mass loss.
The results confirmed the *in vitro* tests: only the panels with 10% Wolsit concentration (m/m) showed an increased durability against decay fungi.

Also, some experimental plywood with different wood species (paulownia, mix composition of okoumé-hornbeam, douglas veneers) were tested.
The preliminary results obtained on the experimental uncoated panels made with different wood species suggested no resistance against decay fungi since the mass losses recorded were near to 30%. Only paulownia plywood showed the lower mass loss of 9.9% with *Coriolus versicolor* critical fungus test. Concerning non-destructive testing, the research seems to confirm the diagnostic effectiveness of ultrasounds. Ultrasonic velocities result sensitive to degradation: a negative trend is always observed passing from the healthy samples to the decayed ones.
A first step was to establish that ultrasonic measurement have to be carried out in the transversal direction of the samples because the longitudinal direction measurement could give misleading data due to the unknown contact angle between the ultrasonic transducers and plywood. Moreover it was realized that some plywood, in this case Finnforest, could give problems in first arrival time reading and, consequently, in ultrasonic velocity measurements. Finnforest problems occurred with any measurement direction and any wave frequency. A second step was to understand the relationship between ultrasonic velocity decrease and mass loss, taking into account the moisture content of the samples. In fact, the observed velocity decreases are

probably determined by fungal degradation but also the moisture content may play an important role in ultrasonic velocity setting. The potential effect of moisture content on the measurements was determined evaluating the ultrasonic velocity on samples impregnated with water in order to obtain different moisture contents. The moisture content has more effect on ultrasonic longitudinal velocity but it has also some effect in the transversal, so in detecting decay with ultrasonic test plywood moisture content should be considered with attention. In particular, ultrasonic longitudinal velocity values of solid wood decrease with moisture content increasing while transversal velocity values don't.. Apparently transversal velocity seems to increase but this trend could be included in a measurement error. With respect to reference plywood samples, velocity trends are similar concerning longitudinal sample direction but it's not possible to generalize. Instead, transversal velocity behaviours are very similar when solid wood and different plywood are compared. A preliminary result suggests that the detection of a low level of mass loss seems difficult because the decrease of transversal velocity caused by degradation is hidden by the increase due to the higher moisture content. Consequently, in a moisture content range of 10-200%, the use of ultrasonic technique for assessing the wood decay could only be suitable with mass losses greater than 10%.

Concerning the electrical properties, it was noted that there is a similar trend for all the panels and the examined fungi. The resistivity decreases strongly passing from the controls (not decayed), at normal moisture content, to the decayed samples. The permittivity has the opposite trend: it increases from the controls to the decayed samples.

The potential effect of samples moisture content on the measurements was determined evaluating electrical properties of samples impregnated with water in order to obtain different moisture contents.

After a first data elaboration, at equal moisture contents, it was realized that resistivity values change with decay and these changes are more appreciable than those concerning permittivity. Anyway, electrical measurement gave us valuable results in detecting decay on P2 plywood: when P2 plywood is in service it's now possible to detect and quantify its decay using mass loss classes.

Consequently, the next pourpose is to obtaine similar results for each plywood.

The work carried out by UNITO also included a hardness test with portable instruments (especially for field evaluation) in order to find a possible correlation with the results obtained from biodegradation (ENV 12038).

As planned UNITO has investigated shore hardness properties on references plywood in order to propose a quick non-destructive test method. As a first step, the work was focalised on:

- find a possible relationship between shore hardness and MC,
- find a possible relationship between shore hardness and mass loss,
- find a possible relationship with other hardness test methods (Brinell).

The shore hardness is measured with a digital portable device that determines the hardness value by the penetration of the indenter into the wood sample. If the indenter completely penetrates the sample it is obtained a reading of "0", while if no penetration occurs the value is "100". The reading is dimensionless.

UNITO has verified the repeatability and the sensitivity of the test method to different surface characteristics and density of references plywood.

Repeatability conditions are satisfied when independent results of measurement are obtained with the same procedure, by the same measuring system, used under the same conditions, over a short period of time. In other words repeatability is the "precision under circumstances which are as consistent as possible (same laboratory, technician etc.).
Five sound samples for each reference plywood conditioned at 20/65 have been selected and a double series of 6 shore hardness measurements were made with two handle device shore A and shore D. The best repeatability was found for shore D.
The results confirmed that shore is a reliable comparative measurement of the hardness of material of the same type and structure (species/composition etc.), conditions for which it is quite accurate, with homogeneous and lower standard deviation.
Consequently, five different measurements for each sample were conduced on the reference plywoods with shore D portable device (Mitutoyo Hardmatic HH-300) for determining wood surface hardness with a good repeatability of measurement (better precision). The measure was made before and after exposure to the ENV 12038 testing in correspondence of the four corners and the center of the specimen.
The measure of hardness was made on the samples of reference plywood and on the solid wood, before and after exposure to the ENV 12038, in correspondence of the four corners and the centre of the specimen. As a first step we have conditioned sound reference plywood and solid wood samples at different levels of moisture content, in order to better understand the relationship between shore hardness and MC. In this respect, the results show generally that no high correlation between shore hardness and MC of wood exists and in some cases (P3 and S4/S5) we registered an $r^2 < 0.5$.

As expected, in the sound solid wood samples the shore hardness decreases with the increase of MC and we found the same behaviour As well in the references sound plywood samples.
The results clearly showed that shore hardness test values and its relationship with MC may be accurate only for homogeneous groups of plywood (same specie and structure).The shore hardness values measured on decayed samples are always lower than the theoretical values obtained on sound samples for the same level of MC. Anyway, the hardness values calculated on the bases of the relationship shore/Mc are, generally, congruous with those measured on the sound samples before the biological testing (C2 average experimental hardness of 53.2 versus a calculated value of 53.0 for 9% MC).

Furthermore, the work carried out by UNITO included the evaluation of relationship between shore hardness and mass loss. Concerning this topic, we can underline the following considerations:

- generally, the analysis of the experimental results highlights that it does not exist an high correlation between shore hardness and mass loss since often the shore hardness shows irregular trend with the increasing of fungi attack.
- in some cases we did not find a clear correlation between hardness and mass loss (as in the C2 reference plywood with $r^2 < 0.58$),
- for different types of samples the results showed a different level of decrease of the shore hardness at the same mass loss which cannot be explained with the only influence of the different wood density and moisture content of plywood's samples (F2 samples after ENV 12038 test for *Coriolus versicolor* show an average mass loss of 4.2% against an average decrease of shore

hardness of 39%, while C2 samples show an average mass loss of 26% versus an average shore hardness variation of 52%).

The results also show that:

- the shore methods need a certain practice to guarantee a good repeatability in the measurements;
- for the irregular surface of decayed samples, the measurements of shore hardness may be affected by non-systematic relevant error;
- shore test is not reliable for comparing the hardness and the relationship hardness/MC of two different plywood (which differ for wood species, thickness, surface coating etc.).

For the above considerations the shore hardness values calculated for each decayed reference plywood may be used only as a “qualitative parameter” for predicting a potential presence of decay by “in situ” measurement, while its use as a non-destructive test method for estimating the level of plywood decay in service appears hardly reliable.

P3: Concerning the testing of the industrial plywoods, the ultrasonic measurements were continued. The indentation tests have started as well on spare samples from these industrial panels. The initial indentation device had to be changed to fit all panel thicknesses, as the metal piece used for the indentation has to penetrate up to 70% into the panel.
Due to many failures, the conditioned room where the fungal tests are carried out had to be totally renovated. Consequently, the biological tests carried out on this set of panels were stopped at the beginning of the year and started again in December 2005.
As for the ultrasonic measurements, plywood made of non durable timbers has been tested against fungi, according to the protocol of ENV 12038. The biological exposure was stopped at different times (stopped at 22, 45, 67, 90 and 112 days). For each set, mass loss was measured and indentation tests were done. Correlation between the mass loss and the loss of indentation energy showed that there was proportionality between them. The loss of indentation energy appeared to be on average 2.5 times more sensitive.

Partner 3 has also produced optimized plywood with poplar and cypress wood. Different plywoods have been manufactured:

- 5 plies, pure cypress heartwood;
- 5 plies, exterior plies of cypress heartwood, interior plies of poplar.

These optimized plywoods were sent to Partner 1.

A set of optimized plywoods was received from partner 1. They have been put in a conditioned room (20°C, 65% RH).

P4: Most panel types showed high mass losses in the lab test according to ENV 12038. Effects of 6 months natural weathering in comparison to 12 weeks pre-conditioning were visible but in most cases had no significant effects on the assessment of the durability according to ENV 12038. However, natural weathering induces higher mass losses in some PF-glued panels through *Coniophora puteana* and *Coriolus versicolor*. The application of edge sealing reduces mass loss in the lab test significantly. Panels made of wood species with higher durability (Moabi, Sapelli) performed well in comparison to those tested in the first test series. The field test assessment (including bending tests and microscopic investigations) and the lab tests were set into correlation. As no significant discrepancies occurred, the results allow (roughly up to now) to identify plywood for external uses. Mass loss in the lab tests and the field test assessment indicate a better performance for those panels made of durable wood species in comparison the non-durable ones.

Progress during the fourth reporting period

P1: All ENV 12038 testing of reference and optimized plywood types was completed and analyzed during working year 4. Plywood specimens of all Plybiotest optimized material (32 plywood types, sample sizes 50 x 50 mm, n=6) were tested for their resistance against *Pleurotus ostreatus* and *Coniophora puteana*, the two obligatory test fungi mentioned in the ENV 12038.

All panel types (reference and optimized) were tested against *Coriolus versicolor*, including both edge sealed and not sealed specimens.

To estimate the influence of the preconditioning method a selection was made of 10 plywood types (optimized and reference), comprising poplar, okoumé, spruce and birch as wood species variation as well as UMF and PF glues. Specimens were leached according the EN84 procedure.

Solid wood specimens (birch, spruce and poplar), 50x50x15mm in size, were tested against *Coniophora*, *Pleurotus* and *Coriolus* to allow comparison with equally sized plywood specimens.

The results confirm *Pleurotus* to be rather glue-indifferent, attacking both UMF and PF glued plywood types easily, while the presence of PF-glue stays a restricting factor for decay by *Coniophora*, even after 12 weeks of preconditioning in a ventilated room. This glue-inhibitory effect can be reduced for *Coniophora* by implementation of an EN 84 leaching procedure prior to testing. However, for UMF-glued plywood material a leaching procedure has an adverse effect on plywood durability (due to removal of nutritious substances, making UMF-plywood less attractive to fungi).

When no edge-sealing is applied it is impossible to make a difference in durability between coated or not-coated plywood material. Edge-sealing is required for the assessment of the coating quality or the effect of a durable top veneer.

No difference between softwood and hardwood species can be made based on type of test fungi since spruce plywood is showing high mass losses for *Pleurotus* while pine plywood is not, and spruce plywood is not consistently decayed by *Coniophora*.

P2: Completed ENV 12038 test on 10 optimised plywood, chosen among those produced by the all partners during the previous years, and ultrasonic and electrical measurements were completed on the tested plywood.
Data processing was carried out and finished.

Concerning the last durability tests, no optimised plywood can be assessed s durable plywood according to ENV 12038 test. According to the durability test data, even if some are limited as referring only to 2 decay fungi only, it is pointed out that not all coating improved enough plywood performances, so coated plywoods are not always suitable for severe exposure conditions.
Moreover the large standard deviations of mass losses hint a high data variability, which could be attributed to not only fungal biology but also to the reduced number of plywood specimens used in the ENV 12038 test.

It can be stated that, after a generic comparison between the PF and the UMF plywood, the UMF plywoods are more decayed by *C. puteana* and *C. versicolor* than by *G. trabeum* and *P. ostreatus*.

Concerning ultrasonic measurements, it can be observed that the ultrasonic measurement system is not suitable to detect or to predict decay because ultrasonic velocity is decreasing significantly when plywood decay is higher than 10% of mass loss.
Concerning electrical measurements, it can be pointed out that resistivity, permittivity and loss tangent are differently sensitive to decay in respect to the 3 plywood features glue, wood species and coating. Decay for most of UMF glued plywood could be assessed using permittivity parameter while resistivity is suitable for most of PF glued plywood but it is not possible to use a single math function to assess or to predict decay of all plywood. Consequently, electrical measurements could be suitable to use for non-destructive mechanical test because of electrical parameters sensitivity to decay of many plywood. However some problems concerning the absence of sensitivity to decay for some plywood have to be solved yet.

In order to evaluate the reliability of the non destructive measurements UNITO has carried out and finished shore hardness measurements.
The first results over industrial plywood showed that there exists a valid relation between shore hardness and wood density for reference plywood conditioned at 20°C/65R.H., if not yet decayed. Under these conditions the device gives reliable results within three shore units.
Because of the fact that the accuracy of an instrument reflects how close the reading is to the 'true' value measured, and may change with the variation of the conditions under which the tests should be done, it is necessary to consider the performance (in terms of uncertainty) of the instrument device for decayed specimens.
Accuracy and repeatability have been taken into account as essential elements for determining the uncertainty of measurement of the test method. In fact, there are many error sources that can affect the accuracy of the shore test.

- the position of the device,
- the pressure applied,
- the flatness of the surface and its roughness,
- the surface modification caused by wood decay.

Regarding the repeatability of the shore test method, the results show that it can achieve a good level of repeatability thanks to a pressure gradually applied and maintained on the test piece for at least two minutes, according to the indications obtained by the producer and a certain practical experience in using the device.

It is well known that any measurements can be perfect, and the uncertainty of measurement of each measure is defined as a parameter, associated with the result of a measurement, that characterises the dispersion of values that could reasonably be attributed to the measurement.

It is typically expressed as a range of values in which the value is estimated to lie within a given statistical confidence, but it does not allow to define or rely on a unique true value. On the basis of accuracy and repeatability data in decayed specimens, the dispersion of values that could reasonably be attributed to the measure is very high. The uncertainty of measurement is about of $\pm$ 20 units.
In other words, if the hardness of two test pieces from the same panel is tested, and the difference on the shore scale is more than twenty hardness units, it is sure that there is an absolute difference in the hardness of the specimens.

Concerning this topic the following considerations should be underlined:

- there is no clear relationship between hardness and mass loss: the test method is not sensitive enough for modest variations in the wood density. The results show that there is no definite discrimination in shore value for low wood density variation as is present within one type of plywood;
- moreover, because of the irregular surface of decayed specimens, the measure of shore hardness is affected by relevant errors: the shore value, related to indenter penetration under applied force, depends not only to the shape of indenter but also to the response to indentation. Phenomena of swelling and irregularity of the decayed surfaces of sample strongly affect the values measured;
- many error sources can affect the uncertainty of measurement of the shore test: if the difference on the shore scale is less than twenty hardness units, it is not sure that this is due to the effect of the mass loss of the decayed specimens;
- as expected in sound test pieces, the shore hardness decreases with the increasing of MC. The hardness values calculated on the basis of the relationship shore/MC are generally congruous with the hardness measured on the sound samples before the biological testing. However, the results show that is not possible to define a common relationship hardness/MC valid for all different types of plywood.

In conclusion, the use of standard shore D test as a non destructive method to estimate decay of plywood in service appears inadequate. The shore test, although this method generally shows good accuracy, cannot be applied to wood-based product strongly affected by wood decay. Today there are not other types of portable devices available for hardness test measurement, it may be possible (technically feasible) to modify the size/type of indenter and/or the calibrated spring of shore device, but it is difficult to evaluate the capacity of the modified device of reducing the error sources.

P3: All the biological tests according to ENV 12038 have been done on industrial plywood and for a fungal exposure of 2, 4, 8 and 16 weeks. From the obtained results, it is clear that the time of the fungal exposure can not be shortened less than 8 weeks.
The ultrasonic measurements were still to be carried out as well as the indentation tests by month 48.

P4: Partner 4 (BFH) performed additional work on Moisture uptake of lab specimens.

The moisture uptake in samples with sealed edges was lowest, followed by the ones with a hole in the edge sealing and the samples with edges sealed and hole drilled through panel. Highest moisture was found as expected in the controls without edge sealing. The influence of glue, number of plies, wood species and layout of the veneer sheets was also covered. Focussing on the glue indicates that PF glued panels show higher moisture uptake compared to MUF-glued ones. The influence of the number of plies was indifferent.
Samples with parallel glued layers show faster moisture uptake than those glued crosswise. Wood species influence is obviously and overruled former ones.
X-ray examination was used to visualize moisture uptake and to determine fungal decay. It was concluded that extra work was needed to ensure suitable methodology.

Deliverables
D9: fast test method, based on non destructive testing, month 24.

The non-destructive mechanical testing is not yet completed because the degradation of the samples extracted from the references plywood has not been finished yet.

D12: the relationships between the mass loss of inoculated plywood samples and their electrical/ultrasonic properties and hardness value, both determined by non destructive test methods, haves been validated as planned for month 36.

Lab-tests according to ENV 12038 were completed by partner 4 and set into relation (see Technical Report)

D13. Proper information on plywood characteristics for different external uses derived from field and laboratory tests, month 36

Data obtained from field tests after 12 months and laboratory tests were used to describe plywood characteristics for external uses. These may be amended by the further field test assessments.

D14. Better evaluation of ENV 12038 at month 36 by selecting from
- agar medium with preconditioning or vermiculite without preconditioning
- pre-treatment: short leach, 12 weeks ventilated room, artificial ageing, natural weathering
- additional mechanical evaluation
- definition of reference test material

This deliverable was finalized in year 4.

D15. Factors defined affecting degree of decay overtime in relation to moisture, month 36.

This deliverable was finalized in year 4.

Milestones

M2. Month 24. Data sufficient to produce optimized products.

Comments from P4 on M2: Due to late arrival of further material required, following kiln-drying and a protracted preparation of the samples the data set of EN 12038 after 6 month natural weathering will be available in month 32 (8 months later than planned)

Comments from P2 on M2: Partner 2 (UNITO) has completed the ENV 12038 durability testing on reference plywood. Some further panels were produced at laboratory level and then tested with the aim to propose optimised plywood. For each sample, at the end of the degradation period, ultrasonic and electric measurements were made.
The complete data set of durability tests carried out by P2 is available as planned.

M4. Month 30. Data sets available to interrelate lab results, field test results and survey results.

This milestone was met.

WP 3. Accelerated outdoor testing of plywood

Workpackage number: **3**

Start date: Month 6
Completion date: Month 48

Partners responsible
Planned person months per partner and total:
Devoted person months per partner and total:

4	1	Total
29 + *6*	10	**39 + *6***
34 + 2	9	**43 + *2***

Objectives
The objective of WP3 is to find suitable field test methods to determine the durability of plywood in hazard class 3. Up to now the discrepancies between results of plywood testing according to ENV 12038 (lab-test) and the prediction of durability of plywood according to ENV 1099 can merely be undeceived by the use in service because an accelerated field test procedure for panel products is not yet available. Therefore, different field-test procedures for plywood are applied / developed suitable for panels of different thickness.

Methodology and study materials

3.1 Outdoor testing of plywood based on ENV 12037

Panels produced in WP1 are cut to specimens, the cross sections are sealed and then exposed to weathering according to ENV 12037 (modified) and according to two new test methods (harsh and moderate humidity regime). The effect of natural weathering and the biological attack are assessed by visual inspections (every 6 months). Additionally the moisture content will be monitored and changes in moisture uptake behaviour of selected weathered specimens will be investigated in detail under controlled conditions in the laboratory. The mechanical properties of non-decayed specimens are determined after one and two years. Solid wood of the corresponding wood species and of some durable wood species as well as two coated panels (from WP 4) are included in the experiments for comparison.

3.2 Outdoor testing covered

To mimic the different sub categories of hazard class 3 also field exposure using covered situations will be validated. Both roof cornice systems and specific cross cut coverings will be included.

3.3 Accelerated outdoor testing by means of moisture control

Partner 1 will use specific moistening devices to predict decay behaviour under controlled moisture content. Moisture monitoring as critical parameter for development for decay will be tested.
The improved knowledge on the durability of poplar plywood in well-defined hazard class 3 situations will allow predicting the lifetime of components made from poplar plywood. The development respectively improvement of a reliable field test method for plywood will also allow to predict the lifetime of plywood made of other wood

species which is the premise for increasing the use of wood composites as load bearing elements exposed to hazard class 3 conditions.

Progress during the first reporting period

P1: Draft protocols were prepared for three different exposure systems for use (hazard) class 3 situations (see technical report P1). These protocols intend to cover realistic outdoor exposure of plywood. The three methods range in moisture exposure using a first technique of free hanging panels, a second one as a roof cornice system and thirdly the worst case scenario using an in build of plywood with additional moistening device.

P4:

3.1 Outdoor testing of plywood based on ENV 12037

From the plywood distributed by P1 in January 2004, 10 panel types have been selected for outdoor testing according to ENV 12037 and two further methods. The last mentioned methods create a harsh (horizontal double-layer test, non sealed) and a moderate humidity regime (vertically hanging, non sealed). Cutting schemes for the panels as well as different types of exposure racks have been developed and prepared. Most of the test specimens have been cut and will be installed in the field in April 2004. Further investigations have been planned and terminated as follows:

The first assessment will be in October 2004 and will be repeated every six months. The moisture content of selected weathered specimens will be monitored by weekly gravimetrically measurement. The moisture uptake behaviour will be surveyed in three different laboratory scenarios. After one and two years the bending strength as indicator for the mechanical properties will be determined.

3.2 Outdoor testing covered

In contradiction to the description under "Methodology and study materials" of WP 3 a roof cornice system will not be included. From results of field tests applied with solid wood at BFH, which have been similar to the planned ones in WP 3, it is assumed that this method is not suitable. Samples covered by a roof cornice system will not show any biological attack in between 5 years test duration

The validation of covered situations will be carried out by using the methods introduced for simulating harsh and moderate humidity conditions (see 3.1) – in these cases the samples will be covered with an edge-sealing.

The corresponding solid wood and Scots Pine as reference has been ordered from project partners resp. been bought from local traders.

Progress during the second reporting period

P1: Three different outdoor exposure test set ups were installed on the outside exposure site at the Ghent University according to the draft protocols prepared during working year 1. The three methods range in moisture exposure intensity using a first technique of free hanging panels, a second one as a roof cornice system and thirdly the worst case scenario using an in build of plywood with additional moistening device. The exposed plywood samples are monitored monthly using gravimetrical and capacitance moisture measuring devices. All reference plywood panels are included in the test set up

P4:

3.1 Outdoor testing of plywood based on ENV 12037

All samples were placed in the field test set ups as described representing the scenarios developed in period 1. The set ups also were successfully installed in France (CTBA, Bordeaux) and Finland (VTT, Espoo) in order to estimate the influences of climatic effects.

3 of 6 further panel types delivered additionally were cut, prepared, conditioned and included in the test program. Birch panels (K1) and solid Birch were chosen as reference (master type). 18 stems (usually used as veneer rolls) of Birch and 12 stems of Spruce as well as further panels of Spruce plywood (F1) were delivered from Finnforest (Partner 9). Further panels of Birch plywood (K1) were delivered from Koskisen (Partner 10). The stems were kiln-dried, cut to specimens, prepared, conditioned and exposed in the different test set ups. Initial bending strength (with and without water storage) of the panel types and the corresponding solid wood was determined. Further specimens have been included in an extra set up (in the harsh humidity regime) in order to differentiate the effects of water storage, weathering and duration of exposure. Initial moisture content of all samples exposed was determined, moisture monitoring is running as indicated in the work plan.

3.2 Outdoor testing covered

For validation of covered situation samples were prepared with an edge sealing and exposed using the methods introduced for simulating harsh and moderate humidity conditions (see 3.1)

<u>*Progress during the third reporting period*</u>

P1: The outdoor field exposure of reference plywood samples was continued. A visual assessment was performed, evaluating the performance of all reference plywood types after 18 months of outdoor exposure. No fungal decay was detected on samples exposed in the freely hanging and the covered outdoor field tests. All plywood specimens were rated for the occurrence of blue stain, moulds and wood destroying fungi, panel deformations (cup and twist) and weathering signals (crack formation, defibrillation, damage by insects and erosion). Staining was present on most samples. Spruce plywood showed severe crack formation while only starting surface degradation was present for the other plywood types.

The accelerated weathering set up including sponge wetting was finished and the samples were prepared for analysis.

A sealed and a not sealed specimen of all optimized and reference plywood types were delivered at the tropical test site in Kourou (maintained by partner 3). The specimens are included in a frame made from perishable beech and spruce wood with the frames allowed to hang freely on two hooks. This field test will allow comparison of weathering intensity between a tropical situation and a worst case accelerated weathering in Ghent.

A field test method allowing continuous water monitoring of outdoor exposed plywood specimens is under development at the UGENT weathering site as well. Results will be available in 2006.

P3: The indentation tests have been done after the biological degradation. The biological degradation due to *Coniophora puteana* was too high, so the non destructive tests were done only on the samples degraded by *Coriolus versicolor*.
Once the non destructive tests were done, shearing tests (totally destructive) were performed on the plywood samples.
The indentation tests (the loss of indentation energy) can be well correlated to the mass loss of the samples, but the loss of shearing resistance appeared to be better correlated to the mass loss. Nevertheless, the indentation test is easier, faster to perform and almost non destructive.
In every case, the mix of durable plies with non durable plies increased the resistance of the plywood. From the indentation tests, 2 models could be drawn to explain the behaviour of the plywood with durable top veneers.

P4: The first assessment of the field tests indicated any fungal attack after 6 months. Appearing staining and UV-degradation were intensive. Heaviest staining occurred in the set up that caused highest moisture contents (double layer). Depending on the set up fungal attack was detected in the 2nd Assessment after 12 months: none of the samples in the hanging set up were attacked by basidiomycetes while in the Lap joint set up several Scots Pine samples showed signs of beginning decay. The double layer set up induced fungal attack in timber specimens of Birch, Scots Pine and Spruce. Assessments of the samples in France showed similar results. The additional bending test and microscopic investigations indicated that also Poplar plywood was decayed. The moisture monitoring and the field test assessments clarify a close relationship between fungal attack and the construction of the sample setups which cause different humidity regimes in use class 3. An influence of edge sealing on the moisture content was remarkable

Progress during the fourth reporting period

P1: The outdoor field exposure of reference plywood samples was continued. A second visual assessment was performed, evaluating the performance of all reference plywood types after 30 months of outdoor exposure. Still no fungal decay could be detected on specimens exposed in the freely hanging and the covered outdoor field tests. All plywood specimens were rated for the occurrence of blue stain, moulds and wood destroying fungi, panel deformations (cup and twist) and weathering signals (crack formation, defibrillation, damage by insects and erosion). Staining was present on most samples. Due to defibrillation and disappearance of the outer greyed surface layer, mould and blue stain fungi are more easily detected. This leads to higher scores for mould and blue stain presence for most plywood specimens.
Spruce and maritime pine plywood show severe crack formation while continuing surface degradation was present for the other plywood types.

The accelerated weathering set up including sponge wetting was finished and the samples were prepared for analysis. Results were partly presented at the annual IRG conference.

The Continuous Moisture Monitoring (CMM) test set up was constructed and its preliminary results on plywood moisture behaviour in outdoor exposure applications were analysed. Results are partly to be presented at the IPPS 2007 conference in Cardiff. This monitoring set up includes a fully equipped weather station consisting of a solar energy sensor, a tipping bucket rain gauge, a relative humidity probe, a thermometer, an anemometer and a wind vane. Every 5 minutes the weather data together with the signal of 56 load cells bearing an attached plywood specimen is logged and saved. Obtained time series allow comparison between plywood types on single shower level as well as on seasonal basis.

P4: BFH performed further visual assessments of the 3 exposures set ups for field testing.
In the Lap joint set up several panel types were affected by starting decay. Two Poplar panel types (C2 and P3) showed intensive decay, while coated Birch (K3) was not decayed. Regarding the timbers testes, decay started in all species except Maritime Pine (Maritime Pine was not exposed in the Double Layer Set up).
Discolouration was intensive on all external surfaces except the coated panel types. In the joint area all panel types except A5 and A6 were discoloured.

In the Double Layer set up the number of samples failing in the bending test supplementing the visual assessment increased. Particularly poplar panel types were decayed intensively.
Discolouration was intensive except the coated panels and Sapelli plywood A6.
Scots Pine sapwood timber samples were less affected in the Double Layer set up than in the Lap joint set up. Several panel types (S5, R1, F2, K3, A4, A6) were not decayed after 1,5 years in the Double Layer.

Tests on the influences of the parameters exposure duration, water storage and natural weathering mechanical strength were completed. The results indicate, that

1. The bending strength decreases over time (samples stored in 20°C / 65% r.h.) over time.
2. 10 days water storage before the bending test procedure reduces strength values roughly to the half.
3. The effect of water storage seems to overlay the effect of time and natural weathering. In the bending test supplementing the decay assessment 1 of 11 samples of the same panel type failed.

When using mechanical bending tests in addition to visual assessment, a storage in climate chamber may be considered instead of water storage although this procedure would be very time consuming.
Tendencies described in detail in working year 3 regarding the differences between the set ups, the influence of coating, top veneer and edge sealing were confirmed.
Resuming moisture monitoring, setting moisture content of all samples in correlation, taking water uptake after 10 days water storage into account proves the impact of the different exposure set ups. As planned the hanging set up fits well for inducing moderate humidity while the double layer test leads to very high moisture contents. The Lap Joint Set up show intermediate values regarding moisture content and appearance of decay.
The different exposure conditions induce different levels of moisture content and hence only those exposure set ups with sufficient moisture can be assessed through lab fungal tests. Differences in moisture content for a specific exposure situation may be used to select suitable plywoods.

Deliverables

D10. A draft protocol for modified ENV 12037

Partner 4 included a draft of the test protocol for modified ENV 12037 in the Technical report.

D15. Factors defined affecting degree of decay overtime in relation to moisture, month 36.

This deliverable was finalized in year 4.

D16. Difference between covered and non covered exposure, month 36.

Partner 1 showed that the gutter system provides in a covered exposure with lower impact than the free hanging test.

Milestones

M2. Month 24. Data sufficient to produce optimized products.

M6. Month 42. All optimised products under test.

Milestones M2 and M6 were accomplished in time.

M8. Month 48. All data processed to fine-tune overall result.

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By the end of year 4 most data were processed though fine-tuning the overall result in collaboration with industry took up to 2nd half of 2008.

WP 4 Impact evaluation of plywood coatings

Workpackage number: **4**

Start date: Month 6
Completion date: Month 48

Partners responsible	**5**	1	3	Total
Planned person months per partner and total:	16	3	11	**30**
Devoted person months per partner and total:	17	2	12	**31**

Objectives
The goal of this work package is to define the performance of the coated birch and spruce plywood in hazard class 3 using different modified methods. The effect of coating types on the performance of plywood will be tested using accelerated weathering test methods developed for coated wood and the performance will also be tested using biological tests prior and after the weathering.

Methodology and study materials

4.1 Impact of coatings on laboratory and field testing results

The performance of the coated and edge-sealed plywood samples will be tested using different modified test systems in the laboratory and outdoors. In order to accelerate outdoor exposure samples will be aged in laboratory using combination of water immersion and UV-ageing (modified prEN927-6). Exterior exposure will be carried out according to modified EN927-3 and with a new method, which involves mechanical loading during the exposure. Water permeability of different coating systems will be measured before and after weathering. Uncoated birch and spruce plywood will be used for comparison.
Multiple laboratory biological decay tests (EN 12038, EN 927) including mould testing will be carried out after ageing procedures. Also strength properties will be measured. The results from decay and weathering tests are compared to results from service. Final conclusions of expected service life predictions will be moved to WP 6.

4.2 Impact of durable top veneers

Timber species known for their important natural durability and their dimensional stability will be chosen in order to produce durable top veneers for plywood. The ability of wood to be glued, its machinability, as well as its supply will be taken into consideration. A restricted choice of timber will be used to produce plywood with durable top veneer. This plywood will then be tested for their durability as in WP 2 task 2.1 and 2.2.

4.3 Impact of edge-sealing

A range of edge-sealing systems will be tested in order to predict the importance of moisture penetration. Partner 1 will interrelate these results with the findings of task 3.3 on moisture controlled field exposure.

Progress during the first reporting period

P1: Work under workpackage 4 is still in the planning phase for laboratory evaluation and is being organised to be included in the set up of work package 3. Accelerated laboratory weathering tests will be delayed to the second year.

P3: Ability of chestnut, cypress and cedar to be used in plywood as durable veneers: the manufacturing of mixed plywood is completed and their biological evaluation is on going.

P5: Test sample size has been fixed and the test material for the tests has been manufactured. The laboratory weathering tests has been planned and preliminary tests series performed with part of the test material. The method has water immersion (floating-freezing-drying cycles) and UV-ageing (modified EN927-6). The outdoor weathering test system has been planned and a preliminary test has been started at Otaniemi, Espoo. The effect of durable top veneer has not yet been studied. Preliminary tests on the effect of edge sealing against decay and water penetration has been performed. The preliminary test on durability against soft rot test has been carried out. The accelerated weathering with UV light was needed to find differences in the condition between tested coated plywood types. In the biological tests, the used edge sealing paint was not effective against soft rot fungi in biological tests.

Progress during the second reporting period

P1: Coated reference plywood samples were included in the ENV 12038 test set up and in the three different outside exposure test regimes. Testing of the impact of edge sealing is performed as well in the ENV 12038 testing by using beech and spruce plywood edge sealed with a two component polyurethane sealant (Sigmadur HB Finish).

P3: All the experimental plywoods with durable top veneer have been tested according to ENV 12038 (with a 3 month pre-conditioning at room temperature) using *Coniophora puteana* and *Coriolus versicolor* (16 weeks of exposure to fungi). The mass losses for each type of experimental plywood has been evaluated and correlated to the evolution of the ultrasonic measurement (done before and after the biological test on each sample used when possible, i.e. when the degradation of the sample is not too important).
The indentation tests have been performed as well and their interpretation is on going.

P5: The outdoor weathering tests to study the effect of coating types on the performance of plywood started at Otaniemi, Finland in May 2004. UV aging (modified EN 927-6) started in September 2004. The first results on the performance of coated and uncoated products were obtained in December 2004. The effect of surface injuries, edge sealing and follow-through was studied using the water immersion (floating-freezing-drying cycles). The outdoor weathering tests to study the effect of durable top veneer started in September 2004. The reference samples for tests on biological durability were prepared. Co-operation with the partners 1, 4 and 6 started on the tests of out door performance tests on coated plywood products.

Progress during the third reporting period

P1: Coated reference plywood samples were included in the ENV 12038 test set up and in all outside exposure test regimes. The influence of a coating was assessed during floating tests allowing investigation of absorption and desorption parameters of plywood.

Testing of the impact of edge sealing is performed as well in the ENV 12038 testing by using a two component polyurethane sealant (Sigmadur HB Finish) as edge sealant for all reference plywood specimens.

P5: The outdoor weathering tests to study the effect of coating types on the performance of plywood have been continued. The moisture content and condition of the samples during 1.5 years' exposure have been reported in the meeting at CTBA. Accelerated UV aging (modified EN 927-6) have been executed prior different efficacy testing. Additional samples will be exposed for biological tests in 2007.
Biological tests, ENV 12038 and mould test at high humidity have been performed with one year outdoor weathered and un-weathered samples. According to the results, one year outdoor weathering has a minor effect on the resistance of coated plywood against brown rot and discolouring. Edge sealing of the samples has more significant effect, and even the acrylate edge sealing paint performed well in the ENV 12038 test reflecting a good resistance of coated plywood against brown rot (*Coniophora puteana*). The results pointed out, that the ENV 12038 test method in combination of natural pre-weathering may also be used to determine the biological durability of coated plywood. Moisture content of the plywood samples were unexpected high during the mould test in chamber with high ambient relative humidity (RH 100 %). The type of edge sealing used was not suitable for the mould tests. A proposal for a new accelerated test for coated plywood products is based on natural weathering and EN 12038 method.

Progress during the fourth reporting period

P1: Coated reference plywood samples are included in all test set ups (ENV 12038 durability testing, outside test exposure systems, CMM...). The influence of a coating was assessed during floating tests allowing investigation of absorption and desorption parameters of plywood.

Testing of the impact of edge sealing was performed as well in the ENV 12038 testing by using a two component polyurethane sealant (Sigmadur HB Finish) as edge sealant for all reference plywood specimens.

P5: The outdoor weathering tests to study the effect of coating types on the performance of plywood have been finished. Samples for future use are still remaining in the test field of VTT at Otaniemi, Espoo Finland. The moisture content and condition of the samples during 2 years' exposure have been reported in the meeting at Ghent. Accelerated UV aging (modified EN 927-6) have been executed prior different efficacy testing. Additional samples have been exposed for biological tests in 2006.
Biological tests – ENV 12038 and soft rot tests – have been performed using one year outdoor weathered and un-weathered samples as well as samples from different

artificial weathering cycles. According to the results, one year outdoor weathering has a minor effect on the resistance of coated plywood against brown rot and discolouring. Edge sealing of the samples has more significant effect, and even the acrylate edge sealing paint performed well in the ENV 12038 test reflecting a good resistance of coated plywood against brown rot (*Coniophora puteana*). The resistance of coated and edge sealed samples was satisfied also against other tested fungi (*Coriolus versicolor* and *Pleurotus ostreatus*) The results pointed out, that the ENV 12038 test method in combination of natural pre-weathering or mixed QUV weathering and outdoor weathering may also be used to determine the biological durability of coated plywood. A proposal for a new accelerated test for coated plywood products is based on integrated weathering and EN 12038 method. The soft rot test seemed not fit very well for the coated plywood products. If using this test method, a very tight edge sealing should be used. The test would be useful to test the performance of edge sealing in high exposure condition.

Deliverables

The following deliverables were covered:

D2. Preliminary test protocol to test coated plywood under laboratory conditions, month 12

The following deliverables were delayed, but covered during the third year:

D3. Results from the accelerated laboratory weathering tests were delayed but presented after 30 month.

D11. A proposal for a new accelerated test method for coated exterior plywood, month 24. The proposal for a new accelerated test was presented and the first tests were performed after 36 month. The accelerated test will combine the tests of weathering of coatings and the biological resistance of coatings against decay and discolouring. The final proposal will be fine-tuned and presented after the final test results in 2007.

D17. Results on coated plywood from the exterior weathering site, month 36. All results are summarized in Technical of P5. The last results will be presented during the next period.

Partner 5 confirmed that the following deliverable was delayed caused by delay in the weathering and biological tests, but was covered during the fourth year.

D18. Final results from the laboratory tests and from the mixed tests, month 36.

Milestones

M2. Month 24. Data sufficient to produce optimized products.

The data sufficient to produce optimized products are obtained.

M5. Month 36. Factors defined to predict positive impact of coatings are obtained using outdoor weathering tests and EN 12038 test.

M6. Month 42. All optimised products under test.

Milestone was met.

<u>WP 5. Survey on outdoor performance of plywood</u>

Workpackage number: **5**

Start date: Month 0
Completion date: Month 48

Partners responsible
Planned person months per partner and total:
Devoted person months per partner and total:

6	1	2	5	Total
15	5	1 + *2*	2	**23 + *2***
12	3	1 + *2*	2	**18 + *2***

<u>Objectives</u>
Actual performance of plywood in practice needs to be checked thoroughly in order to be able to link laboratory test results with potential service life.

<u>Methodology and study materials</u>

5.1 Identification of specific exposure systems under hazard class 3

The correlation of performance against decay hazard of plywood with possibilities of increased moisture content being established over longer periods will be evaluated. Specific time-to-failure scenarios will be checked and linked to specific applications under hazard class 3.

5.2 Survey on exterior performance of plywood

This survey will provide in the collection of practical cases of external uses of plywood, identification of their production background and their exposure conditions in service. Focus will be on cases of external uses of plywood, which has performed good results in term of long life service and serviceability. Survey on panels exterior performance by electric and ultrasonic tests (in situ or in laboratory on samples extracted) will be done to determine their exterior performance.

5.3 Classification of suitable plywood

Classification of suitable plywood for outdoor use will be based on the data from well defined plywood service-life validation.

<u>Progress during the first reporting period</u>

P1: The survey work is being organised for the moment both interacting with the other partners, including industry partners and with national institutes related to the building sector.

P2: In the sub-task 5.2 "Survey exterior performance", P2 participated to the definition of specific exposure systems and to the indication of the environments where to program and realize future in field sampling and controls. Referring to the participation of P2 in WP5, the assessment on exterior performance of plywood will be carried out in the Alpine Climate.

Deviations from the work plan: Differently from the Technical Annex WP 5.2 and according to the decision taken during the meeting of Montpellier, for the outside controls CIRAD and UNITO propose to perform the ultrasonic measurements and the "indentation test" but not the electrical measurements. The electrical analysis will not be done because the too low moisture content expected from the test pieces would invalidate the analysis. The measurements will be carried out on the healthy part and on the decayed area of each test pieces at least on 5 panels (from buildings) and 5 windows from field testing. The results will be compared with the values measured in laboratory.
UNITO and CIRAD will meet during the first half of 2004 with the aim to compare the first NDT results obtained from the specimens of durability tests.

P5: Not yet started.

P6: Identification and description of specific plywood exposure systems.

Progress during the second reporting period

P1: The survey has been discussed and interaction with partner 6 (CTBA) was established.

P2: The work carried out by partner 2 (UNITO) included a study on the current external use of plywood in the Italian continental climate through a network of contacts relating to the national building sector (constructors, architects, engineers, experts, plywood manufacturers and dealers).
Partner 2 has investigated the most interesting constructions using plywood in exterior applications at national level, collecting information about the sites and selecting some cases for field inspection according to CTBA protocol. Survey on exterior panel performance by non destructive testing will start in spring 2005.

P3: The test pieces and the plywood exposure system have been received from the CTBA. The test pieces have been preconditioned and conditioning is on going. On the other hand, the ultrasonic test device needs some changes to be able to make the measurements before outdoor exposure.

P5: Buildings having coated plywood products were collected and preliminary detection of plywood structure was done.

P6: Survey of specific plywood exposure systems Hazard Class 3: Façades Plywood. A collection of practical cases of external uses of different plywood, and their exposure conditions in service has been initiated. Partner 2 and 5 and other partners help to find this collection in different climates. A Form to study the practical cases has been proposed with partner 2, 4 and 5. Natural weathering racks according to these 3 types of systems have been exposed.

Progress during the third reporting period

P1: The survey has been discussed and interaction with partner 6 was established.

Partner 1 (UGENT) has decided to work on the Benelux area for the survey. The following organisations have been contacted in order to provide with good case study projects:

- Finnforest company
- Bruynzeel company (Allin)
- FEIC, Brussels
- Wood Forum, Brussels

P2: Thanks to the information gathered during the second period through a network of contacts in the national building sector, UNITO has selected more cases of external use of plywood for site inspection according to CTBA protocol. As planned, survey by UNITO of the relevant buildings or applications started in may 2005. These cases concerned to:

- a plywood factory warehouse (Compensati Benazzi srl, Dosolo – Mantova)
- an hotel building (Hotel Blu srl, Collegno - Torino)
- field signs at San Rossore National Park (Tirrenia - Livorno)
- a private house (Lambrugo – Como)

For each case UNITO has selected all the information about the sites (photo, reports etc., according to CTBA check list).

P3: Due to the size and geometry of the samples, it was impossible to perform the ultrasonic measurements. The indentation tests have been done prior to outdoor exposure. The specimens have been put in the field, but so far no biological decay occured on the plywood specimens.

P5. A number of different buildings with coated plywood structures have been analysed. The co-operation with partners 2, 4 and 5 has been continued. The moisture content and condition of the samples in different exposure systems have been measured. The results will be compared in the year 2007.

P6: Partner 6 still requires integration of survey results obtained from the other partners.

Progress during the fourth reporting period

P1: Partner 1 (UGENT) conducted a survey of representative plywood constructions in the Benelux. Several cases including plywood in class 3 outdoor exposure situations were assessed. Results were compiled and delivered to partner 6 (CTBA) to be incorporated in the developed database.

P2: As planned, UNITO has continued to select examples of exterior applications of plywood in alpine climate:

- a plywood field testing located in the northern Italy.
- campings – Bibione Pineda, about 50 km west of Venice in the northern Italy.

The first case concerned a field testing of a Italian plywood mill, were specimens have been exposed since 1991 – 1994 and 1999, located near the city of Ivrea, 40 km west of Turin. The last case regards about 800 bungalow units built between 1988 and 2003.

The units are located in two campings about 100 m far from the sea. Walls and partitions of bungalows were made with face in phenolic pine plywood (produced from French mill), edge of panel was covered with strip of solid wood.
For this sites has been selected all the information about the sites monitored (photo, reports etc., according to CTBA check list).

Deviations from the work plan: Differently from the Technical Annex WP 5.2 and according to laboratory results discussed in WP 2.2 (shown that the measure of shore hardness is affected by relevant errors) the shore measurements were not conduced over the exterior application monitored.

P3: Plywood samples sent by partner 3 were evaluated for the degradation. The plywood will stay another year in outdoor exposure before doing indentation tests to evaluate their mechanical performance.

P5: The results from different buildings with coated plywood structures have been sent to partner 6. The co-operation with partners 2, 4, 5 and 6 has been continued. The moisture content and condition of the samples in different exposure systems have been measured and compared.

P6: A data base of assessments on exterior performance of plywood was compiled by CTBA. It has been done according to the CTBA Durability database model. This specific database is an internal one. Xavier Foulon has developed this database.

In 2006, CTBA assessed 10 more building sites, helped UNITO, VTT and Ghent University to do their own survey according to the survey template document, collects data from the three partners and integrates all the documents (survey document and photo) in the data base.

A total of 75 building sites have been assessed, representing 2075 considered plywood panels.
Among these building sites, 60 sites have been assessed by CTBA, representing 1780 plywood panels.

Plywood constructions described by CTBA are mainly situated in France, Switzerland, The Netherlands, and Finland.
Those described by UNITO are situated in Italia (Alpine climate)
Those described by VTT are situated in Finland
Those described by Ghent University are situated in Belgium and The Netherlands.

CTBA collected the survey template document in the data base. 2 types of document have been included:
A complete survey template document for CTBA, and a slightly modified version for VTT, Ghent University and UNITO were compiled.
All the assessments put in the data base present relevant information about plywood durability in hazard class 3 situations.

Deliverables

The following deliverables were covered:

D4. Identification of specific exposure systems, month 12.

D19. Survey results on service-life of coated plywood, month 36.

D20. Estimation of time to failure for specific applications, month 36.

D22. Specifications for critical characteristics for exterior plywood, month 48.

Milestones

M3. The identification of suitable plywood based on survey results requires a more detailed approach according to exposure intensity (micro-climate, covered-uncovered, coated-uncoated). This will be possible when more survey results (from different regions) are integrated.

M4. Data sets available to interrelate lab results, field test results and survey results.

This milestone was only covered in year 4 since more data were required for sufficient and adequate statistical interrelating.

WP 6 Fit for purpose concept for quality marking of plywood

Workpackage number: **6**

Start date: Month 24
Completion date: Month 48

Partners responsible	1	2	5	4	7 & 9	Total
Planned person months per partner and total:	3	2 + *2*	3	1	0.5	**10 + *2***
Devoted person months per partner and total:	2	3 + *2*	3	0	0.5	**9 + *2***

Already devoted person months per partner and total:

Objectives
Based on the results from the other workpackages a test methodology will be proposed to estimate the suitability of plywood in relation to exterior applications.

Methodology and study materials

6.1 Methodology for testing out of ground contact, exterior usage of plywood

Partner 2 will participate to the evaluation and comparison of results from the different tasks in order to find the foreseen solutions concerning the validation of the ENV12038 and the definition of correlated and faster test method for the evaluation of plywood performance in relation to service classes and exposure conditions.
Results from the different workpackages will be integrated. Where possible adequate statistical methods will be used to define the time factor relationship. Non parametric testing using median values will be used to interrelate different experiments.

6.2 Quality requirements related to exposure and service life

Test results from WP2, WP3 and WP4 will be compared to outdoor service data. Quality requirements will be defined in relation to specific applications talking into accounts factors for e.g. presence of coating.

6.3 Fit for purpose concept and quality marking of plywood

Based on expected service life and specific hazard identified for well defined purposes a quality labelling will be established using a fit for purpose concept.

Progress during the first reporting period

P1: Work under workpackage 6 is planned to start at month 24

P2: Work under workpackage 6 is planned to start at month 24

P4: Work under workpackage 6 is planned to start at month 24

P5: Work under workpackage 6 is planned to start at month 24

P7: Work under workpackage 6 is planned to start at month 24

P9: Work under workpackage 6 is planned to start at month 24

Progress during the second reporting period

P1: Work under workpackage 6 is planned to start at month 24

P2: Work under workpackage 6 is planned to start at month 24

P4: Work under workpackage 6 is planned to start at month 24

P5: According to the results of the first inspection of outdoor weathering test, the coatings are needed to protect the plywood products against weathering and biodeterioration of the surface on outer veneers.

P7: Work under workpackage 6 is planned to start at month 24

P9: Work under workpackage 6 is planned to start at month 24

Progress during the third reporting period

P1: Obtained laboratory and field results are being processed and linked in order to define the base plywood parameters necessary for construction of a fit for purpose concept and proposal for quality marking of plywood. Results will lead towards implementation on standard criteria to be used for integrated CE-labelling.

The Project Co-ordination Committee meetings and intermediary meetings for the scientific research partners prove to be essential as platform for sharing inter-laboratory data and information.

P2: Partner 2 (UNITO) is elaborating data set to compare the results with the other scientific partners in order to find the foreseen solutions concerning the validation of the standard ENV12038 and the definition of correlated and faster test methods.

P5:

6.1 Methodology for testing out of ground contact, exterior usage of plywood

Partner 5 started to evaluate the effect of coating on the performance, moisture content and use condition of different type of coated birch and spruce plywood. The moisture content and condition of the samples in different exposure systems have been measured and the results will be compared during the next period.

6.2 Quality requirements related to exposure and service life

The comparison of test results from WP4 and outdoor survey data of coated plywood has been started. The preliminary results indicate that coatings are necessary to protect the outer veneers against water, weathering and biological attack. Especially birch plywood with phenol film and paint base film with paint are performing well. Also other critical factors affecting the service life of plywood products are protection of edges and fixing points. This concerns specially in service conditions with high moisture hazard (use class 3.2 or more severe).

6.3 Fit for purpose concept and quality marking of plywood

The comparison of results from different test system (weathering and biological tests) is in progress. So far according to the results on different test systems, the coatings systems, birch plywood with paint base film and opaque paint or film, are protecting plywood well in conditions to be included in a wide service area of use class 3. For quality marking of plywood, wood species used as a raw material for the manufacturing plywood may have minor effect when comparing different variables. Facts such as coating type, protection of edges, a way of fixing and use of plywood structures in different exposure environment may have much bigger influence on the final service life of plywood products.

P9: Finnforest inspected the surfaces of different facade plywood of several buildings. Finnforest has also evaluated the condition of old paper faced transport plywood and the condition of old wire mesh floor plywood in vehicles.

<u>Progress during the fourth reporting period</u>

P1: Partner 1 (UGent), the coordinator used the input from all partners and of all other workpackages to come to an implementation document related to standardisation.

The below summary was used as brainstorming document to interact with the FEIC Technical Group.

This scope of the document on brainstorming was to summarize some core elements useful to proceed in implementing a component on biological durability in the standardisation process related to plywood. In no way this is an independent document and should always be used together with the actual implementation document produced by the consortium of the EU project PLYBIOTEST (QLK5-CT-2002-1270). All plywood discussed already fulfils physico-mechanical requirements as defined by the standards related to outdoor usage. Below topics are first covering different types of plywood that can be identified. Within each group different performance levels can be created additionally. The concept is based on a stepwise approach: (1) identify durable plywood suitable for worst case situations, (2) differentiate optimized plywood showing characteristics making it performing adequately without coating, and finally (3) develop criteria for performance assessment of coated plywood.

Durable plywood

The test method according to ENV 12038 is able to identify durable plywood. Mass loss criteria could however be altered, e.g. critical value of 7% mass loss and not 5 or 3 %. The option to have also intermediate durability classes is very useful. In this respect ENV 12038 will be divided in 2 parts. Part 1 will be dealing with identifying efficacy of treatments (as the standard is now doing) and part 2 will focus more on classification of durability levels similarly to the natural durability approach of solid timber.

This durable plywood is envisaged to be used when conditions for wood rot and even soft rot cannot be avoided. This means

(1) Long service life expectation outdoor under wet micro-climate, not covered, or
(2) In ground or water contact (use class 4).

Optimized plywood

This plywood consists of mainly of non-durable wood species or at least not highly durable wood species. The approach of medium durability can be used to specify this plywood, but sufficient performance can also be achieved by product characteristics controlling moisture dynamics. This means one has to proof that a plywood type does not get wet or when it gets wet it dries out fast enough to prevent fungi from developing and causing decay.

This plywood could be used in outdoor conditions without using additionally a method to increase intrinsic durability. A first option is to identify a set of criteria related to the relevant characteristics of plywoods in this respect, like top veneer thickness, liquid water impermeability and vapour permeability of the glue-line, wood species related water sorption-desorption rates… A second option is to test the plywood based on actual water uptake and moisture release under local climatic conditions (CMM, continuous moisture measurements). This reveals the risk of decay developing depending on the time of wetness. In a second stage such approach can even be simulated by means of lab testing.

Coated plywood

When testing coated plywood according to ENV 12038 it is hard to identify enhanced intrinsic durability. Similarly to optimized plywood the functionality of the performance of coated plywood is not based on higher resistance to decay of the material but merely to the prevention of moisture content being long enough at a level to allow development of decay. Testing only non-edge sealed small specimens is not differentiating this material enough, but remains a useful tool to identify performance at edges (worst case). Testing edge sealed specimens could give additional information, but should anyhow be complemented with tests including weathering. However to prove adequate performance it is unlikely that a test evaluating the potential of a fungus to penetrate a coating is fully adequate. In this respect it was proposed to use additionally the time of wetness approach. Water sorption – moisture desorption after a period of artificial weathering (equivalent to expected service life) should provide a tool to identify performance differences between coatings.

Concept summary for implementation

(1) Linking types of plywood and their application will need to be based on service life. The use of durable plywood under conditions where decay can be avoided or delayed without requiring high intrinsic durability should be avoided. This is not only overkill but it also requires the use of either durable wood species (limited resources, tropical origin,…) or treatments (use of biocides, environmental impact,…). Equally as for timber it is important to use these strategies (durable wood, wood preservation) only where they contribute to an important and/or required service life increase.

(2) Intrinsic biological durability as defined by EN 350 can be complemented by technical characteristics of plywood preventing the panels of becoming and/or staying

wet for longer periods. Hence product characteristics can contribute to biological performance even when not identified as toxic for fungi. In addition to testing against fungal decay (ENV 12038 – biological durability), the moisture dynamics of the plywood type can be used to specify sufficient performance based on limiting time of wetness under less critical outdoor situation or for a shorter service life. This two step approach is further complemented by the differentiation between adequate performance without coating and enhanced performance plywood due to a quality coating being incorporated in the product.

(3) The entire concept of evaluating the biological durability of plywood can be summarized as identifying the time up to failure. This consists of a time up to conditions for decay are present (time lag based mainly on physico-mechanical characteristics) and a time for decay to develop (rate of decay depending mainly on intrinsic durability).

(4) Three approaches are available to identify whether a plywood type belongs to one of the categories (or sub-categories) used for biological durability classification. The first one is based on plywood characteristics, like wood species, top veneer thickness,…. A second method can be the definition of cut off criteria for both fungal tests and assessment of moisture dynamics. The third method could be that plywood is being tested similarly as in the second approach, but the outcome is not based on absolute result values but in relation to a predefined set of reference plywood types.

P2: Partner 2 has contributed to the evaluation and comparison of results from the different tasks in order to find the foreseen solutions concerning the validation of the ENV12038.

Concerning this topic, it was suggested to modify the ENV 12038 test method. The data clearly show that there exists a large dispersion of values of mass loss and a low repeatability of the biological test method. If the test is carried out with the ordinary care, according to ENV 12038, the method gives reliable results with a mean coefficient of variation of 63%. For this value of CV the standard ISO 3129-75 (Wood Sampling methods and general requirements for physical and mechanical tests) required a sample of 219 specimens (minimum) for a coefficient of variation of 37% in order to obtain results with statistical confidence of 95% and accuracy of 5%. On the basis of these considerations, it is suggested to increase the number of replicates up to 25 – 30 specimens.
It is further suggested to also increase the maximum level of mass loss allowed: 6% for the use class 3.
In order to better understand the relationship between fungi and adhesive systems and test each type of plywood considering the more aggressive conditions, UNITO suggests selecting two different series of fungi related to different classes of resins:

a) *C. puteana* and *C. versicolor* for UMF and MUF adhesive system (aminoplastic resins),
b) *P. ostreatus* and *C. puteana* for PF adhesive system.

It is well known that PMUF, UMF and MUF adhesive systems are degraded into elementary components by means of the acidification of substrate operated by fungi during the hydrolysis of the wood polymers into digestible units. The results obtained show that the aminoplastic adhesive systems are more sensible to the acidification by *C.*

puteana and *C. versicolor*. Moreover, some test results, but not all of them, seem to confirm a better performance of phenolic adhesive systems.
Finally, it is not fully sure that there really exists an inhibitory effect on the biological activity of fungus by formaldehyde and/or phenol emission. This aspect may be object of future action.

It is clear that the prediction of the expected long-life serviceability, under specific conditions of use of plywood, does not depend only on the biological durability of wood veneers used, but it is a more complex system based on the interaction of many factors.
In other words, the durability of plywood consists in its capacity to perform for a specified period of time (service life) the function for which it was intended, whether it is structural safety (CE marking), serviceability, amenity or for aesthetic purpose, etc.:

- natural durability of wood species,
- design (incl. details for protection),
- surface protection (paint) and edge sealing,
- chemical and physical modification of wood,
- bonding quality and type of glue (lay-up),
- dimensional stability,
- periodical maintenance and its frequencies.

The biological test ENV 12038 allows to determine the mass loss related to natural durability: this mass loss gives an indication which does not always relate to the behaviour of plywood exposed to exterior conditions.
In this context, the results obtained from laboratory test and inspection conduced over some exterior applications of plywood helped to understand the relationship between biological durability and performance in use of plywood.

1. The results obtained in WP 5 were not always comparable with ENV 12038 results. In some application the performance of not durable or less durable wood species based plywood was better (at least in the short period) than could be expected on the basis of the mass loss determined with ENV 12038 test method.
2. Moreover plywood made by wood species of natural durability classified in class 3 - moderately durable (e.g. African mahogany), with expected service life of 10-15 years, shows a service life shorter than expected, while in the same exposure conditions other plywood with natural durability of class 4 – less durable (e.g. okoumé and maritime pine) do not show any trace of decay after about 12 years.

On the basis of the results from biological tests according to ENV 12038 and the inspections under WP5, UNITO defined a partial quantitative classification of plywood performances that correlate each class of service life to the exposure conditions and estimated long-life (from 5 up to more than 20 years) and the characteristics of the plywood tested during the project.
All types of plywood (wood species, lay-up, film, etc.) and / or adhesive are usable for the use class 2: in this context the main critical factors are the glue bond quality of the plywood and its dimensional stability under MC variation due to temporary wetting. Under these exposure conditions there is no risk of decay, and therefore no requirements for mass loss are needed. The situation is very different for the use class 3: the better performing plywood has been detailed for each specific condition.

Finally, it is also suggested to compile a guideline or to revise the ENV 1099 adding some examples (with photos or other practical examples) of different plywood adequate for the use in class 3.1 and 3.2.

P5:

6.1 Methodology for testing out of ground contact, exterior usage of plywood

Partner 5 finished to evaluate the effect of coating on the performance, moisture content and use condition of different type of coated birch and spruce plywood. The moisture content, condition of the samples in different exposure systems and water permeability have been measured and the results have been compared during the period. Different test systems concerning the performance and durability of coated plywood products have been evaluated.

6.2 Quality requirements related to exposure and service life

The comparison of test results from WP4 and outdoor survey data of coated plywood are finished. The results indicate that coatings are necessary to protect the outer veneers against water, weathering and biological attack. Especially birch plywood with phenol film and paint base film are performing well. Performance of coated birch plywood seemed to be better than that of coated spruce plywood. Also other critical factors affecting the service life of plywood products are the protection of edges and fixing points. This concerns specially in service conditions with high moisture hazard (use class 3.2 or more severe).

6.3 Fit for purpose concept and quality marking of plywood

The comparison of results from different test system (weathering and biological tests) is finished. According to the results on different test systems, the coatings systems, birch plywood with paint base film and opaque paint or film, are protecting plywood well in conditions to be included in a wide service area of use class 3. For quality marking of plywood, wood species used as a raw material for the manufacturing plywood may have minor effect when comparing different variables. Parameters such as coating type, the protection of edges, a way of fixing and use of plywood structures in different exposure environment may have more significant influence on the final service life of coated plywood products.

P7 & P9:

Both industrial partners attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Deliverables

D21. Critical plywood characters influencing service life of coated plywood, month 42.

D22. Specifications for critical characteristics for exterior plywood, month 48.

D24. Full definition of degree of exposure in relation to specific applications, month 48.
comparison of results from WP 2,3, 4 and 5

Milestones

M7. Month 42. Rough fit-for-purpose concept and test methodology defined.

M8. Month 48. All data processed to fine-tune overall results.

By the end of year 4 most data were processed though fine-tuning the overall result in collaboration with industry took up to 2nd half of 2008.

3. ROLE OF PARTICIPANTS

Partner 1

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Objectives

- As overall co-ordinator of the project partner 1 considers the main objective having highest priority.
- A more specific objective is to interrelate the outcome of laboratory decay testing and outdoor service life performance of plywood.
- The main approaches are based on the following items:
- improved laboratory decay testing
- controlled outdoor testing
- survey of outdoor performance of plywood as used up to now

Workplan

WP 1

Partner 1 will produce some specific board using laboratory equipment. Based on poplar different products will be developed including durable veneers like eucalypt or glue line additives. Laminated veneer lumber will be included to verify the impact veneers in parallel direction on the degree of decay and the suitability of testing with the Minnesota shear test.

WP 2

Fine-tuning of the ENV 12038 test method will include the use of a shorter exposure period and vermiculite overlay. Topics like reference material and edge sealing will also be included. Artificial ageing will be introduced as alternative to the pre-conditioning now used in the standard. Specific decay testing of a range of plywood types will be carried out in order to allow interrelating mass loss and strength loss based on the Minnesota shear test.

WP 3

Work on outdoor testing will focus on the impact of different moisture conditions in outdoor out of ground contact applications. This will include a covered set up and an accelerated testing using drip irrigation. Plywood tested will be matched with specimens used under WP2.

WP 4
Partner 1 will include different coated plywood types in laboratory testing and outdoor exposure as defined in WP's 2 and 3. Both film coating systems and durable top veneer plywood types will be compared in a time to failure assessment scenario.

WP 5
As co-ordinator partner 1 will focus on field performance assessment based on constructions identified by the European plywood producers and their respective retailer structure. Plywood giving input for the service life relationship will be tested as similar or identical products using methods as defined under WP 2.

WP 6
Based on statistical compilation of data from the different work packages a fit for purpose concept will be derived enabling a prediction of service life and as such proposing a quality marking for plywood.

Deliverables
The following deliverables were covered:

D2. Preliminary test protocol to test coated plywood under laboratory conditions, month 12
D4. Identification of specific exposure systems, month 12.
D8. All plywood available for testing, month 24.
D13. Proper information on plywood characteristics for different external uses, month 36.
D14. Better evaluation of ENV 12038 at month 36 by selecting from
- agar medium with preconditioning or vermiculite without preconditioning
- pre-treatment: short leach, 12 weeks ventilated room, artificial ageing, natural weathering
- additional mechanical evaluation
- definition of reference test material
D15. Factors defined affecting degree of decay overtime in relation to moisture, month 36.
D16. Difference between covered and non covered exposure, month 36.
D17. Results on coated plywood from the exterior weathering site, month 36

The following deliverables were delayed and were finally covered during working year 4:

D3. Results from the accelerated laboratory weathering tests, month 12
D18. Final results from the laboratory tests and from the mixed tests, month 36
D19. Survey results on service-life of different plywood types, month 36.
D20. Estimation of time to failure for specific applications, month 36.

The final deliverables were in part completed by month 48.
D21. Definition of critical plywood characters influencing service life of coated plywood, month 42.
D22. Specifications for critical characteristics for exterior plywood, month 48.

D23. Evaluation criteria using methodology based on laboratory testing, month 48.

D24. Full definition of degree of exposure in relation to specific applications, month 48.
comparison of results from WP 2,3, 4 and 5

By the end of year 4 most data were processed though fine-tuning the overall result in collaboration with industry took up to 2nd half of 2008.

Research activities during the <u>first</u> reporting period

WP 1: Partner 1 collected the plywood reference material produced by partners 7 to 13. The reference material was sampled according to a specific sampling scheme and send to partners 1 to 6.

WP 2: The Ghent University executed laboratory fungal tests. The main focus of this first series of tests on a range of plywoods produced in the lab was to evaluate the influence of glue types in combination with veneer thicknesses ranging from 1 to 3 mm. These fungal test were performed in accordance with the technical description for Basidiomycete fungal testing of board materials as described in the European standard ENV 12038

WP 3: Draft protocols were prepared for three different exposure systems for use (hazard) class 3 situations. These protocols intend to cover realistic outdoor exposure of plywood. The three methods range in moisture exposure using a first technique of free hanging panels, a second one as a roof cornice system and thirdly the worst case scenario using an in build of plywood with additional moistening device.

WP 4: Work under workpackage 4 is still in the planning phase for laboratory evaluation and is being organised to be included in the set up of work package 3.

WP 5: The survey work is being organised for the moment both interacting with the other partners, including industry partners and with national institutes related to the building sector.

Significant difficulties or delays experienced during the first reporting period

No significant delays were experienced during the first reporting period. Only work on accelerated laboratory weathering tests was delayed enforcing that deliverable D3 will only be covered in the second working year.

Sub-contracted work during the first reporting period

No sub-contractor for partner 1.

Research activities during the <u>second</u> reporting period

WP1: During the extra meeting between partners 1-6 in Montpellier (September 2004) and the third PCC meeting in Hamburg (November 2004), partner 1 together with the other partners discussed the subject of the production of optimized plywood panels. It was agreed for the industrial partners to produce several different types of optimized plywood, and send 6 panels of each to the Ghent University (P1). At the end of 2004 the first set of panels arrived in Ghent. They were processed according to the agreed sampling scheme and made ready for delivery to the other research partners.

WP2: Several fungal decay tests were performed according the European standard ENV 12038. A first test setup focussed on testing the effectivity of incorporating glueline biocides. Two different propiconazole based glueline additives were added to the glue of laboratory produced beech, poplar and spruce plywood (UMF and PF glue). Samples of 50x50mm were subjected during 16 weeks to fungal attack in conditioned circumstances. The types of fungi used were *Pleurotus ostreatus*, *Coniophora puteana*, *Coriolus versicolor* and *Gloeophyllum trabeum*. A chosen set of decayed plywood samples was subjected to the Minnesota Shear Test in an attempt to link the mass loss to the loss in strength. The results of these tests were presented during the PCC meeting in Hamburg (November 2004) (see technical report). Two different tests were set up during 2004. The first includes all plywood reference material using two fungi (*Pleurotus ostreatus* and *Coniophora puteana*). In the second test set up, beech and spruce plywood samples were edge sealed with an edge sealing product (Sigmadur HB Finish, a two component high build semigloss aliphatic acrylic polyurethane finish) in order to test the effectivity of the edge sealing product for use in fungal decay testing. The choice of edge sealing product was made after preliminary laboratory weathering tests. Results of these two tests will be presented during the spring 2005 PCC meeting in Hameenlinna, Finland.

WP3: Three different outside exposure set up systems were developed according to the draft protocols made in working year 1. Tests started in June, the test field is located at the outside exposure site at the Ghent University and samples are monitored monthly by ways of gravimetrical and capacitance moisture content measurement. All Plybiotest reference plywood material is included in the test set ups (3 repetitions for each panel type in each exposure category).

WP4: Work under workpackage 4 is included in the outdoor exposure test set ups and in the ENV12038 fungal decay testing of plywood reference specimens. It has been decided to add a choice of coated plywood panels to the category of optimized plywood panels.

WP5: The survey has been discussed and interaction with partner 6 was established.

WP6: Work under workpackage 6 is planned to start at month 24

Significant difficulties or delays experienced during the second reporting period
No significant delays were experienced during the second reporting period. Accelerated weathering tests will be performed in 2005.

Sub-contracted work during the second reporting period
No sub-contractor for partner 1.

Research activities during the <u>third</u> reporting period
WP1: As discussed during the 2004 meetings in Montpellier (September 2004) and Hamburg (November 2004), the industrial partners produced several different types of optimized plywood, and sent 6 panels of each to the Ghent University (P1). Partner 1 collected all panels, processed them according to the agreed sampling scheme and prepared and completed the delivery to the other research partners. At the end of 2005 all optimized panels were processed and redistributed.

On request of partner 1 (UGENT), partner 3 (CIRAD) produced in their laboratory 2 more panel types (throughout cypress plywood and a cypress/poplar combi plywood). Partner 1 received these panels and incorporated them in the different test set ups at the Ghent University.

Details on optimized panel types can be found in the 2005 technical report of partner 1.

WP2: ENV 12038 testing of all reference plywood types was completed with the compulsory test fungi *Coniophora* and *Pleurotus*. The test results revealed a difference in decay preference by *Coniophora* and *Pleurotus* for birch and poplar plywood. The latter fungus is rather glue-indifferent and attacks both plywood types easily, while the presence of PF-glue seems to be a restricting factor for decay by *Coniophora*, even after 12 weeks of preconditioning in a ventilated room. No difference between soft and hardwoods can be made based on type of test fungi since spruce plywood is showing high mass losses for *Pleurotus* while pine plywood is not, and spruce plywood is not consistently decayed by *Coniophora*.

A new ENV 12038 test set up including edge sealed specimens is started as well as a test set up including all optimized plywood specimens and solid birch, spruce and poplar wood (*Coniophora*, *Pleurotus* and *Coriolus*).

WP3: The outdoor field exposure of reference plywood samples was continued. A visual assessment was performed, evaluating the performance of all reference plywood types after 18 months of outdoor exposure. No fungal decay was detected on samples exposed in the freely hanging and the covered outdoor field tests. All plywood specimens were rated for the occurrence of blue stain, moulds and wood destroying fungi, panel deformations (cup and twist) and weathering signals (crack formation, defibrillation, damage by insects and erosion). Staining was present on most samples. Spruce plywood showed severe crack formation while only starting surface degradation was present for the other plywood types.

The accelerated weathering set up including sponge wetting was finished and the samples were prepared for analysis.

A sealed and a not sealed specimen of all optimized and reference plywood types were delivered at the tropical test site in Kourou (maintained by partner 3). The specimens are included in a frame made from perishable beech and spruce wood with the frames allowed to hang freely on two hooks. This field test will allow comparison of weathering intensity between a tropical situation and a worst case accelerated weathering in Ghent.

A field test method allowing continuous water monitoring of outdoor exposed plywood specimens is under development at the UGENT weathering site as well. Results will be available in 2006.

WP4: Coated reference plywood samples were included in the ENV 12038 test set up and in all outside exposure test regimes. The influence of a coating was assessed during floating tests allowing investigation of absorption and desorption parameters of plywood.

Testing of the impact of edge sealing is performed as well in the ENV 12038 testing by using a two component polyurethane sealant (Sigmadur HB Finish) as edge sealant for all reference plywood specimens.

WP5: The survey has been discussed and interaction with partner 6 was established.

Partner 1 (UGENT) has decided to work on the BENELUX section of the survey. The following organisations have been contacted in order to provide with good case study projects:

- Finnforest company
- Bruynzeel company (Allin)
- FEIC, Brussels
- Wood Forum, Brussels

WP6: Obtained laboratory and field results are being processed and linked in order to define the base plywood parameters necessary for construction of a fit for purpose concept and proposal for quality marking of plywood. Results will lead towards implementation on standard criteria to be used for integrated CE-labelling.

The Project Co-ordination Committee meetings and intermediary meetings for the scientific research partners prove to be essential as platform for sharing inter-laboratory data and information.

Significant difficulties or delays experienced during the third reporting period
No significant delays were experienced during the third reporting period. Accelerated weathering tests will be performed in working year 4.

Sub-contracted work during the third reporting period
No sub-contractor for partner 1.

Research activities during the <u>fourth</u> reporting period
WP1: Since all test panels were successfully processed and distributed to the partners involved and as a result of analysis of the test results on reference panel types optimized plywood types were produced, processed and redistributed as well during working year 3, no additional work was necessary for work package 1.

WP2: All ENV 12038 testing of reference and optimized plywood types was completed and analyzed during working year 4. Plywood specimens of all Plybiotest optimized material (32 plywood types, sample sizes 50 x 50 mm, n=6) were tested for their resistance against *Pleurotus ostreatus* and *Coniophora puteana*, the two obligatory test fungi mentioned in the ENV 12038.

All panel types (reference and optimized) were tested against *Coriolus versicolor*, including both edge sealed and not sealed specimens.

To estimate the influence of the preconditioning method a selection was made of 10 plywood types (optimized and reference), comprising poplar, okoumé, spruce and birch as wood species variation as well as UMF and PF glues. Specimens were leached according the EN84 procedure.

Solid wood specimens (birch, spruce and poplar), 50x50x15mm in size, were tested against *Coniophora*, *Pleurotus* and *Coriolus* to allow comparison with equally sized plywood specimens.

The results confirm *Pleurotus* to be rather glue-indifferent, attacking both UMF and PF glued plywood types easily, while the presence of PF-glue remains a restricting factor for decay by *Coniophora*, even after 12 weeks of preconditioning in a ventilated room. This glue-inhibitory effect can be reduced for *Coniophora* by implementation of an EN 84 leaching procedure prior to testing. However, for UMF-glued plywood material a leaching procedure has an adverse effect on plywood durability (due to removal of nutritious substances, making UMF-plywood less attractive to fungi).

When no edge-sealing is applied it is impossible to make a difference in durability between coated or not-coated plywood material. Edge-sealing is required for the evaluation of coating quality or the effect of a durable top veneer.

No difference between soft and hardwoods can be made based on type of test fungi since spruce plywood is showing high mass losses for *Pleurotus* while pine plywood is not, and spruce plywood is not consistently decayed by *Coniophora*.

WP3: The outdoor field exposure of reference plywood samples was continued. A second visual assessment was performed, evaluating the performance of all reference plywood types after 30 months of outdoor exposure. Still no fungal decay could be detected on specimens exposed in the freely hanging and the covered outdoor field tests. All plywood specimens were rated for the occurrence of blue stain, moulds and wood destroying fungi, panel deformations (cup and twist) and weathering signals (crack formation, defibrillation, damage by insects and erosion). Staining was present on most samples. Due to defibrillation and disappearance of the outer greyed surface layer, mould and blue stain fungi are more easily detected. This leads to higher scores for mould and blue stain presence for most plywood specimens.
Spruce and maritime pine plywood show severe crack formation while continuing surface degradation was present for the other plywood types.

The accelerated weathering set up including sponge wetting was finished and the samples were prepared for analysis. Results were partly presented at the annual IRG conference.

The Continuous Moisture Monitoring (CMM) test set up was constructed and its preliminary results on plywood moisture behaviour in outdoor exposure applications were analysed. Results are partly to be presented at the IPPS 2007 conference in Cardiff. This monitoring set up includes a fully equipped weather station consisting of a solar energy sensor, a tipping bucket rain gauge, a relative humidity probe, a thermometer, an anemometer and a wind vane. Every 5 minutes the weather data together with the signal of 56 load cells bearing an attached plywood specimen is logged and saved. Obtained time series allow comparison between plywood types on single shower level as well as on seasonal basis.

WP4: Coated reference plywood samples are included in all test set ups (ENV 12038 durability testing, outside test exposure systems, CMM...). The influence of a coating was assessed during floating tests allowing investigation of absorption and desorption parameters of plywood.

Testing of the impact of edge sealing was performed as well in the ENV 12038 testing by using a two component polyurethane sealant (Sigmadur HB Finish) as edge sealant for all reference plywood specimens.

WP5: Partner 1 (UGENT) conducted a survey of representative plywood constructions in the Benelux. Several cases including plywood in class 3 outdoor exposure situations were assessed. Results were compiled and delivered to partner 6 (CTBA) to be incorporated in the developed database.

WP 6: A fir-for-purpose methodology was worked out and discussed with industrial partners and the FEIC Technical Group.

Significant difficulties or delays experienced during the fourth reporting period
By the end of year 4 most data were processed though fine-tuning the overall result in collaboration with industry took up to 2^{nd} half of 2008.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 1.

Partner 2

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Scientific team

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Objectives

- Production of different panel types: MUF poplar plywood, poplar LVL and exotic plywood with different veneer thickness/lay-up; poplar plywood with treated glue lines.
- Control and measurement of the plywood panels and LVL selected for testing.
- Development of MUF glued poplar plywood with surface protection (overlaid by phenolic film, resin coated and/or edge painted) and with faces made of veneer of durable wood species or with mixed layers (combi).
- Production of plywood with durable top veneers.
- Production of optimised plywood types.
- Improvement of the evaluation procedure for ENV 12038
- Development of non destructive mechanical tests to control mechanical properties
- Correlate mass loss and mechanical property loss at different decay stages, in order to estimate realistic durability of plywood and estimate if accelerated tests can be valid
- Non destructive testing and mechanical shear testing for the evaluation of the bonding quality of plywood and LVL.

Workplan

WP 2

2.2 Non-destructive mechanical testing

Partner 2 will perform commodity testing for measurement of the electric and ultrasonic properties of samples. All the measures will be performed on controls and different decay level samples (after 2, 4, 8 and 16 weeks).

Measures, data implementation and results interpretation need highly qualified persons: a PhD in "Wood Science and technologies" and a PhD in "Forest Pathology" experienced in non destructive testing. In 2005, Debora Susco, a graduated student with a good experience in "Wood Technology" reached at the National Research Council – Tree and Timber Institute of Florence, co-worked with Dr. Roberto Martinis, performing biological and mechanical tests. From January 2006, she will replace Roberto Martinis. And she will work in co-operation with Dr. Simona Ricca, performing all the mechanical tests (ultrasound and electric measurements) on the optimized plywood.

Since the electrical wood properties are strongly influenced by fungal decay, due to both ionic concentration and moisture content, the electrical measurements will be performed by plate electrodes on the whole surface of each specimen.

These copper electrodes are connected to an impedance analyzer that allows measurements with a frequency range of 10 Hz–10 MHz. Electrical resistivity, dielectric constant and loss angle will be measured at different frequencies to determine which parameter is the best to assess the plywood quality and at which frequency.
Elastic properties are strictly correlated to wood integrity. On the same samples, measurements will be performed by an ultrasonic indicating tester with piezoelectric transducers (frequency range of 54 kHz–1 MHz). The ultrasonic measurements will be done in different positions of each specimen with a couple of exponential shape transducers, if the flat shape transducers will be used only one position will be considered. The signals will be recorded and analysed to calculate the first arrival time, the velocity and the amplitude. After each level of degradation has been reached, moisture content and loss mass will be calculated. To assess the effectiveness of the above non destructive techniques, correlations between electrical/ultrasonic parameters and the moisture content/mass loss will be calculated at different stages of decay.

WP 5
5.2 Survey on exterior performance of plywood
Partner 2, according to the decisions taken at the meeting of Montpellier, will do survey on plywood panels by ultrasonic tests to determine their exterior performance. The measures will be carried out on the healthy part and on the decayed part of each sample of at least 5 panels and 5 windows outside exposed. The methodology will be the same of laboratory testing (WP 2) and the results will be compared with the values measured in laboratory.

Deliverables
D1. Coated and uncoated birch and spruce plywood samples for other WPs, month 6
D5. Technical quality of different coating systems.
D7. Experimental validation and realisation of optimised poplar plywood with better performance for exterior use (construction and transportation sector).
D9. Fast test method, based on non destructive testing, month 24.
D12. The relationship established between the loss of mass of inoculated samples and their residual bending properties, bonding quality and electrical/ultrasonic properties, month 36.
D14. Better evaluation of ENV 12038 (by selecting additional mechanical evaluation), month 36.
- agar medium with preconditioning or vermiculite without preconditioning
- pre-treatment: short leach, 12 weeks ventilated room, artificial ageing, natural weathering
- additional mechanical evaluation
- definition of reference test material

D19. Survey results on service-life of different plywood types, month 36.
D24. Full definition of degree of exposure in relation to specific applications, month 48.
comparison of results from WP 2,3, 4 and 5

Research activities during the first reporting period

In the WP 1.1 "Development and production of non-coated exterior quality hardwood plywood", the work carried out by P2 (UNITO) included a study on the production, market (consumption and current use) and the latest developments in the European plywood sector, with special attention to the exterior quality panels and to the new EN standards implemented for plywood and LVL, particularly those concerning the CE marking.

P2 has been also charged of the coordination of the industrial partners in order to give indications about technical parameters for the panels to be produced in the project and to prepare technical sheets for the samples to be tested by laboratories.
In the same period P2 gave assistance to P7 (Panguaneta) for the production of poplar plywood through different meetings and mutual decisions.

P2 took part to the definition of the experimental design in cooperation with P1.
P2 participated to the 1st Project Coordinating Committee (PCC) meeting in Helsinki Finland (in January 2003) and organized together with P7 the 2nd PCC meeting in Sabbioneta Italy (in October 2003).

The preliminary study about plywood and its production process has been useful to define the main criteria for the composition of the reference panels (selection of wood species – also combined in non homogeneous lay-up – veneer's thickness and appearance class, panel's lay-up, bonding type and quality, surface and edges protections). This has made possible to select the most common plywood types used in the European market and which are technically adequate or established for applications in humid and exterior conditions (with bonding classes 2 and 3 according to EN 314).
The above decisions have been agreed with the project coordinator and the industrial partners in order to include in the testing program a representative range of the European plywood production and of the final uses connected with the aims of the project but also to verify the effects of the different technical parameters of the panels selected on their durability in use. This topic has been discussed since the 1st PCC meeting and then the final experimental design has been approved unanimously.

During the period considered the following uncoated panels have been produced:

- Poplar plywood (with the clones I-214 and Beaupré),
- Poplar plywood with okoumé faces,
- Poplar plywood with moabi faces,
- Mixed (combi) plywood with longitudinal grain veneers on okoumé and cross veneers on poplar (with okoumé faces)
- Maritime pine plywood
- Okoumé plywood
- Spruce plywood
- Birch plywood
- Spruce LVL.

Some of the above uncoated panels have been realized using veneers of different thickness/lay-up. In total 15 different types of uncoated panels have been produced for durability testing.

P2 in the WP 1.2 “Production of coated plywood” has also contributed in the coordination of the industrial partners involved in the production of the reference coated panels (plywood and LVL), discussing and giving to them indications about the technical parameters and preparing the sheet for collecting the product’s properties.

The following uncoated panels have been produced:

- Birch plywood coated with phenolic film (with 2 basic weights)
- Birch plywood coated with melamine film
- Birch plywood coated with paint (2 types)
- Spruce plywood coated with paint
- Spruce LVL coated with paint.

Some of these were provided of special edge-sealing. In total 7 different types of coated panels have been produced for durability testing. Considering uncoated and coated types it as been produced a total number of 130 panels. Reference plywood and LVL delivered to each scientific partner.

No	Partner	PCC 1	PCC 2	Code	n	Coating	Wood species	Glue	Thickness
7	PANGUANETA	Bruno CASTELLINI	Nicoletta AZZI	P1	6	non-coated	poplar	UMF	15 mm
				P2	6	non-coated	poplar	UMF	18 mm
				P3	6	non-coated	top veneers okoumé, inner veneers poplar	UMF	18 mm
8	COBLO	Filip AGNEESENS	Erik VANDENBOSCH	C1	6	non-coated	poplar	UMF	15 mm
				C2	6	non-coated	poplar	UMF	20 mm
9	FINNFOREST	Jouko VEISTINEN	Jukka KARINIEMI	F1	6	non-coated	spruce	PF	15 mm
				F2	6	non-coated	spruce - LVL	PF	27 mm
				F3	6	coated with 1x Aquagrund + 2x Aquatop	spruce - LVL	PF	27 mm
10	KOSKISEN	Erkki MERILUOTO	Tomi KIVISTÖ	K1	6	non-coated	birch	PF	15 mm
				K2	6	coated with phenolic film dark brown 120g	birch	PF	15 mm
				K3	6	coated with phenolic film dark brown 220g	birch	PF	15 mm
				K4	7	coated with melamine white 440g	birch	PF	15 mm
11	SCHAUMAN	Esa LAPPALAINEN	Ilkka SEPPÄNEN	S1	4	non-coated	birch	PF	15 mm
				S2	2	non-coated	spruce	PF	15 mm
				S3	6	coated with 1x Visasol + 2x Aquatop 2920-04 paint	birch	PF	15 mm
				S4	6	coated with 1x Visasol + 2x Aquatop 2920-04 paint	spruce	PF	15 mm
				S5	6	coated with SP paint base (LP) + 2x Aquatop 2920-04 paint	birch	PF	15 mm
12	ALLIN	François ALLIN	Philippe TEXIER	A1	6	non-coated	top veneers okoumé, inner veneers: length okoumé, cross poplar	PF	15 mm
				A2	6	non-coated	top veneers okoumé, inner veneers poplar	PF	15 mm
				A3	6	non-coated	okoumé	UMF	15 mm
				A4	6	non-coated	top veneers moabi, inner veneers poplar	PF	15 mm
13	SMURFIT	Serge ROUGER	Daniel BRIZARD	R1	10	non-coated	maritime pine	PF	17 mm

LVL has cross veneers in 3rd layer

On the bases of the harmonized standard EN 13986: 2002 “Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking”, that defines the performance characteristics required by wood-based panels, including plywood, for use in construction applications, and were a set of tables lists the relevant performance characteristics for load bearing (structural) and non-structural applications in the three service conditions (dry, humid and exterior), we prepared a technical sheet in order to have a common framework to describe and compare the plywood made by the industrial partners. Data concerning the physico-mechanical properties inserted in the above sheet have been obtained from quality controls done directly by each company or from results of testing made through national federations of plywood industries. Considering the above mentioned aim of the sheets, specific test to check the declared performance data of the different panels are not been done.

Some types of plywood originally indicated in the Technical Annex (those made of beech, ayous, fuma, eucalyptus, willow and aspen) have not been produced because, from the discussion between partners, they were considered not relevant in view of the objective and the expected results of the project and of an eventual comparison with the reference plywood realized. These types will be eventually produced later as

defined in the 2nd project meeting of Sabbioneta (see minutes of the 2nd PCC meeting).
Differently from the previous indications has been add a poplar plywood with faces on moabi (*Baillonella toxisperma* Pierrre), wood specie of durability class 1 against basidiomycetes (EN 350-2), because it has been judged interesting for its possible use in class 5 of biological risk.

Also, some types of poplar plywood with surface protection have not been realized because the surface protections were already well represented in the other reference panels produced by the industrial partners. These types will be eventually produced later according to the decision taken during the 2nd PCC meeting of Sabbioneta.

Finally, for the degradation test included in WP 2.1 "Durability testing according to ENV 12038", the following decay fungi were achieved: *Coniophora puteana* BAM Ebw 15, *Pleurotus ostreatus* FPRL 40C, *Gloeophyllum trabeum* BAM Ebw 109 and *Coriolus versicolor* CTB 863A. The strains were maintained on the PDA medium and were propagated for the degradation test. The culture vessels used have a capacity of 600 ml which conforms to the reference standard.
According to ENV 12038, wood specimens for the control of virulence were prepared having the dimension of 50 $\pm$ 0.5 mm x 25 $\pm$ 0.5 mm x 15 $\pm$ 0.5 mm. The wood species used were Scots pine (sapwood) for *C. puteana*, *G. trabeum* and beech for *P. ostreatus* and *C. versicolor*. Test pieces were conditioned at 20 + 1 °C and 65 + 5 % R.H. in order to reach 12 % of wood moisture content.
The degradation test lasted 16 weeks.

The loss in mass of the specimen used to control the virulence of each fungus is shown in the table below:

Mass loss (%)				
	Coriolus versicolor	*Pleurotus ostreatus*	*Gloeophyllum trabeum*	*Coniophora puteana*
Pine			25.7	34.9
Beech	40.2	25.9		

The results are above the minimum value (20 %) required by ENV 12038.

Moreover, Partner 2 (UNITO) organized with partner 3 (CIRAD) a meeting in Montpellier in November 2003 in order to define the measurement modalities to be used in laboratory and to determine a common protocol.

<u>Protocol measurements</u>
The measurements will consist on ultrasound wave propagation and on electrical properties. In the case of ultrasound, the signal will be recorded and analyzed to calculate the first arrival time, the velocity and the amplitude. On the same specimens, the electrical measurements will be performed by plate electrodes on the whole surface of each test pieces. The resistivity, the dielectric constant and the loss angle will be calculated.
The measurements will consist on ultrasound wave propagation and on electrical properties. In the case of ultrasound, the signal will be recorded and analysed to calculate the first arrival time, the velocity and the amplitude. On the same specimens, the

electrical measurements will be performed by plate electrodes on the whole surface of each test pieces. The resistivity, the dielectric constant and the loss angle will be calculated.
According to the decisions from the meeting of Montpellier, UNITO and CIRAD will perform biological tests on the bases of ENV 12038. With the purpose to realize a data bank on the behaviour of the electric and elastic properties of decayed wood, some experiment will be carried out on all reference plywood. In particular, test pieces of beech and poplar solid wood (dimensions 50x25x15 mm) and specimens extracted from the panels of plywood produced by the industrial partners (dimensions 50x50xthickness mm) will be used.

All the test pieces will be exposed to the degradation of two fungi: *Coniophora puteana* BAM Ebw. 15 (brown decay) and *Coriolus versicolor* CTB 863A (white decay).
The controls of weight loss will be done after 2, 4, 8 and 16 weeks. From each panel of plywood, 48 specimens will be obtained, for a total of above of 2,500 test pieces over the test control. The electric properties (in a range of frequencies between 1 Hz and 1 MHz) and ultrasonic properties (with frequency 1 MHz) will be performed by UNITO. CIRAD will realize ultrasonic measures (at the same frequencies) and "indentation test" on the decayed samples conditioned at 20°C and 35% RH.

Significant difficulties or delays experienced during the first reporting period
No delays were experienced during the first reporting period.

Sub-contracted work during the first reporting period
No sub-contractor for partner 2.

Research activities during the <u>second</u> reporting period
WP1: In the WP 1.3 "Production of optimized plywood" the work carried out by partner 2 included the evaluation of commercial waterborne preservative compounds and the possibility of improvement of plywood durability through their addition in the adhesive system. This approach has been discussed between partners during the 3rd Project Coordinating Committee (PCC) meeting in Hamburg; it was considered relevant in view of the scope of product optimised plywood.
Partner 2 studied the market for the preservative products suitable for wood-based panels, with attention to those compatible with thermosetting adhesives.
Different types of optimized poplar plywood with preservatives added in the glue mix, originally not indicated in the Technical Annex, have been produced.
The aim of this work is to verify the efficacy of the selected preservatives and to establish a possible relationship between their concentration in the glue mix and the decay resistance of the final plywood. Two different types of preservatives have been chosen:

1) natural preservative: commercial powder of modified quebracho tannin extract, named Fintan 737;
2) low environmental impact preservative: commercial liquid preservatives, named Wolsit® F-SP.

In total 8 different types (two preservatives added with four different concentrations) of optimised panels have been produced for ENV 12038 durability testing.
All the experimental plywood panels for this test were manufactured using veneer produced by the industrial partner 7 (Panguaneta) and bonded with a commercial

UMF resin suitable for wood-based panels for use in humid conditions (bonding class 2, EN 314). The adhesive is characterized by low molar ratio and low free formaldehyde content but is suitable for obtaining high bonding strength with high percentage of wood fiber failure. For this work a modified powder quebracho tannin extract was used for two main reasons: the lower expensive cost and commercial availability and the better speed of co-polymerization with UMF resin in the aminoplastic hardening pH range.
It could be also possible to use a water solution of tannins extract with a concentration between 45 and 50%. In this case it may exists problems of low bonding resistance of the glue line for the considerable addition of water and the dilution of the resin content in the glue mix.
As reported in literature, due to its high reactivity in the pH range from 4.5 to 5.5 where aminoplastic adhesives are highly reactive, tannins added during the preparation stage of the UMF glue mix are copolymerized in the body of the resin itself during the hot pressing and will not reduce the strength of the glue line (as a great number of commercial preservatives does) but will increase the water/weather resistance properties of the resin.
In this way, quebracho tannin extract become "fixed" in the plywood during the hardening process of the TUMF (Tannins + UMF resin) adhesive system, which means that the tannins are virtually insoluble.

The following set of experimental uncoated panels made in laboratory with different wood species of potential interest, also combined in non homogeneous lay-up and veneer's thickness, has been produced and is now on testing for determining the natural durability against fungal decay in order to increase base information for development of the optimized products:

- mixed (combi) plywood with longitudinal grain veneers on okoumé and cross veneers on hornbeam
- plywood made by douglas veneers throughout
- plywood made by paulownia veneers throughout.

WP2: Partner 2 is carrying out the evaluation of the resistance decay of the optimised plywoods according to the ENV 12038 test method.
The most performing results that will be obtained from this experimental panels made in the laboratory will be validate with the production of a set of the same type of panels realized at industrial site and conditions by P7.

According to the decisions taken during a special meeting in Montpellier with partner 3, CIRAD, in 2003, partner 2 is now performing the biological tests on the bases of ENV 12038.
In particular, test pieces of beech and pine solid wood (dimensions 50x25x15 mm) and specimens of plywood (dimensions 50 50xthickness mm) were used. For each panel type, 96 specimens were extracted according to the agreed cutting scheme. In total partner 2 cut more than 2500 test pieces. Because of their high numbers, it was decided to subdivide them in 4 groups. In the 2004, 700 test pieces were decayed according to ENV 12038 and submitted to non-destructive measurements.
Half of the specimens have been cut at 90° (A) and the others at 45° (B). This solution has been chosen in order to study the effects of the fiber direction on the propagation of the elastic waves that are used for non-destructive evaluation (NDE) of panel decay.

All the test pieces were exposed to the degradation of two fungi: *Coniophora puteana* BAM Ebw. 15 (brown rot) and *Coriolus versicolor* CTB 863A (white rot). In particular, for every panel, 48 samples have been decayed from *C. puteana* and the others from *C. versicolor*. The controls of mass loss have been done after 2, 4, 8 and 16 weeks. Beyond to the decayed test pieces, the non destructive analyses have been carried out on control (not decayed) test pieces for every type of panel.

Table 1. Results after 2, 4 and 8 weeks of reference plywood ENV 12038 durabilty testing

		weeks of degradation					
		2		4		8	
Ind. partner	**Fungi**	**loss of mass (%)**	**MC (%)**	**loss of mass (%)**	**MC (%)**	**loss of mass (%)**	**MC (%)**
COBLO	CP	<1	30 ± 5	5 ± 0,8	97 ± 19	16 ± 5	120 ± 50
	CV	<1	25 ± 4	2 ± 0,2	60 ± 11	5 ± 3	60 ± 8
FINNFOREST	CP	<1	38 ± 10	2 ± 0,6	88 ± 20	5 ± 1,3	109 ± 26
	CV	<1	30 ± 5	2 ± 0,8	75 ± 25	5 ± 2	83 ± 27
KOSKISEN	CP	0	28 ± 3	2 ± 0,7	82 ± 14	3 ± 1	93 ± 18
	CV	<1	22 ± 5	4 ± 0,7	76 ± 6	6 ± 0,8	75 ± 11
PANGUANETA	CP	<1	30 ± 5	7 ± 2,3	92 ± 15	10 ± 7	116 ± 26
	CV	0	25 ± 7	1 ± 0,5	62 ± 12	3 ± 0,5	64 ± 17
ROLPIN	CP	0	28 ± 11	0,0	65 ± 17	0,0	90 ± 9
	CV	0	22 ± 8	0,0	66 ± 15	0,0	89 ± 7
UPM Kymmene	CP	<1	29 ± 8	3 ± 0,5	72 ± 16	5 ± 0,5	80,5 ± 6
	CV	<1	28 ± 5	3 ± 0,3	76 ± 14	6 ± 0,7	73 ± 7

Each test pieces, at the end of the degradation period, was analysed by ultrasonic and electric measurements.
Data concerning the physico-mechanical properties of the original technical sheets (produced by the manufacturers) has been completed and integrated with physical and mechanical testing on small test pieces done by partner 2 in order to obtain a harmonized framework that could describe and compare the plywood made by the industrial partners. All test results confirm the values declared by producers.
Bonding quality test (EN 314) is not yet completed. The results of this last mechanical test could be useful to find a correlation with the results of the ENV 12038 durability testing.

Table 2. Data on physical and mechanical properties of reference plywood

				Moisture content	Density	MOR_L	MOE_L	MOR_T	MOE_T
No	**Industrial Partner**	**Code**	**Thick./layers**	**(%)**	**EN 322 (kg/m^3)**	**3p Bending Test - EN 310 (N/mm^2)**			
7	Panguaneta	P1	15/7	8.3	404 (± 5.6)	37.7 (± 3.4)	4070 (± 168)	21.1(± 1.4)	2880 (± 41)
		P2	18/9	8.8	425 (± 2.0)	30.1 (± 6.4)	3600 (± 360)	30.7 (± 4.4)	2690 (± 230)
		P3	18/9	7.8	421 (± 3.9)	28.8 (± 2.9)	3290 (± 88)	28.5 (± 1.8)	4040 (± 142)
8	Coblo	C1	15/11	9.2	439 (± 10.7)	41.5 (± 2.9)	4690 (± 152)	32.7 (± 3.3)	3220 (± 125)
		C2	20/9	8.8	499 (± 11.0)	29.0 (± 1.9)	3490 (± 115)	48.9 (± 2.3)	5600 (± 160)
9	Finnforest	F1	15/5	9.2	458 (± 7.2)	43.5 (± 12.0)	6040 (± 161)	32.3 (± 5.2)	2580 (± 195)
		F2-F3 *	27/9	8.8	505 (± 6.3)	31.1 (± 16.7)	10580 (± 305)	19.8 (± 6.6)	1855 (± 220)
10	Koskisen	K1	15/11	7.9	695 (± 4.6)	90.7 (± 13.2)	11430 (± 290)	75.3 (± 2.5)	6860 (± 220)
		K2-K3	15/11	8.5	718 (± 4.9)	87.4 (± 11.4)	11231 (± 310)	72.8 (± 3.8)	6900 (± 185)
		K4	15/11	8.0	732 (± 7.7)	88.5 (± 12.0)	11445 (± 450)	65.8 (± 6.2)	7630 (± 390)
11	UPM Kymmene	S1	15/11	8.6	691 (± 5.0)	85.7 (± 8.9)	10230 (± 380)	64.1 (± 5.5)	6280 (± 198)
		S2-S4	15/5	9.4	442 (± 15.0)	33.0 (± 8.9)	7200 (± 160)	21.7 (± 6.2)	3020 (± 218)
13	Smurfit Rol Pin	R1	17/9	8.8	606 (± 16.0)	47.5 (± 8.8)	5090 (± 188)	39.0 (± 3.4)	3040 (± 375)

Concerning WP 2.3, the work carried out by partner 2 included a research and evaluation of different methods of measurement of hardness on wood-based products, and on the availability from the market of a portable device able to measure hardness of wood-based panel and to establish a relationship between plywood degradation and hardness. In fact, the hardness is directly related to wood density and so its measurement may constitute a non destructive method to detect and estimate the decay (by mass loss) of plywood in service.
Different measurements of hardness were conduced on the reference plywood to select the best portable device for determining wood surface hardness with adequate accuracy and repeatability. Five samples of every reference plywood have been selected and a double series of four shore hardness measurements were made with two handle devices: shore A and shore D. The hardness resulted into a range from 23,5 to 41,0 shore.
On the basis of the above considerations and the results of measurements with shore devices, it was chosen a shore D portable digital hardness tester (Mitutoyo Hardmatic HH-300) supplied with external data output. This device is potentially suitable to make in field and laboratory tests. The measure of the hardness will be made on the test pieces of reference plywood, before and after exposure to the ENV 12028, in correspondence of the four corners of each specimen.
If the test method shore D turns out reliable in the evaluation of mass loss following wood decay, it will be used, as a fast non-destructive mechanical test, in the program of survey on exterior performance of plywood, as described in Workpackage 5.
Since there are not well known relations between the standard wood hardness (Brinell) and Shore hardness, it could be established a series of measurements on controls (not decayed) and decayed plywood samples in order to built a scale of comparison Brinell-Shore D.

Significant difficulties or delays experienced during the second reporting period
No delays were experienced during the second reporting period.

Sub-contracted work during the second reporting period
No sub-contractors have been used by P2.

Research activities during the <u>third</u> reporting period
From September 2005, Debora Susco, graduated in "Forest Science", with a good experience in "Wood Technology" at the National Research Council – Tree and Timber Institute of Florence, is collaborating with UNITO in this project. From January 2006, she replaces Dr. Roberto Martinis. The above period of copresence has been necessary in order to pass information from the exiting to the incoming researcher.

WP1: In July 2005 the following first set of industrial optimised panels were produced by Partner 2 (UNITO) and 7 (Panguaneta) with the poplar clone "I 214" or other wood species, also combined in non homogeneous lay-up, coated with phenolic film or uncoated, and with different veneer's thickness.

- maritime pine plywood, UMF glued, nominal thickness 17/7 mm made with veneers (supplied by Smurfit-France) of 2.5 mm,
- paulownia plywood, UMF glued, nominal thickness 18/9 mm made with veneers of 2.1 mm,
- oak plywood, UMF glued, nominal thickness 15/9 mm made with veneers of 1.8 mm.
- poplar plywood (raw), PF glued (clone I-214), nominal thickness 18/9 mm made with veneers of 2.1 mm,
- poplar plywood as above but phenolic film faced,
- poplar plywood (raw), UMF glued (clone I-214), nominal thickness 15/11 mm made with veneers of 1.4 mm,
- poplar plywood as above but phenolic film faced.

These plywood panels were manufactured using industrial veneers produced by partner 7 and bonded with a UMF (melamine-urea-formaldehyde) resin mixture suitable for gluing wood-based panels for use in humid and exterior conditions (complying with bonded class 2 of EN 636 and EN 314). The main specifications of the UMF resin used are as follows:

- final molar ratio of melamine-urea and formaldehyde: 1: 1.1,
- free formaldehyde content of resin: 0.2%,
- solid content: about 63%,
- viscosity: 1000 MPa's,
- storage life (at 20° C) 5 weeks,
- pot-life (20° C): 4-5 hrs..

This resin contains about 20% of melamine with a low free formaldehyde content (in order to comply with class A of formaldehyde release of the EN 1084) and it is similar to the UMF used for experimental panel made by UNITO at laboratory level. Panels with size of 125x250 cm and nominal thickness between 15 and 18 mm were made using the normal industrial process. All the UMF panels were glued with the adhesive mix showed below.

Table: Formulation of the UMF glue mix used.

UMF glue mix composition	Part by mass
UMF liquid resin	100
Coconut shell flour (300 mesh)	10
NH_4Cl (20% solution)	8

Partner 2 (UNITO) and 7 (Panguaneta) also produced a second set of PF glued optimised panels, as follows:
- poplar plywood (raw), PF (phenol formaldehyde) glued, nominal thickness 18/9 mm, made with veneers of 2.1 mm,
- poplar plywood as above but phenolic film faced.

For the raw (uncoated) poplar plywood a commercial phenol-formaldehyde glue mix was used which was applied at the spread rate of about 240 g/m2 for a single glue line. The hydraulic mono-daylight press temperature was 118°C and the pressure 6 kg/cm2. Pressing time lasted 20 min.

For the production of the film faced plywood a rapid phenolic film (AKZO Nobel Swedotec TPS 751 type, suitable for concrete shuttering plywood and for panels destined to the transport industry) was used. The colour of the film is dark with a weight of the raw paper of 75 g/m^2 and that of the final impregnated film of 210 g/m2. The pressing parameters were the same used for the production of the above mentioned PF glued raw poplar plywood (temperature of 118°C and pressure of 6 kg/cm^2 with pressing time of 20 min).

Finally a set of industrial optimised uncoated panels made again with the "I 214" poplar clone bonded with a traditional UMF adhesive system added with different two preservative selected from UNITO (Wolsit® F-SP and Fintan 737, a modified quebracho tannin extract) and with resorcinol was made. These panels were:

- poplar plywood, UMF + wolsit glued (WUMF), nominal thickness 18/9 mm made with veneers of 2.1 mm,
- poplar plywood, UMF + tannin glued (TUMF), nominal thickness 18/9 mm made with veneers of 2.1 mm,
- poplar plywood UMF + resorcinol glued, nominal thickness 18/9 mm made with veneers of 2.1 mm.

On the basis of previous laboratory results obtained from experimental plywood made by UNITO at laboratory level, the selected preservatives were added to the resin at the maximum concentration of 10%. In particular, for the commercial powder of modified quebracho tannin extract this value was the maximum percentage compatible with an allowable final viscosity of the UMF resin used by P7 and with the climatic conditions at the mill during the manufacture of the same panels.
Concerning the resorcinol, it has been added in powder form to the UMF adhesive (see table below) in order to improve the bonding performance. In fact this glue mix is used in the Italian plywood mills for the production of plywood to use outdoor, since generally it is not always possible to reach the bonding class 3 using an adhesive mix only based on UMF resin.
The various components were mixed by a mechanical stirrer in a polypropylene beaker before panel's lay up. The glue mix was applied in a range of about 200 g/m^2 for a single glue line.
A solution of ammonium chloride was used as hardener.

Table: Formulation of resorcinol UMF glue mix used

Resorcinol - UMF glue mix composition	Part by mass
UMF liquid resin	100
Coconut shell flour (300 mesh)	10
Resorcinol	5
NH4Cl (20% solution)	8

An hydraulic 14 multi-daylight press with the temperature of 105°C and the pressure of 8 kg/cm^2 was used to press for a time of 9 minutes
Before the glue mix application, the TUMF viscosity was controlled at the press line using an. 6 Ford cup: the viscosity of the glue mix turned out higher than 180”. Because the high temperatures registered inside the factory, the glue mix showed a very short pot-life (about 1 h at 40°C for 10% of tannin addition): the roller spreader had heavy problems due to the fast reaction of tannin with formaldehyde that increases the molecular weight of the glue mix and determines a rapid polymerisation of the adhesive system.

The bonding quality of this second set of industrial optimised plywood produced was determined according to the standard EN 314 after a 5.1.3 pre-treatment required for plywood used in exterior condition (72 h of boiling water). In fact, type and quantity of the preservative added in the glue mix must assure not only the biological protection required but also the performance of the wood–based product in terms of mechanical characteristics and resistance of the glue line in exterior conditions. For the determination of bonding quality by shear tests a testing machine with an automatic data acquisition and processing system was used on the optimised products, recording the ultimate load of each test piece.

Table: Bonding quality: mean shear strength values and wood failure % for the optimised plywood produced at industrial level with the UMF modified adhesive systems.

Optimised product	**Shear resistance N/mm^2 (Mean value)**	**Wood failure % (Mean value)**
Poplar plywood TUMF glued	1.0	11
Poplar plywood WUMF glued	0.8	--
Poplar plywood UMF + resorcinol glued	1.5	16

Concerning the TUMF glued poplar plywood, after the 5.1.3 pre-treatment required by EN 314 the results showed a mean shear strength value of 1.0 N/mm^2 and a wide irregularity in bonding quality with lower shear values (average 0.8 N/mm^2) for the external glue lines. When the shear strength is lower than 1 N/mm2, the reference standard states than the mean percentage of wood fibres remaining on the wood/glue line interface (cohesive failure) must be measured. Consequently, the wood fibre failure for each tested glue line was controlled. In all cases the test pieces showed a lower wood fibre failure and poor cohesive adhesion with a mean value of 11% for the external glue lines and a maximum of 20% for the central ones associated with a satisfactory shear resistance. So the bonding quality of the TUMF poplar plywood did not meet completely the requirements for use in exterior conditions (class 3) at least for the external glue line.
This was caused by excessive viscosity of the adhesive mixture due to the high summer temperatures (over 35°C), which determined a fast hardening of the glue mix especially in the case of the external glue lines.
Concerning the central glue line of the examined test pieces, the shear strength values showed a interesting bonding quality and a good resistance to cycling boiling which is not achievable with a normal UMF adhesive system. In this case the shear value of TUMF seem to confirm an improvement of characteristic and strength of the glue lines and to guarantee, with a correct viscosity, a sufficient mechanical and physical interlocking of the hardened adhesive and poplar veneer.

The wood failure for each tested glue line has been controlled, the test pieces showed a maximum release for the central glue line (20%, see enlargement to right) associated with a satisfactory shear resistance.

For WUMF glued poplar plywood, after pre-treatment 5.1.3 the results show a mean shear resistance of 0.8 N/mm2 and a poor wood fibres release: in this case the addition of the preservative did not confer an improvement of bonding quality but can only be considered in terms of its biocidal efficacy.
The poplar plywood bonded with UMF + resorcinol adhesive system submitted to the same pre-treatment as above, showed good bonding quality specially in terms of shear resistance (1.5 N/mm2) and wood failure (16%) able to satisfy the requirements for use in exterior conditions (Class 3 EN 314) at least for the external glue line

Table: List of the optimised plywood produced by partner 7 in cooperation with partner 2.

Code	Coating	Wood species	Glue	Thickness	Plies	Veneers
U1	non-coated	maritime pine	UMF	17 mm	7	2.5 mm
U2	non-coated	paulownia	UMF	18 mm	9	2.1 mm
U3	non-coated	oak	UMF	15 mm	9	1.8 mm
U4	non-coated	poplar	PF	18 mm	9	2.1 mm
U5	phenolic film	poplar	PF	18 mm	9	2.1 mm
U6	non-coated	poplar	UMF	15 mm	11	1.4 mm
U7	phenolic film	poplar	UMF	15 mm	11	1.4 mm
P4	non-coated	poplar	Resorcinol UMF	18 mm	9	2.1 mm
P5	non-coated	poplar	Wolsit UMF	18 mm	9	2.1 mm
P6	non-coated	poplar	Tannin UMF	18 mm	9	2.1 mm

All the optimised panels will be tested by scientific partners to determine their decay resistance. At the moment, the underline optimised panels are in testing (ENV 12038) by UNITO.

WP2: Partner 2 completed biological tests on reference plywoods. For this activity, test pieces of beech and pine solid wood and specimens of reference plywoods were used. For each type of panel, 96 samples were extracted for a total of more than 2500 test pieces. All the test pieces were exposed to the degradation of two fungi: C. puteana and C. versicolor. Mass losses were recorded after 2, 4, 8 and 16 weeks. Results about biological experiments according to ENV 12038 evaluation methods, are showed in the following graph where mass loss averages are indicated in respect to the critical fungus.

All the 22 tested panels did not exceed the decay tests according to ENV 12038 procedure except plywood named with A2 and A4 code which features are showed in the following table.

Partner	Code	Coating	Wood species	Glue	Thickness	Plies	Veneers
ALLIN	A2	non-coated	top veneers okoumé, inner veneers poplar	PF	15 mm	7 plies	1.0 / 3.0 / 2.0 mm
	A4	non-coated	top veneers moabi, inner veneers poplar	PF	15 mm	7 plies	1.0 / 3.0 / 2.0 mm

Also F3, K4, R1, S4 plywood gave low mass losses but some samples had mass loss upper than 5% so, according to ENV 12038 evaluation method, these plywood failed the test.

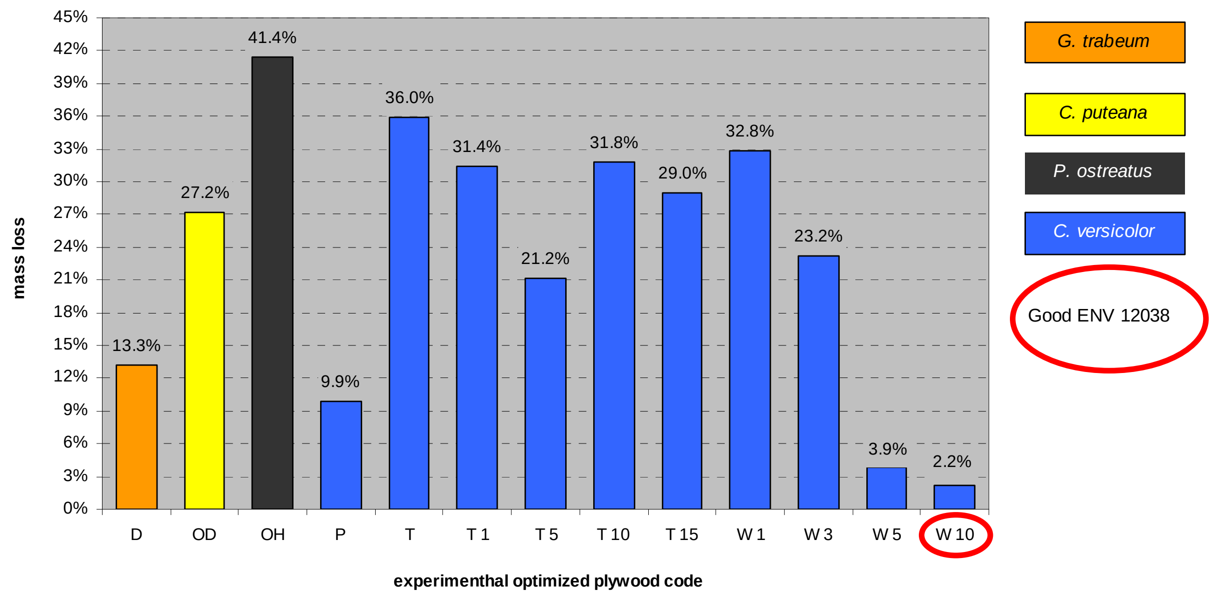
With the aim to realize optimised panels (WP1), UNITO evaluated the biocidal effects of two preservative compounds added to the glue mix: the Wolsit F-SP and quebracho tannin extract. Preliminary, in vitro tests were carried out: cellulose disks impregnated with different concentrations of active substance, the same used in the WUMF and TUMF glue mix, were put on the mycelium grown on Petri dishes. Wolsit showed a biocide effect above 5% while tannin quebracho composite suggested only a preliminary inhibiting effect on the mycelium growing.
Results from the lab-test were the guideline to realize the corresponding experimental Wolsit/tannin plywood which were tested using 4 decay fungi according to ENV 12038 test methods.
In order to identify the different types of panels and to evaluate the effect of the preservative addition, the following codes were used (where the last number concerns the concentration of the preservative added):

- poplar plywood bonded with standard UMF glue mix, coded T,
- poplar plywood bonded with WUMF (Wolsit + UMF) glue mix, coded W1, W3, W5, W10,
- poplar plywood bonded with TUMF (Fintan + UMF) glue mix, coded T1, T5, T10, T15.

Moreover, some experimental optimised plywood with different wood species (paulownia, mix composition of okoumé-hornbeam, douglas veneers) of potential interest, also combined in non homogeneous lay-up and veneer's thickness were tested. These panels were made as follows:

- douglasia MUF plywood, nominal thickness 16 mm/7 layers, code D,
- mixed okoumè-douglasia (combi) plywood, longitudinal grain veneers on okoumé and cross veneers on douglasia, nominal thickness 15 mm / 7 layers, coded OD,
- mixed okoumè-horbeam (combi) plywood, longitudinal grain veneers on okoumé and cross veneers on hornbeam, nominal thickness 15 mm / 7 layers, coded OH,
- paulownia plywood, nominal thickness 12 mm / 11 layers, coded P.

The following graph shows the mass loss averages recorded for each plywood type in respect to the critical fungus.



The results confirmed the vitro tests: only the panels with a Wolsit concentration above 5% were resistant to fungal decay.
The results obtained on the experimental uncoated panels made with different wood species suggested no resistance against decay, with mass losses near to 30%. Only paulownia plywood showed the lowest mass loss of 9.9% caused by *Coriolus versicolor*.

The non destructive analyses by ultrasonic and electric measurements were carried out on sound and decayed samples for every type of references plywood. Some hardness measurements were also carried out on the reference plywood after each degradation period.

Concerning ultrasonic measurements, the first result was to establish that ultrasonic measurement have to be carried out in the sample transversal direction because longitudinal measurement could give misleading data due to the unknown contact angle between the ultrasonic transducers and plywood. Moreover it was realized that some plywood, in this case Finnforest, gave problems in first arrival time reading and, consequently, in ultrasonic velocity measurements. Finnforest problems occurred with any sample measurement direction and any waves frequency (1 MHz and 54 kHz).
Concerning the relationship between decay and ultrasonic measurements, the results obtained with decayed samples seem to confirm the diagnostic effectiveness of ultrasounds. Ultrasonic velocity is sensitive to degradation: in fact a negative trend is always observed passing from the healthy samples to the decayed ones. Consequently, a second step was to understand the relationship between ultrasonic velocity decrease and mass loss taking into account the samples moisture content.
In fact, the observed velocity decreasing is probably determined by fungal degradation but the moisture content of the sample play also an important role. This potential effect was determined evaluating solid wood and reference plywood samples impregnated with water in order to obtain different moisture contents.
Results suggested that the moisture content has more effect on ultrasonic longitudinal velocity and less in transversal. In particular, ultrasonic longitudinal velocity values of

solid wood decrease with moisture content increasing, while transversal velocity values don't. Apparently transversal velocity seems to increase but this trend could be included in a measurement error. With respect to the reference plywood samples, velocity trends are quite similar considering the longitudinal direction of the samples but it's not possible to generalize. Instead, transversal velocity behaviours are very similar comparing reference plywood between each other and comparing them with solid wood

A first data processing suggested that the assessment of a low level of mass loss in samples with high moisture content seems difficult because the decrease of transversal velocity due to degradation is hidden by the increase due to the moisture content.

Consequently, in a moisture content range of 10-200%, the ultrasonic technique can only be sensitive when the mass loss is greater than 10%.

Concerning the electrical properties, it was noted that there is a similar trend for all the panels and the examined fungi. Resistivity decreases strongly in passing from sound samples, conditioned at 20/65, to the decayed. Permittivity has the opposite trend: it increases in passing from sound to the decayed samples. The potential effect of moisture content was also determined evaluating electrical measurements of samples impregnated with water in order to obtain different levels of moisture contents.

After a preliminary data elaboration, at equal moisture contents, it was realized that resistivity values change with decay and these are more appreciable than the permittivity variation.

Afterwards, 20 kHz electrical measurement gave us valuable results in detecting decay on P2 plywood and in this case it seems possible to quantify the decay in service.

Consequently, the future work will focus to obtain similar results for each plywood type.

UNITO carried out also an hardness test with a portable device in order to evaluate and propose a fast non-destructive method that could be useful for detecting fungal decay in situ.

For this purpose and as planned, UNITO investigated panels hardness (shore) properties on reference plywood.

Hardness is conventionally defined "the resistance of a material to permanent penetration by another harder body with measurement being made after the force has been removed". The principal parameters that influence hardness and that show strong influence in applying conventional hardness test methods (Brinell and Janka), are wood density and moisture content. So, the aim of the work done was:

- to find a possible relationship between shore hardness and MC,
- to find a possible relationship between shore hardness and mass loss,
- to find a possible relationship with other hardness test methods (Brinell).

Shore hardness was measured with a portable device that determines the penetration of an indenter into the wood sample. If the indenter penetrates completely the sample the instrument gives a reading of "0", if no penetration at all occurs the reading is "100". The measurement is dimensionless.

In particular, the shore durometer consists of a reference presser foot, an indenter, a display indicating the result and a calibrated spring that applies the force throughout

the indenter. The difference between the durometers used (which were of the type A and D) only concerns the shape of the indenter and the calibrated spring.
UNITO validated the repeatability and the sensitivity of the measurement respect to different surface characteristics and density of the reference plywood.
Five sound samples of all reference plywood conditioned at 20°C/65%RH were selected and a double series of 6 hardness measurements were made with the two portable devices shore A and D. The best repeatability was found for shore D.
The results obtained during some preliminary tests have confirmed that especially shore D (for its better precision) is a reliable comparative for determining the surface hardness of plywood of the same type and structure (species/composition etc.). In this context it gives accurate results, with a good repeatability, homogeneous values and low standard deviations. Consequently, five different measurements for each sample were done on the reference plywood with shore D portable device. The measurements were made before and after exposure to the ENV 12038 test in correspondence of the four corners and the centre of each specimen.

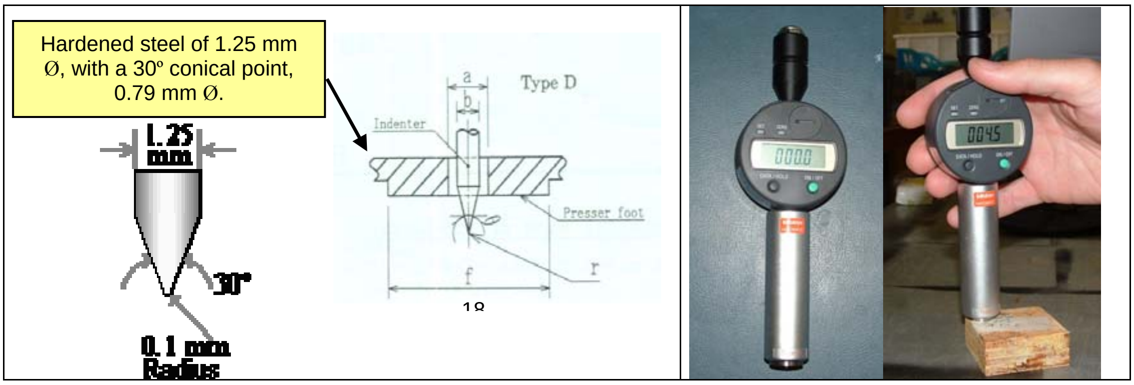
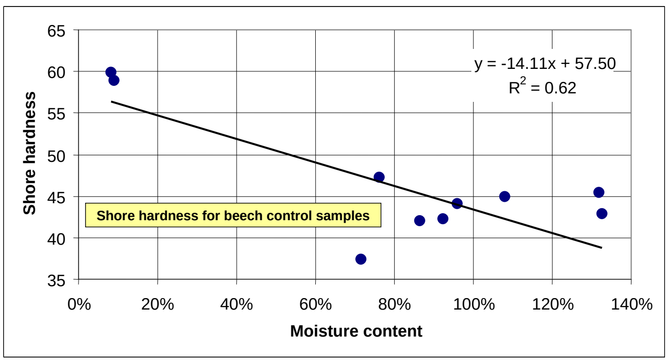
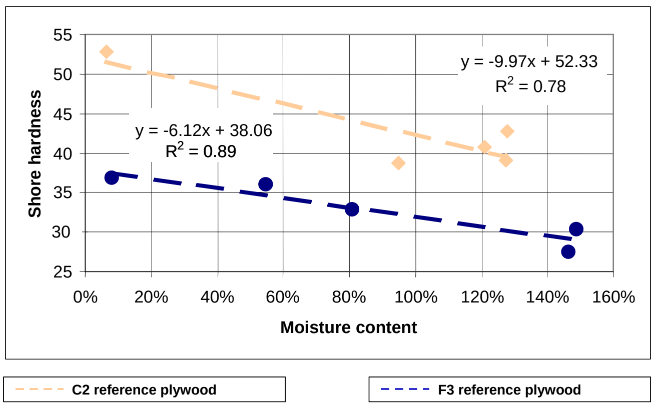


Figure: Shore D portable device.

As a first step, with the aim to better understand the relationship between shore hardness and MC, we conditioned samples of sound reference plywood and solid wood at different levels of moisture content.
As expected, in the beech sound solid wood samples the shore hardness decreases with the increasing of MC and the same trend was registered for the reference sound plywood samples (see figures below). The results anyway show that generally it does not exist always a high correlation between shore hardness and MC since in some cases (for P3 and S4/S5 we found $r^2 < 0.5$).

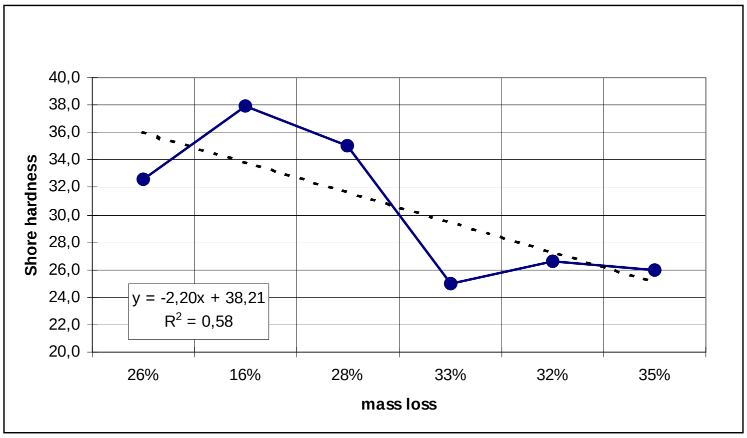




For this reason, we stated that shore hardness test values and its relationship with MC may be quite accurate only for homogeneous groups of plywood (same specie and structure).
Moreover, the shore hardness values measured on decayed samples are always lower than the theoretical ones calculated on sound samples for the same level of MC. The hardness value calculated on the bases of the correlation shore/Mc that we have found are generally congruous with the hardness measured on the sound samples before the biological testing (C2 average experimental hardness of 53.2 versus a calculated value of 53.0 for 9% MC).

Finally, the work carried out by UNITO included the evaluation of the relationship between shore hardness and mass loss. About this we can say that:

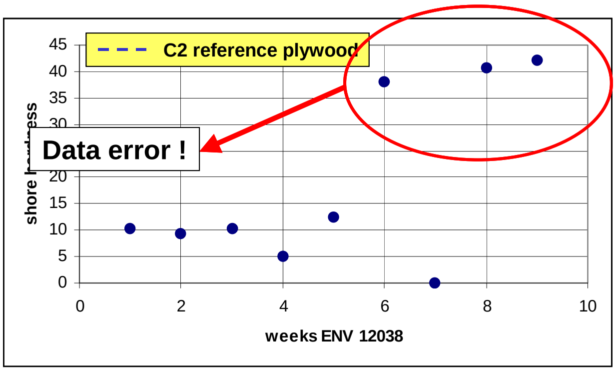
- generally, the analysis of the experimental results highlights that also between shore hardness and mass loss it does exist an high correlation because quite often the shore hardness shows irregular trend with the increasing of fungi attack;
- in some cases (C2 reference plywood) the above correlation gave us an $r2 < 0.58$;
- considering the different types of samples the results show a different trend in the decreasing of the shore hardness for the same level of mass loss which seems difficult to be explained only for the influence of the different wood density and moisture content of plywood (after ENV 12038 test for Coriolus versicolor F2 samples show an average mass loss of 4.2% against an average decrease of shore hardness of 39%, while C2 samples show an average mass loss of 26% versus an average shore hardness variation of 52%).



In conclusion, the above results show that wood hardness measurement is rather a difficult mean to estimate the value of wood decay, for the following reasons:

- the shore methods need a certain practice to guarantee good repeatability in the measurements,
- shore test is not reliable for comparing the hardness on the basis of the relationship hardness/MC of two different plywood (wood species, thickness, surface finishing etc.).
- the correlation between shore hardness and mass loss of decayed samples did not give a statistically high result, also because the irregular surface of the decayed samples may be affect the measurements of shore hardness by a non-systematic relevant error.

- shore hardness value (indenter penetration under the applied force) do not depends only on the shape of the indenter but also on the phenomena of swelling and irregularity of the decay surfaces of the sample that can affect the measurement. In presence of a strongly irregular surface, the source of error (see figure below) due to friction and surface characteristics is evident, therefore one cannot expect an "absolute value of hardness".



For the above considerations, the shore hardness value calculated for each decayed reference plywood may be used only as a "qualitative parameter" for detected a potential presence of decay while the use of shore test as a non-destructive method to estimate the exact fungal decay of plywood in service by "in situ" measurements, if still remains attractive, appears hardly reliable and needs further research.
Possible relationships with other hardness test methods for wood-based panels are in progress.

Anyway UNITO obtained many data (400.000 data as showed in the following table) in the third research period and will give more appreciable results after a full scale-data processing.

Number and type of plywood	Decay Fungi number	Decay weeks	Samples number for each plywood type	Ultrasonic measurement for each sample (2 frequencies, 2 sample directions)	Electrical measurement for each sample (50 frequencies x 3 electric parameters)	Physical properties for each sample
22 reference	2	2	24	4 ultrasonic velocities	150 electrical data	5 Hardness data* 3 Dimensions data Moisture content Mass loss
		4	24	4 ultrasonic velocities	150 electrical data	5 Hardness data* 3 Dimensions data Moisture content Mass loss
		8	24	4 ultrasonic velocities	150 electrical data	5 Hardness data* 3 Dimensions data Moisture content Mass loss
		16	24	4 ultrasonic velocities	150 electrical data	5 Hardness data* 3 Dimensions data Moisture content Mass loss
12 experimental optimised	4	16	30	4 ultrasonic velocities	150 electrical data	3 Dimensions data Moisture content Mass loss
16 wetted reference plywood	none	none	10	4 ultrasonic velocities	150 electrical data	5 Hardness data* 3 Dimensions data Moisture content

* hardness data were recorded with a sampling method.

WP 5: On the basis of the information about the current external use of plywood in the alpine continental climate collected through a network of contacts in the framework of the Italian building sector, UNITO has selected some other cases for field inspection according to CTBA protocol. As planned, survey on exterior plywood performance started in may 2005.

These cases are concerned to:
- a plywood factory warehouse (Compensati Benazzi srl, Dosolo – Mantova)
- an hotel building (Hotel Blu srl, Collegno - Torino)
- field signs at San Rossore National Park (Tirrenia - Livorno)
- a private house (Lambrugo – Como).

For each case UNITO has collected all the information about the site (photo, reports and questionnaire). The moisture content of plywood was determined using a digital moisture meter instrument based on dielectric constant measurements. With this the specific weight of the tested wood material has to be taken in consideration for an accurate estimation. For this reason the instrument is equipped with a setting device for the various species of wood. The moisture content of each structure was calculated as an average of five points of measurement taken at random on the accessible surfaces of the wood material in examination.

<u>Plywood warehouse</u>

The first case concerned the walls of a warehouse that was finished in 1992. The building is adjacent to an Italian plywood factory located in the Po valley. The walls were made with a 38 mm/17 layers raw poplar plywood, without any type of coating or film, glued with an UF adhesive system reinforced with the addition of melamine (in the past this gluing type was quite common in the plywood market and was commercially known as IW67).
The external layer showed a diffuse delamination; in this case there is strong evidence of the hydrolysis of the glue line of the plywood directly exposed to rain and weather. The inside part of the wall (back of the panel) showed a diffuse discoloration (grey) of the raw surface of the plywood but without delamination. The average moisture content of the plywood was 14.0%.

<u>Hotel building</u>

The building was finished in 2003. In this case we found two different situations of exposure in exterior conditions for the plywood used: uncovered (case of a varnished okoumè plywood) and protected under a metallic structure (case of a raw pine plywood). The building is located in the city of Turin, northern Italy. The plywood was used as not structural element for the decorative details of balcony of the principal face and for the closed balcony of the backside of the building. The panels for the front side were made with okoumè plywood (21 mm/13 layers) MUF glued, without edge sealing but varnished with polyurethane cycle. Passing screw bolts were used for the fixing system. It was not possible to gather other information about the type of finish and the supplier of plywood.
From the survey we noted that there was not evidence of delamination or hydrolysis of the glue line of the plywood but we observed some areas of discoloration around the bolt heads that fix the panel to the iron structure of the balcony. The average moisture content of the panels was 15.5%.

On the front face of the building there was a metallic penthouse with the internal side on raw pine plywood. Also for this component of the structure there was not presence of delamination but some diffuse areas of discoloration showed a point of great infiltration of rain, an absence of adequate ventilation and potential points for fungal attack. Furthermore, because its form and arrangement, the structure is not directly examinable without using an elevator. For this reason the determination of the moisture content of these components was not done. Neither for this type of plywood was it possible to obtain further information about its technical characteristics and the supplier.
All plywood used in the structure was not submitted to any maintenance.

San Rossore National Park
This case does not concern a building but is an example of a simple wooden structure finished in 2003 used as field sign in exterior conditions. These structures are located in a national park along the Tirrenic coast, in the central Italy. In this case pine plywood (made with the same wood specie that grows in the park) was used as not structural element. The plywood was glued with MUF without any type of coating (neither surface nor edge protection). The average moisture content of the panels was 17.4%.

Private house
This case is a rare example of an Italian private house using plywood as “façade” in exterior conditions. The house was finished in 2003. The structure of building is in concrete but the main faces are in “marine” plywood. The building is located in Lambrugo, a small town near the Como Lake in northern Italy. The plywood was used as not structural element for covering with a decorative and natural surface the structure of the house.
All the façades of the building were made with okoumè plywood PF glued and overlaid with teak slide veneers 1.5 mm thick (the final panel was 20 mm/11 layers).
The panels were produced by an Italian manufacturer specialised in “marine” plywood. They have been installed without edge sealing and varnished with a polyurethane cycle not specific for wood exposed to exterior conditions. It was not possible anyway to gather other information about the type of finishing. The fixing system was made by screw.

The exterior walls of the building were covered with a simple modular structure constituted of decorative elements of 100x50 cm in order to realize a ventilated façade.
At the time of our inspection, there was not evidence of delamination of the plywood, but the panels exposed to south without protection showed a quick discoloration (grey surface) and degradation of the varnish applied (film cracking). In fact, about six months ago, the property, on the advice of the designer, decided to arrange for an extraordinary maintenance of the portion of the façade with sign of discoloration. About 72 panels were replaced with the same type of plywood painted with a new type of coating system certified for wood exposed to exterior conditions. The supplier tested this type of coating in according to EN 927-3. The average moisture content of the elements used on the south face of the building was 14.8%.

The results until now registered, clearly showed no presence of decay or delamination in all the plywood structures that have been examined by UNITO.

Significant difficulties or delays experienced during the third reporting period
No significant delays were experienced during the third reporting period.

Sub-contracted work during the third reporting period
No sub-contractor for partner 2.

Research activities during the fourth reporting period
Partner 2 (UNITO) completed ENV 12038 test on 10 optimised plywood chosen among those produced by the all partners during the previous years: none of these optimised plywood can be identified as durable plywood (3% ML criterion).

Ultrasonic and electrical measurements were completed on tested optimised plywood and data processing was carried out and finished.

According to the durability test data, even if some are limited as only 2 decay fungi were used, it can be pointed out that not all coating improved enough plywood performances to identify them as suitable for severe exposure conditions.
Moreover, the large standard deviations of mass losses hint a high data variability, which could be attributed not only to fungi biology but also to the reduced number of plywood specimens used in the ENV 12038 test.

Finally, after a generic comparison between PF and UMF glued plywood, it was concluded that UMF plywood is more decayed by *C. puteana* and *C. versicolor* than by *G. trabeum* and *P. ostreatus*.

Concerning ultrasonic measurements, the ultrasonic measurement system is not suitable to detect or to predict decay because ultrasonic velocity decreasing is only significant when plywood decay is higher than 10% of mass loss.
Concerning electrical measurements, it was pointed out that resistivity, permittivity and loss tangent are differently sensitive to decay for the 3 plywood features glue, wood species and coating. Decay for most of UMF glued plywood could be assessed using the permittivity parameter while resistivity is suitable for most of PF-glued plywood. However it is not possible to use a single math function to assess or to predict decay of all plywood. Consequently, electrical measurements could be suitable to use as non-destructive mechanical test because of electrical parameters sensitivity to decay of many plywood. However some problems concerning the absence of sensitivity to decay of some plywood have to be solved yet.

During the period considered, Partner 2 in order to evaluate the reliability of non-destructive measurements and to find possible relationships with other hardness test methods, has finished the analysis of shore hardness measurements.
The results obtained from shore hardness measurements with reference and optimised plywood confirms that there is no clear relationship between hardness and mass loss. The test method is not sensitive enough for modest variations in the wood density. The results show that there is no definite discrimination in shore value for low wood density variation as present within one type of plywood.
Moreover, the following considerations should be underlined:

- because of the irregular surface of decayed specimens, the measure of shore hardness is affected by relevant errors. The shore value, related to indenter

penetration under applied force, depends not only to the shape of indenter but also to the response to indentation. Phenomena of swelling and irregularity of the decayed surfaces of sample strongly affect the values measured;
- many error sources can affect the uncertainty of measurement of the shore test: if the difference on the shore scale is less than twenty hardness units, it is not sure that this is due to the effect of the mass loss of the decayed specimens;

On the basis of the results the use of standard shore D test as a non destructive method to estimate decay of plywood in service appears adequate. The shore test, although this method generally shows good accuracy, cannot be applied to wood-based product strongly affected by wood decay. Because of the irregular surface of decayed specimens, the measure of shore hardness is affected by relevant errors and today, there are no other types of portable devices available for hardness test measurement.

As planned in the WP 5 Survey on outdoor performance plywood, P2 has continued to select examples of exterior applications of plywood in alpine climate:
- a plywood field testing located in the northern Italy.
- a camping – Bibione Pineda, about 50 km west of Venice in the northern Italy.

The first case concerned a field testing of an Italian plywood mill, where specimens have been exposed since 1991 – 1994 and 1999, located near the city of Ivrea, 40 km west of Turin.
The last case regards about 800 bungalow units built between 1988 and 2003. The units are located in two campings about 100 m far from the sea.
Walls and partitions of bungalows were made with face in smooth pine plywood (produced from French mill), edge of panel was covered with strip of solid wood.
The first type units built in 1988 showed only moisture traces, discoloration and moulds on the exterior wall. All the structures are well maintained by means of inspection and repair any of obvious damage traces due to erosion/discoloration of the semi-transparent paints.
There is no evidence of delamination of the plywood, but the plywood exposed without any protection to south showed a fast discoloration (grey surface) and degradation of the varnish applied (film cracking).
This case shows that structures based on plywood of moderately durable wood species (maritime pine) can be used for more of 20 years only requiring periodic refinishing to restore the eroded varnish coating.

As planned, on the basis on the analysis of laboratory results and data acquired from the different work packages, UNITO defined a partial quantitative classification of plywood performances.

A report is compiled using some indications of usable plywood for each class of service life related to the exposure conditions and estimated long-life (from 5 up to more than 20 years). This classification could be a simple tool aiding in the choice of plywood during design.

It is clear that the prediction of the expected long-life serviceability, under specific conditions of use of plywood, does not depend only on the biological durability of wood veneers used, but it is a more complex system based on the interaction of many factors.

In other words, the durability of plywood consists in its capacity to perform for a specified period of time (service life) the function for which it was intended, whether it is structural safety (CE marking), serviceability, amenity or for aesthetic purpose.

The biological test ENV 12058 allows to determine the mass loss related to natural durability. This mass loss gives an indication, which does not always relate to the behaviour of plywood exposed to exterior conditions.

In this context, the results obtained from laboratory test and inspection conducted for some exterior applications of plywood helped to understand the relationship between biological durability and performance in use of plywood.

On the basis of the results from biological test according to ENV 12038 and the inspection within WP5, UNITO defined a partial quantitative classification of plywood performances that correlate each class of service life to the exposure conditions and estimated long-life (from 5 up to more than 20 years) and the characteristics of the plywood tested during the project.

All types of plywood (wood species, lay-up, film...) and/or adhesives are usable for the use class 2: in this context the main critical factors are the bonding quality of the plywood and its dimensional stability under MC variation due to temporary wetting. In these exposure conditions there is no risk of decay, and therefore no requirements for mass loss are required. The situation is very different for the use class 3, hence the better performing plywood has been detailed for each specific condition.

Partner 2 has also contributed to the evaluation and comparison of results from the different tasks in order to find the foreseen solutions concerning the validation of the ENV12038 and the definition of correlated and faster test method for the evaluation of plywood performance in relation to service classes and exposure conditions.
Concerning the results obtained from laboratory, UNITO suggest modifying the ENV 12038 test method:

- Increase the number of replicates to twenty five - thirty specimens;
- In order to better understand the relationship between fungi and adhesive systems and test each type of plywood considering the more aggressive conditions, UNITO suggests to select two different series of fungi related to different classes of resins:
    c) *C. puteana* and *C. versicolor* for UMF and MUF adhesive system (aminoplastic resins),
    d) *P. ostreatus* and *C. puteana* for PF adhesive system.

Finally it is suggested to realize a guideline or to revise the ENV 1099 adding some examples (with photos or other practical examples) of different plywood adequate for the use in class 3.1 and 3.2.

Significant difficulties or delays experienced during the fourth reporting period
No significant delays were experienced during the fourth reporting period.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 2.

Partner 3
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Objectives
The main objective is to try to correlate different stages of biological degradation with mechanical loss of performances of different types of plywood, by combining "classical" biological testing with non destructive mechanical testing (ultra-sound waves propagation and mini-indentation tests). From these results, indicators for the degree of decay will be achieved. This will lead to a fast method to evaluate plywood performances.
These tests will be also used to define the performances of plywood coated with durable veneers.

Workplan
Plywood produced from the WP1 will be tested according to the ENV 12038. Many replicates will be done, in order to be able to get samples decayed after 2, 6, 8 … months of fungal exposure. The moisture content and the mass loss at the end of the biological tests will be measured. In parallel, non destructive mechanical testing will be used to test the residual performances of such samples: the use of ultra-sound wave propagation and the use of mini-indentation tests (performed one after the other on the samples). The results of these sets of experiments will be analysed through the utilisation of a 3D finite element methods of multi layered materials. The descriptors for decay and the best explicative correlations should be then given, and lead to a fast test method.
In the same manner, the performances of plywood coated with durable top veneers will also be assessed by combining the biological and mechanical methods described above. The mixed plywoods have been, so far, manufactured with poplar and beech as non durable timber.

Deliverables
D4. Identification of specific exposure systems, month 12.
Deliverable 4 is delivered in time.
D9. Fast test method, based on non destructive testing, month 24.
Deliverable 9 is completed: development and optimisation of fast non-destructive test methods (ultrasonic measurement, indentation tests).

D11. A proposal for a new accelerated test method for coated exterior plywood, month 24.

D12. The relationship established between the mass loss of inoculated samples and some of their residual mechanical properties, month 36.

D13. Information on plywood characteristics for different external uses, month 36.

D14. Better evaluation of ENV 12038 (by selecting additional mechanical evaluation), month 36.

D18. Final results from the laboratory tests and the mixed tests, month 36.

Research activities during the <u>first</u> reporting period

The research activities can be described as follow:

- the development of ultrasonic measurements and indentation tests according the wood material used (massive wood or plywoods)
- the manufacturing of mixed plywoods with durable and non durable wood species
- the evaluation of the durability of such mixed plywood according to ENV 12038 with pre-conditioning in a ventilated room
- the search for correlations between decay (mass loss) and the mechanical properties.

WP 2: The virulence of the fungal strains (*Coriolus versicolor, Coniophora puteana*) for the biological testing has been checked. The plywood from the different partners has been received and conditioned at 20°C, 65% RH prior to cutting in samples. The biological testing according to the guidance of the ENV 12038 will be performed after pre-conditioning of the wood samples.

Ultrasonic testing and the indentation testing as non destructive test methods have been performed on massive wood as well as on experimental plywoods, before and after biological testing towards fungi. Devices and parameters have been set up and optimised for those tests.

A device for the shearing test as also be set up, as this will be considered as the "final mechanical reference" (destructive test).

WP 4: The natural durability of chestnut, cypress and cedar was evaluated on massive wood, in order to use these timbers for durable top veneer. All timbers were shown highly durable.

Chestnut, cypress and cedar have been used to manufactured mixed plywood with poplar or beech (both non durable timbers) according to different models. The evaluation of the durability of these mixed plywood is on going for some plywoods. For those which natural durability as been evaluated, non destructive mechanical tests (ultrasonic and indentation testing) are running.

It has to be underlined that the plywood has been produced with poplar and beech (not on birch and spruce).

WP 5: During the meeting between UNITO and CIRAD (20/11/2003), it has been decided that the tests will be carried out on the healthy part and on the decayed part of each sample of panels and windows in outside exposure above ground (hazard class 3). Different types of panels could be used, such as okoumé panels as well as poplar or birch panels.

Deliverable 4 is completed.

Significant difficulties or delays experienced during the first reporting period
No delays were experienced during the first reporting period.

Sub-contracted work during the first reporting period
No sub-contractor for partner 3.

Research activities during the second reporting period
The research activities can be described as follow:
- the sampling of the plywoods from industry and their testing (non destructive tests and biological tests)
- the evaluation of the durability of mixed plywoods (with durable top veneer) according to ENV 12038 with a 3 month pre-conditioning
- the realisation of the non destructive tests on these mixed plywoods
- for the mixed plywoods, the evaluation of the correlation between decay (mass loss) and decrease of the ultrasonic velocity.

WP 2: The plywoods from industry have been cut according to a common protocol with Partner 2: samples have been cut at 90° and at 45° and selected randomly for the biological tests. Ultrasonic measurements have been started before the biological tests. Biological tests are on going.

WP4: All experimental plywoods have been tested for the biological resistance against *Coniophora puteana* and *Coriolus versicolor* (according to ENV 12038). Prior to the biological tests, ultrasonic measurements have been performed on each sample used (totally non destructive test). Indentation tests have been done on spare samples representative of the panel (as indentation test is slightly destructive).
After the biological tests and conditioning; ultrasonic measurements and indentation tests have been done on each sample used. They were performed only when the degradation was not too high. Correlation between mass losses and decrease of the ultrasonic velocity has been established. Interpretation of the indentation tests and correlation with the mass losses are on going.
Shearing tests on the experimental mixed plywoods have been completed, and interpretation will be discussed when the indentation tests will be interpreted.

WP5: Test pieces have been received from the CTBA and are conditioned prior to non destructive testing. The non destructive test devices have to be adapted to the test pieces.

Significant difficulties or delays experienced during the second reporting period
The conditioned room in which the samples from the industrial plywoods have been subject to climatic disorders (difficulties to reach the right humidity). Several disorders have been registered in the quality insurance system of the laboratory. This climatic room has now been checked and the climatic conditions required are reached. Nevertheless, this has induced some delay in the conditioning of industrial plywood samples.

Sub-contracted work during the second reporting period
No sub-contractor for partner 3.

Research activities during the third reporting period

In order to evaluate the potential use of indentation tests to qualify plywood after biological degradation, biological tests were carried out on non durable plywood (5 plies, made of non durable timber, only one timber used per plywood). The biological tests were done according to ENV12038, using *Coriolus versicolor* or *Coniophora puteana*, and the test was stopped at 22, 45, 67, 90 and 112 days (112 days being the total duration of the test). Mass loss was determined and samples were conditioned at 20°C, 65% RH prior to the indentation tests. Mechanical tests were performed only with the samples degraded by *Coriolus versicolor*. *Coniophora puteana* caused too important decay to allow the re-use of the samples. From Figure 1, it can be seen that the energy of indentation can be correlated with the mass loss of the sample. Moreover, the curves obtained can explain the behaviour of the plywood.

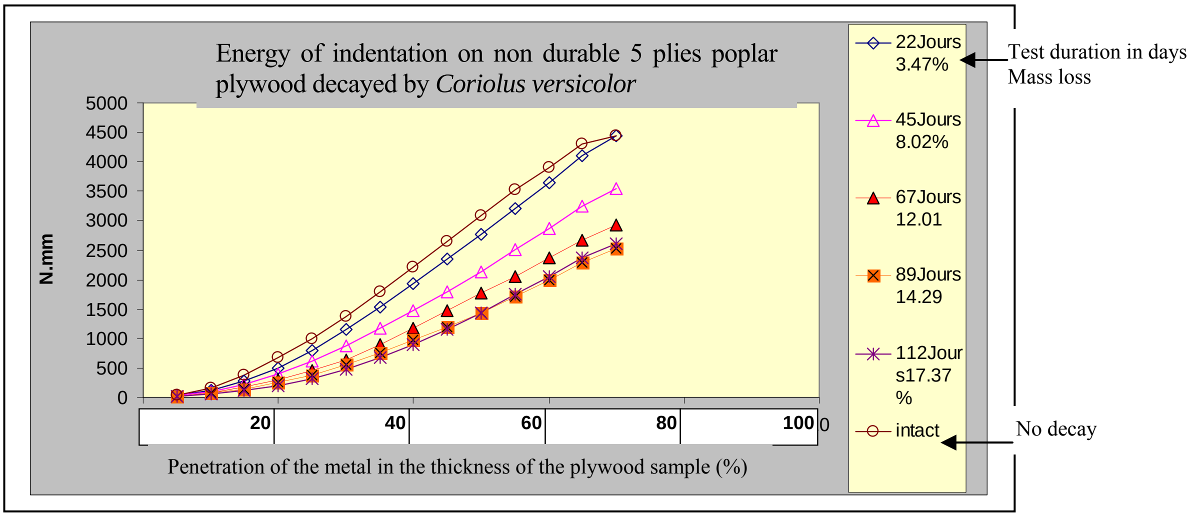

Figure 1. Energy of indentation obtained on poplar plywood decayed by Coriolus versicolor.

In the same manner, indentation tests have been done after fungal exposure to *Coriolus versicolor* (for 16 weeks according to ENV 12038) on experimental plywood. For each case, the mass loss was correlated to the decrease of indentation energy (decrease between non-decayed samples and samples exposed to fungal attack). Figures 2 shows the results obtained for the “pure” durable and non-durable plywood (plywood made of one timber only). These results indicate that this linear correlation is very good, and this for low weight loss as well as for high decay; contrary to ultrasonic measurements, for which decay above 16% could not be linked to a decrease of ultrasonic velocity. Figure 3 shows the same relation established for all the experimental plywood, including the plywood with durable top-veneers. On average, the proportionality between the mass loss and the decrease of indentation energy is 2.5. This indicates that the indentation is a more sensitive test, and that it could be useful to detect the early stages of decay.

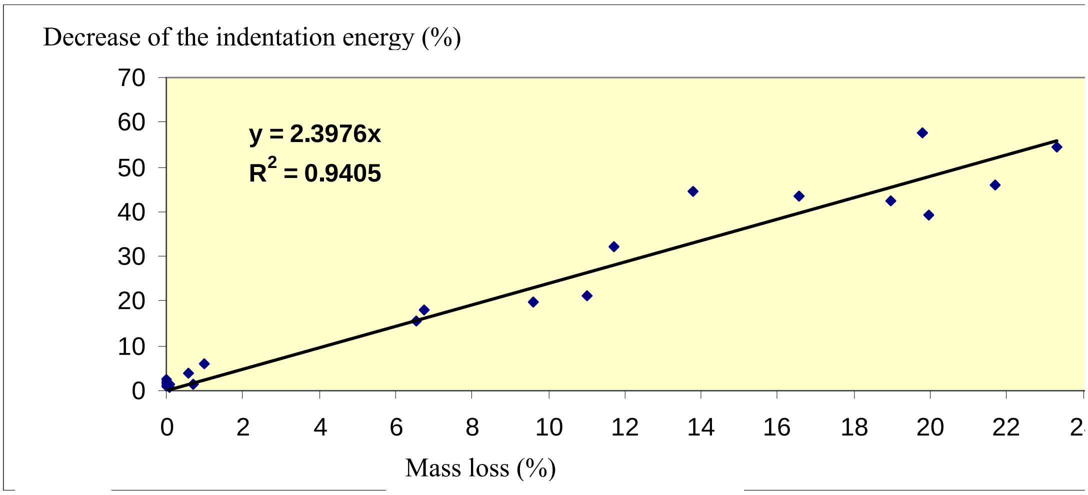

Figure 2. Relation between the decrease of the indentation energy and the mass loss due to fungal decay (20 plywoods tested, 12 samples for each plywood).

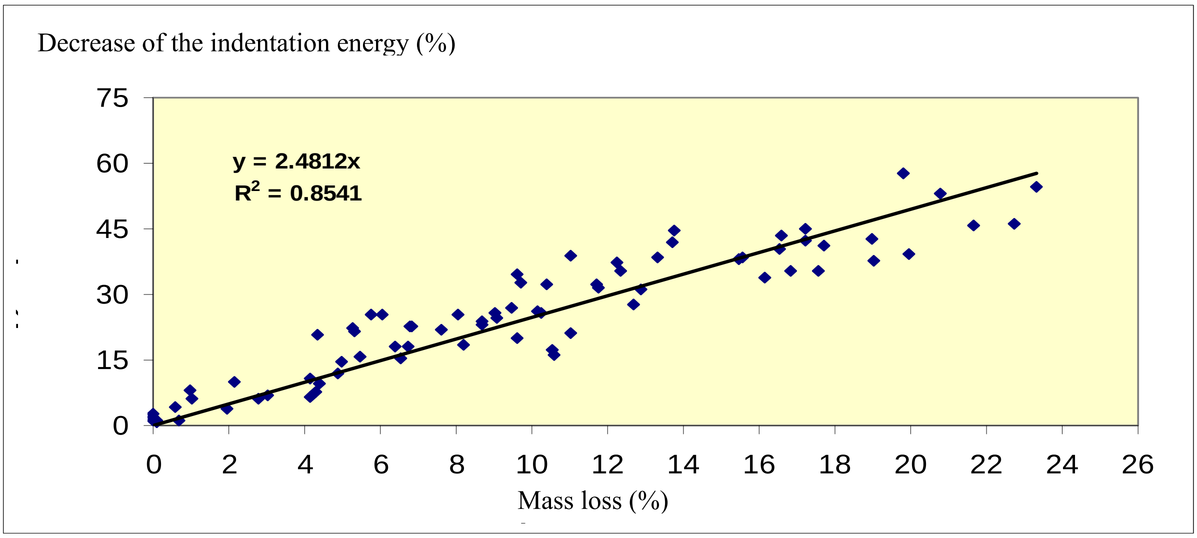

Figure 3. Relation between the decrease of the indentation energy and the mass loss due to fungal decay (96 plywoods tested, 12 samples for each plywood).

From the indentation tests, the behaviour of the experimental plywood with durable top veneers was also drawn. In this case, the energy of indentation is followed during the duration of the test and is related to the thickness of the plywood sample.

Figures 4 and 5 show the results for the "pure" durable and non-durable plywood, and as a comparison, figures 6 and 8 show the results for the plywood with durable exterior plies only (for 1 or 2 durable plies). Two models of plywood are discussed. For the model 1 (figure 6), the average mass loss between all plywood tested was 10% towards *Coriolus versicolor*. The beginning of the curves is the same for the non-exposed and decayed samples, until about 1/4th of the 1st ply width (0.65 mm). It is the elasticity of this ply that explains the slope at the beginning of the test. It has not been modified by the fungal action (as this ply is durable). Once the 1st ply has been pierced, the increasing of the force due to the metal piece rubbing is quite similar for the degraded samples or not. Figure 7 presents the probable displacement of the 1st durable ply, this 1st ply being not supported anymore by the decayed inner plies.

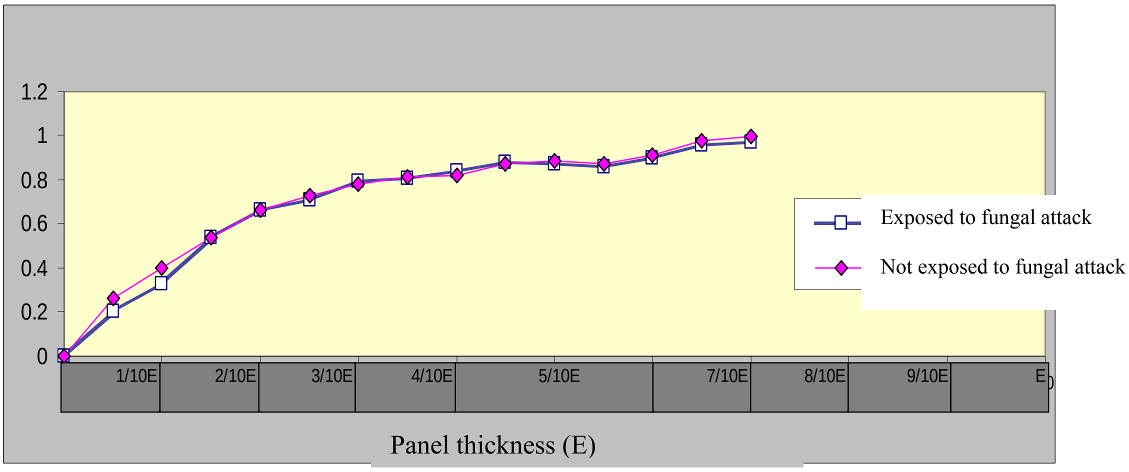

Figure 4. Indentation force for "pure" durable plywoods, made of chestnut, cedar or cypress heartwood.

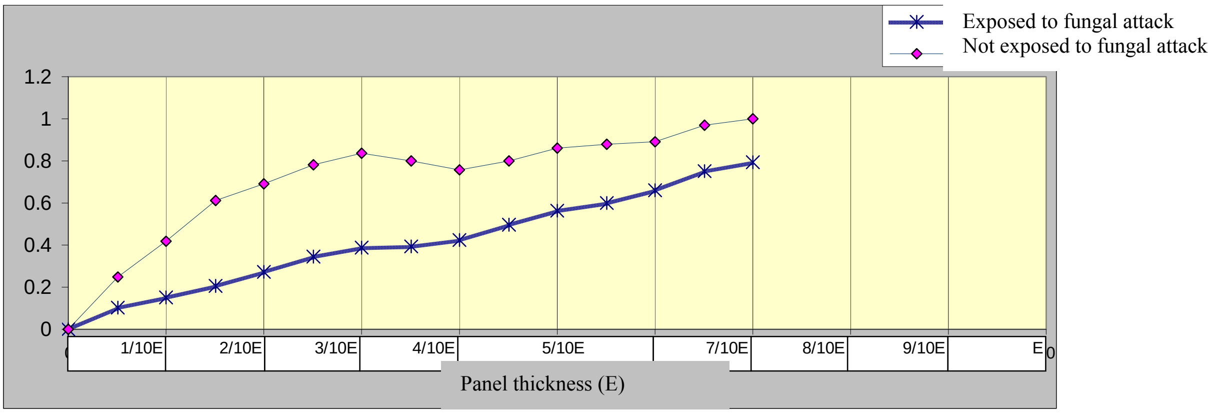

Figure 5. Indentation force for "pure" non durable plywoods, made of poplar or beech.

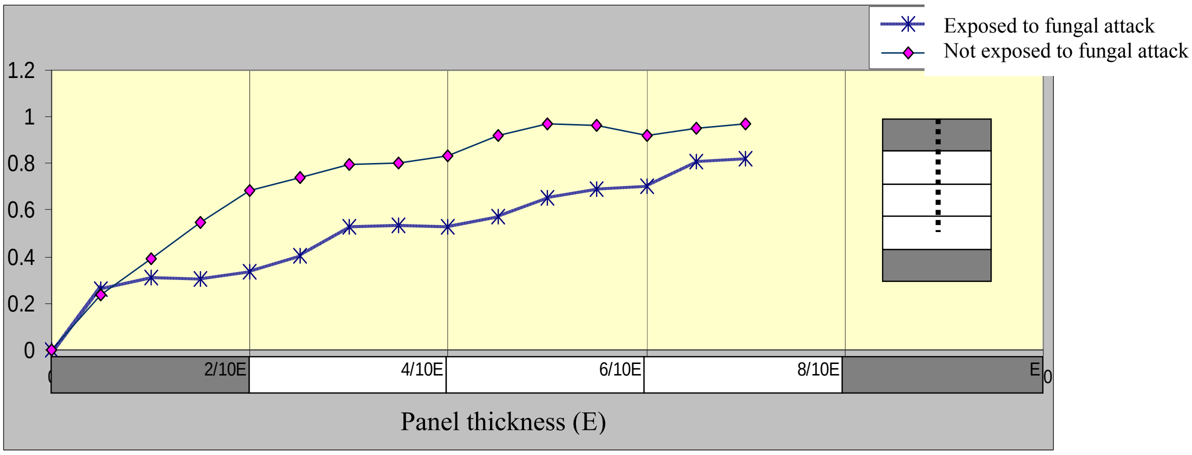

Figure 6. Indentation force for 5 plies plywoods, made of durable top veneers (Model 1)

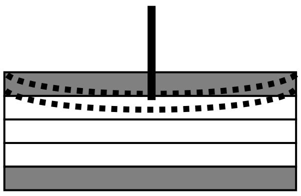

Figure 7. Displacement of the 1st durable ply. Plywood with durable to veneer, Model 1.

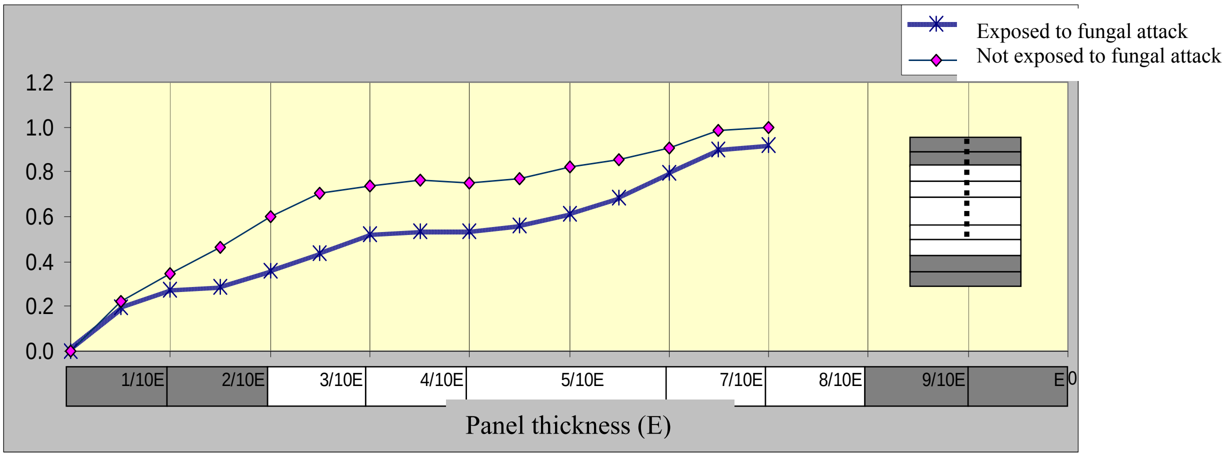

Figure 8. Indentation force for 9 plies plywoods, made of durable top veneers (2 exterior plies on each face) (Model 2)

For the model 2 (figure 8), the average mass loss between all plywood tested was 8.6% against *Coriolus versicolor*. The curves obtained are very similar to those found for the model 1. The difference between the models is the number of plies, and the number of glue lines, thus increasing the resistance towards the fungus.

As the indentation test is extremely little destructive, shearing test was performed afterwards on the same samples. Initial shearing resistance was determined from spare samples of each plywood type. The relation between the decrease of shearing resistance (before and after fungal attack) and mass loss, obtained for all experimental plywood types, is presented in Figure 9.
The mass loss of the plywood is well correlated to the decrease of shearing resistance. On average, this mechanical test is 3.5 times more sensitive than the mass loss measurement. The shearing test is the most pertinent test (used in this study) to evaluate the loss of mechanical integrity of the plywood samples.

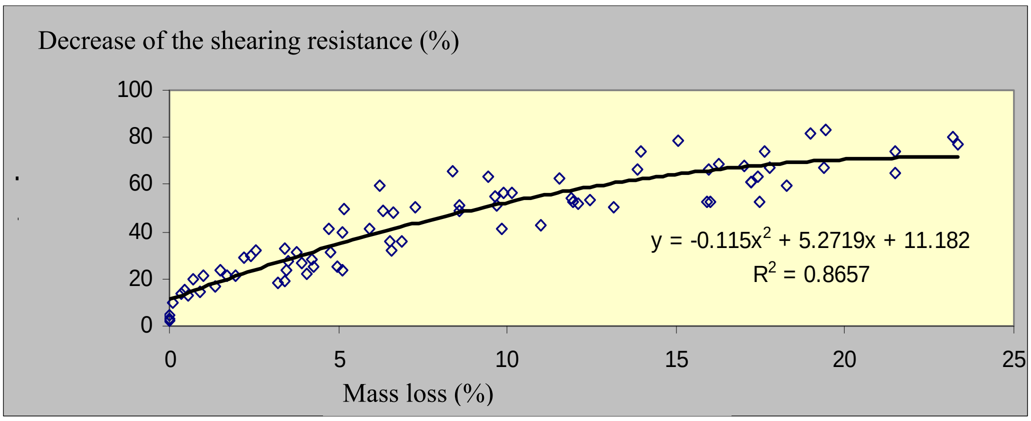

Figure 9. Relation between the decrease of the shearing resistance and the mass loss due to fungal decay (96 plywoods tested, 12 samples for each plywood).

Nevertheless, when compared to the indentation test, it can be underlined that:
- the relation shearing resistance-mass loss is not linear ;

- when the mass loss of the non durable plies is above 20%, the mechanical resistance becomes too weak and no differences are noticed ;
- this test is very heavy to perform and time consuming ;
- it is a totally destructive test.

From these results, the indentation tests can be considered as quite easy to perform, as well as accurate enough to allow decay detection, even in the early stages of decay.
It also as to be underlined, that the mix between the durable and non-durable plies always increased the resistance of the plywood.
Amongst the different experimental plywood types, those made of exterior plies of cypress heartwood performed well and were chosen as optimized plywood for further tests.

Optimized plywood was produced. Poplar and cypress trees were cut down. Veneers (13-15 mm thickness) were cut and dried.
Plywood was made as follows :

- 5 plies, pure cypress heartwood ;
- 5 plies, cypress heartwood for the exterior plies, poplar for the 3 interior plies,
- the glue used was MUF glue (Cascomin MUF 1242, hardener D2542), at 120 g/cm^2 (wet weight);
- the plywood (50 cm x 50 cm x thickness) was pressed at 12 kg/cm^2 at 30°C for 2 hours.

Both plywood types were sent to partner 1 for distribution.

The plywood sent by partner 6 was conditioned at 20°C and 65% RH. Because of the size and geometry of the samples, ultrasonic measurements could not be done.
Indentation tests were performed before outdoor exposure. So far, no decay has been observed on the samples.

Significant difficulties or delays experienced during the third reporting period
The conditioning room, in which the samples from the industrial plywood types rest, has again been subject to climatic disorders. The culture room in which the fungal tests should have been conducted had permanent failures. All climatic disorders have been registered in the quality insurance system of the laboratory.
The culture room had to be totally renovated and the biological tests could not be done from February until December 2005. This has induced an important delay in testing the plywood from industry (WP2).
M-F Thévenon was away from the laboratory for more than 5 months (maternity leave) and her position stayed vacant during this period. This absence led to difficulties in the realisation of the project in time.

Sub-contracted work during the third reporting period
No sub-contractor for partner 3.

Research activities during the <u>fourth</u> reporting period
The plywood from industry have been tested according to the ENV12038. The test was repeated four times and stopped at 2, 4, 8 and 16 weeks.
The samples were then conditioned again, and used for ultra-sonic measurements and indentation tests. The ultrasonic measurements and indentation on 10 types of panels were performed in 2007-2008 allowing to draw correlations and conclusions.

The optimized plywood sent by Partner 1 has been put in outdoor exposure in French Guyana (November 2006). Evaluation of the degradation will be carried out in the period 2007-2008.

The plywood sent by Partner 6 are still outdoors and degradation has been evaluated. They will stay in place one more year before doing the mechanical tests (indentation).

Significant difficulties or delays experienced during the fourth reporting period
M-F Thévenon was away from the laboratory for more than 5 months (maternity leave) and her position stayed vacant during this period. This absence led to difficulties in the realisation of the project.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 3.

Partner 4

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Objectives

BFH is involved in the Workpackages 2, 3 and 6 and its main objectives are

- to develop suitable field test methods for the determination of the durability of plywood in hazard class 3 which are suitable for panels of different thickness. (Workpackage 3)
- to modify the field test procedures for plywood in order to simulate harsh or mild use conditions concerning the newly established sub-class “covered exterior” of the biological hazard class 3 defined by EN 335 - 3. (Workpackage 3)
- to correlate changes in plywood properties caused by the natural weathering (like changes in moisture uptake and bending strength) with the visual and manual assessment concerning the duration of the outdoor exposure and its condition. (Workpackage 3)
- to interrelate the performance of panels determined in laboratory testing (Workpackage 2) and with those determined in field testing (Workpackage 3) in order to estimate realistic durability of plywood and to predict service life (Workpackage 6).
- an improvement of the test and the evaluation procedure of ENV 12038 to undeceive the discrepancy between the results of this test and the prediction of durability according to ENV 1099. (Workpackage 2, 3 and 6)

Workplan

The lap-joint technology according to ENV 12037 will be transferred to wood panel products with some adaptations, especially with regard to smaller plywood thickness. A covered test set up will be developed for investigation of plywood performance under outdoor conditions with only limited impact of liquid water. Since good performance of several plywood types in exterior conditions is reported, additionally an accelerated outdoor testing needs to be included e.g. with a shaded set-up.

At selected plywood products the moisture content will be monitored during the outdoor exposure to describe the influence of natural weathering on the moisture uptake. In parallel changes in structure of weathered specimens will be surveyed and changes in moisture uptake behaviour will be investigated in detail under defined laboratory conditions.

The evaluation of the field tests is based on a visual assessment which is supplemented by a manual pick test. At selected panel products the strength of weathered specimens will be monitored by using mechanical strength tests additionally.
For comparison the panels exposed to natural weathering will be tested according to ENV 12038 and some solid timber (specimens of poplar and Scots pine) will be tested in the same way as the plywood.
Results from the different field tests executed at several exposure sites will be used to improve knowledge of the relation between results from laboratory testing according to ENV 12038 and the biological performance in practice.

Deliverables

D10. Test protocol for modified ENV12037, month 24.

D12. Relationship established between the loss of mass of inoculated samples (lab-test) and their performance in field test concerning the pre-conditioning applied: 12 weeks ventilated room,6 month natural weathering, month 36.

D13. Proper information on plywood characteristics for different external uses derived from field and laboratory tests, month 36.

D16. Difference between covered and non covered exposure, month 36.

D21. Definition of critical plywood characters influencing service life of plywood derived from field testing, month 42.

The following critical plywood characteristics influencing service life were identified by partner 4:

Water uptake
Durability
Quality of coating
Quality of edge sealing

D23. Evaluation criteria using methodology based on laboratory testing, month 48.

D24. Full definition of degree of exposure in relation to specific applications, month 48.

- comparison of results from WP 2 and 3
- evaluation criteria for lab testing and field testing for hazard class 3

Research activities during the <u>first</u> reporting period

Suitable field tests for determination of durability of plywood in use class 3 and supplementary laboratory tests as well as methods for investigations in changes of moisture content, moisture uptake, bending strength and structure have been evaluated, developed and prepared.

<u>Field Tests</u>

Different exposure scenarios have been developed resp. modified and prepared. They are named as Lap-Joint technology according to ENV 12037, as Vertically Hanging setup (sealed / non sealed) for simulation of a moderate humidity regime and as Horizontal Double Layer setup (sealed / non sealed) for simulation of harsh humidity regime. Referring to the number of samples and different tests, to which the panels will be exposed, they are divided into three categories – the so called “Full Range”, “Half Range” and “Low Range” test programs

Lap-joint technology
The lap-joint technology has been modified. Instead of working with a panel thickness of 38 mm, each sample will be exposed in the original thickness of the panels. The corresponding solid wood of the same species as well as sapwood of *Pinus sylvestris* will be included in same dimensions and same number of samples (10 replicates each). Vacuum-pressure impregnated racks according to ENV 12037 have been prepared.

Vertically Hanging setup
As further exposure system simulating moderate humidity regime the Vertically Hanging set up (Augusta and Rapp 2003) has been modified. As sample size the so called "stake" (50 mm x 500 mm [in grain direction] x panel thickness) has been adapted from EN 252 (Deviation: the thickness refers to the panel thickness). Racks have been designed in durable materials: Wooden parts have been vacuum-pressure impregnated, fitting parts are made of stainless steel. All racks and most of the samples (all half range set ups) have been prepared.

Horizontal Double Layer setup
For simulating harsh humidity regime the Double Layer test (Rapp *et al.* 2001) (also using the "stake") has been selected. Some modifications of the Double Layer test have been applied in order to minimize microclimatic differences underneath the rack: Instead supporting beams, a vacuum-pressure impregnated wooden surrounding frame laying on concrete blocks has been developed.

Outdoor testing covered
The roof cornice system has been rejected. Results of further tests in similar setups have lead to the assumption, that fungal attack is not expected in between the testing period of 5 years. A covered set up will be tested in the way, that the samples in the two new exposure systems explained above, will be additionally tested with an edge sealing. As material for the edge sealing a MS Polymer (Terostat 9302, Teroson) based material has been selected after preliminary tests (2 weeks artificial weathering). All racks and most of the samples (all half range set ups) have been prepared.

All plywood panels prepared for the half range test program have been stored in a conditioning chamber. Some additional material for the full range test program as well as corresponding solid wood have been ordered from several project partners resp. from local traders.

<u>Additional test conditions:</u>
Shaded setup
Shaded set up has been rejected. It was expected to be too harsh (drying rate of shaded samples will be to low).

Monitoring of moisture content
Several systems for monitoring moisture content have been discussed. The problems expected for electronical or conductivity measurements have lead to the decision for gravimetrical determination of the moisture content.

Survey of changes in structure
Several possibilities to survey changes in structure have been tested with wood based panel products (macroscopic studies, microscopic studies, UMSP). In preliminary

tests, methods for cutting and embedding of deteriorated samples (embedding materials, sample size, cutting direction) as well as methods of coloration have been optimized. Embedding with PEG and coloration with Picro Aniline Blue seems to be most effective. Colonization pattern as well decay pattern of several fungi in wood based composites have been studied. Differences between fungi have been obvious.
Different methods for documentation of microscopic work have been tested (application of computer based software vs. classical analogue microscopic photography.

Changes in moisture uptake
For the investigation of changes in the moisture uptake under laboratory conditions, it has been planned to divide the samples dealing as controls for calibration (see monitoring of moisture content) into smaller ones, which will exposed to 3 different climatic situations (storage in water, oven drying, storage at 20°C/65 r.h.).

Evaluation of the field tests
Methods of assessment as well as different schemes for visual assessment have been studied. In order to get more experienced with the visual assessment and the handling of the manual pick test, several assessments of Lap-joints have been accompanied.

Monitoring of strength of weathered specimens
For monitoring the strength of weathered specimens a 3-point-bending-test has been selected and modified: All stakes from the field test will be bended up to 50 - 60% of the maximum bending load.

Laboratory test according to ENV 12038
The laboratory test according to ENV 12038 is planned in detail and will allow a comparison of laboratory results and the effects of natural weathering. Specimens have been prepared and been stored in conditioning chamber.

Preliminary edge-sealing-test
In a preliminary test 6 different types of edge sealings have been investigated. After application of the edge sealing on blocks (Spruce) of 40 mm x 40 mm x 20 mm (axial) in 4 replicates, all samples have been artificial weathered for 2 weeks (= simulating two annual weather periods). The surfaces of the sealings have been assessed visually and the adhesion has been tested manually. Terostat 9302, Teroson has been selected as edge sealing for the field tests.

<u>Demonstration work / Documentation / further activities</u>
Literature belonging to the thematical complex plywood and durability and its determinating parameters has been studied and evaluated.
The presentation of the planned activities for the 2nd project meeting has been prepared (available on the Plybiotest Homepage) and presented in Sabbioneta, Italy at October 9th and 10th. Papers and documents published by members of the working group Wood Biodeterioration have been placed resp. listed at Plybiotest homepage.

Significant difficulties or delays experienced during the first reporting period
Delays:
Delivery of panels in January 2004.
Delivery of further panels in June 2004.

Delivery of solid wood and veneers in April 2004.

Sub-contracted work during the first reporting period
No sub-contractor for partner 4.

Research activities during the second reporting period
The first part of the comparative 12038 Laboratory test (12 weeks conditioning) was finished and the results were analysed. The second part of the ENV 12038 Laboratory test is running. 6 months natural weathering will be finished in February, followed by 4 weeks conditioning in order to adjust equilibrium moisture content before incubation.

Field Tests
All samples were prepared, conditioned and installed in the different test set ups representing the named humidity scenarios as planned. Additional racks were placed in Finland and France for the estimation of effects due to climatic differences. Further panel types as well as solid wood of Birch, Spruce sapwood, Maritime pine sapwood and Scots pine heartwood were included additionally. Preliminary investigation for the survey of structure was taken out.
Moisture monitoring is running, initial bending strength was determined

Demonstration work / Documentation / further activities:
Presentation for the Technical meeting in Montpellier, France at 15th of September 2004 as well as for the 3rd project meeting in Hamburg, Germany at November 4 to 5th 2004 were prepared (available on the Plybiotest Homepage) and presented.

A draft of deliverable D10 was included in the Technical report.

Significant difficulties or delays experienced during the second reporting period
ENV 12038 durability laboratory test as well as field test delayed due to late delivery of several test material and intensive preparation of the samples (see delays in first reporting period).

Sub-contracted work during the second reporting period
No sub-contractor for partner 4.

Research activities during the third reporting period
WP 2: Most panel types showed high mass losses in the lab test according to ENV 12038. Effects of 6 months natural weathering in comparison to 12 weeks pre-conditioning were visible but mostly had no significant effects on the assessment of the durability according to ENV 12038. However, natural weathering induces higher mass losses in some PF-glued panels through *Coniophora puteana* and *Coriolus versicolor*. The application of edge sealing reduced mass loss in the lab test significantly.

WP 3: The first assessment of the field tests indicated any fungal attack after 6 months. Appearing staining and UV-degradation are intensive. Although most panel types were placed in the worst category according to the ENV 12037 grading system for staining, slight differences between the sample set ups were visible. Heaviest staining occurred in the set up that caused highest moisture contents (double layer). Regarding the surfaces the second assessment after 12 months the effects were similar but more intensive.

None of the samples in the hanging set up were attacked by Basidiomycetes while in the Lap joint set up several Scots Pine samples showed signs of beginning decay. The double layer set up induced fungal attack in timber specimens of Birch, Scots Pine and Spruce. The bending test and microscopic investigations indicated that also Poplar plywood was decayed. The moisture monitoring and the field test assessments clarify a close relationship between fungal attack and the construction of the sample setups inducing different humidity regimes in use class 3. In a second bending test series initiated 2004 with reference material (Spruce Plywood) bending strength and the MOE was determined in order to identify the influence of exposure time, water storage and natural weathering.

Results from WP 2 and WP 3 were interrelated. So more and less applicable panels for exterior could be identified. Regarding lab test and field test results any significant discrepancies occurred. Mass loss in the lab tests and the field test assessment indicate a better performance for those panels made of durable wood species in comparison the non-durable ones.

The panels produced in the BFH laboratory containing wood preservatives (glue line additives) were exposed in the double layer set up without edge sealing in March 2005. Their initial bending strength after 10 days water storage was determined. .

Optimised panels delivered in 2005 were prepared for exposure field test (in Hanging Set up with edge sealing and the double layer set up without edge sealing). Conditioning at 20°C/65%RH started in December 2005.

Significant difficulties or delays experienced during the third reporting period
No significant difficulties or delays were experienced.

Sub-contracted work during the third reporting period
No sub-contractor for partner 4.

Research activities during the <u>fourth</u> reporting period
WP 2:
Moisture uptake
Regarding the moisture uptake in correlation to the different types of sample preparation, all panel types showed the same tendencies:
The moisture uptake in samples with *sealed edge*s was lowest, followed by the ones with a *hole in the edge sealing* and the samples with *edges sealed and hole drilled through pa*nel. Highest moisture was found as expected in the *controls without edge sealing*.

Influence of glue, number of plies, wood species and layout of the veneer sheets
Focussing on the glue indicates that PF glued panels show higher moisture uptake compared to MUF-glued ones. The influence of the number of plies was indifferent. Samples with parallel glued layers show faster moisture uptake than those glued crosswise. Wood species influence is obviously and overruled former ones.

Visualization of moisture uptake
a) Sound samples prepared in different ways

The x-Ray examination showed that the method is roughly able to visualize the way water flows through a panel. Especially the edge sealed panels with a hole through the panel illustrate the water following the tracheids (crosswise due to crosswise layers). Effects of a hole in the edge seal were also visible as well as darkened edges in case of no edge sealing.

b) Identification of fungal attack via x-ray
For identification of fungal attack, sound references were scanned. They were needed for calibration. The trials showed, that differences between sound and decayed wood are visible through different grades of grey scales that relates roughly to the water uptake. Further research is needed to evaluate the possibilities of quantification. It has to be found out, at which (early) state of decay, the system is able to detect fungal attack. Further tests with a higher resolution module may lead to more reliable information.

WP3:
Visual assessment
In the third assessment in February 2006 no decay occurred in the *Hanging single set up* – nor edge – sealed samples neither non sealed ones.

Table: Assessment of decay after 1,5 years (February 2006)

Code		thickn. [mm]	Material	Visual assessment + Bending test (min **Median** max)				
				Hanging sealed	Hanging non sealed	Lap joint	Double Layer sealed	Double layer non
01	P1	15	Poplar	0 **0** 0		0 **0** 0		0 **3** 4
02	C1	15	Poplar	0 **0** 0		0 **0,5** 1		1 **2,5** 4
03	C2	20	Poplar	0 **0** 0		3 **3** 3		1 **1** 4
04	F1	15	Spruce	0 **0** 0	0 **0** 0	0 **0,5** 1	0 **0** 0	0 **0** 1
05	K1	15	Birch	0 **0** 0	0 **0** 0	0 **0** 1	0 **0** 4	0 **0** 0
06	S5	15	Birch coated (Melamine)	0 **0** 0		1 **1** 1		0 **0** 0
07	R1	15	Maritime Pine	0 **0** 0		0 **0** 1		0 **0** 0
08	F2	27	Spruce LVL	0 **0** 0		0 **1** 1		0 **0** 0
09	K3	15	Birch coated (Phen.)	0 **0** 0		0 **0** 0		0 **0** 0
10	P3	18	Okoumé / Poplar	0 **0** 0		2 **3** 3		0 **1** 4
11	A4	15	Moabi / Poplar	0 **0** 0		0 **1** 2		0 **0** 0
12	A5	15	Moabi	0 **0** 0		0 **0** 1		0 **0** 4
13	A6	15	Sapelli	0 **0** 0		0 **0** 1		0 **0** 0
20	Timber	15	Scots Pine heartw.	0 **0** 0		0 **0** 1		0 **0** 1
33	Timber	15	Spruce	0 **0** 0	0 **0** 0	0 **1** 2	0 **1** 4	0 **0** 2
35	Timber	15	Maritime Pine	0 **0** 0		0 **0** 0		
36	Timber	15	Birch	0 **0** 0	0 **0** 0	0 **0** 1	0 **0** 4	0 **0** 1
40	Timber	15	Scots P. Sapw.	0 **0** 0	0 **0** 0	0 **1** 1	0 **0** 1	0 **0** 1
42	Timber	20	Scots P. Sapw.	0 **0** 0		0 **1** 1		0 **0** 1
43	Timber	43	Scots P. Sapw.	0 **0** 0		1 **1,5** 2		

In the *Lap joint set up* several panel types were affected by starting decay (see table below). Two Poplar panel types (C2 and P3) showed intensive decay, while coated

Birch (K3) was not decayed. Regarding the timbers testes, decay started in all species except Maritime Pine (Maritime Pine was not exposed in the Double Layer Set up).

Figure: Lap joint samples after 1.5 years exposure (intensive decay in Poplar plywood C2; any decay in coated birch K3)

Discolouration was intensive on all external surfaces except the coated panel types. In the joint area all panel types except A5 and A6 were discoloured.

In the Double Layer set up the number of samples failing in the bending test supplementing the visual assessment increased. Particularly poplar panel types were decayed intensively.
Discolouration was intensive except the coated panels and Sapelli plywood A6.
Scots Pine sapwood timber samples were less affected in the Double Layer set up than in the Lap joint set up. Several panel types (S5, R1, F2, K3, A4, A6) were not decayed after 1,5 years in the Double Layer.

Mechanical strength (Bending tests)
Tests on the influences of the parameters exposure duration, water storage and natural weathering mechanical strength were completed. The results indicate, that

4. The bending strength decreases over time (samples stored in 20°C / 65% r.h.) over time.
5. 10 days water storage before the bending test procedure reduces strength values roughly to the half.
6. The effect of water storage seems to overlay the effect of time and natural weathering. In the bending test supplementing the decay assessment 1 of 11 samples of the same panel type failed.

When using mechanical bending tests in addition to visual assessment, a storage in climate chamber may be considered instead of water storage although this procedure would be very time consuming.

Moisture monitoring
Tendencies described in detail in working year 3 regarding the differences between the set ups, the influence of coating, top veneer and edge sealing were confirmed. The below Table shows the results of moisture monitoring at the fourth assessment in August 2006.

Table: Moisture content of all samples in August 2005						
Code	Material	Lap joint	Hanging sealed	Hanging non sealed	Double layer sealed	Double layer non sealed
P1	Poplar	33,4	12,6	-	-	121,6
C1	Poplar	31,0	13,1	-	-	131,3
C2	Poplar	21,3	12,9	-	-	118,0
F1	Spruce	58,7	16,3	15,9	36,9	107,9
K1	Birch	21,5	18,1	15,6	22,7	57,8
S5	Birch coated	22,5	15,0	-	-	73,3
R1	Maritime P.	35,1	15,8	-	-	87,5
F2	Spruce LVL	32,0	15,9	-	-	87,1
P3	Okoumé / Poplar	22,1	12,6	-	-	130,3
	Scots P. heartw	16,9	15,2	-	-	25,4
	Spruce	51,3	18,5	17,7	32,1	57,4
	Birch	34,9	18,3	17,1	20,3	47,5
	Scots P. Sapw.	58,9	17,6	16,6	44,1	78,8
	Scots P. Sapw.	48,1	17,8	-	-	101,9
	Scots P. Sapw.	46,5	18,8	-	-	93,1

Test Set ups

Resuming moisture monitoring, setting moisture content of all samples in correlation, taking water uptake after 10 days water storage into account proves the impact of the different exposure set ups. As planned the hanging set up fits well for inducing moderate humidity while the double layer test leads to very high moisture contents. The Lap Joint Set up show intermediate values regarding moisture content and appearance of decay.

The different exposure conditions induce different levels of moisture content and hence only those exposure set ups with sufficient moisture can be assessed through lab fungal tests. Differences in moisture content for a specific exposure situation may be used to select suitable plywoods.

Exposure of optimised panels

Optimised panels provided by the industrial partners were exposed in the hanging set up and the double layer set up and assessed after 6 months.

Assessment of optimised panels after 6 months of exposure:

Regarding Single hanging with edge sealing no decay occurred at all. Focussing on discolouring, coated panels were in very good condition (P9 , R5 see figures below) and selected non-coated panels showed low staining while all others were discoloured heavily (Rating: 3 acc. to ENV 12037)

Figure: Oak plywood P 9

Figure : Maritime plywood R5

Comparable to the hanging set up, the discoloration of the non-coated panel types P9 (oak plywood) and R5 (Maritime Pine plywood with wood preservative) was very low. All other non-coated panels were rated 3 acc. the rating scheme of ENV 12037: moulds occurred in Poplar uncoated P12 and mycelium detected on the edges of Beech/Poplar C4

Figure: P6, Double layer set-up without edge sealing (opened):First decay in Poplar uncoated P6, Tannin glued left: lower side right: upper side

Figure: P12 , Poplar uncoated, MUF, P12: Moulds inside of double layer

Figure: Beech/Poplar, C4 Mycelium on edges

WP6:
Results from laboratory tests (WP 2), moisture monitoring and outdoor tests (WP 3) were used for correlation statistics in order to identify the optimum methodology for the simulation of use conditions.
The scenarios tested lead to different degrees of decay rating after two years. However roughly the same tendencies were visible regarding a "ranking" of the assessment results.
Single hanging were hardly affected by the exposure, no impact of sealant was detected. Little or no difference between specimens with regard to biological degradation: no staining, no discoloration, no decay.
Double layer test leads to results differing mainly with regard to panel type. Moisture accumulates over time and induces decay faster than the other test set ups.

As lab tests according to ENV 12038 and the Double Layer set up result into similar decay results**,** the Double Layer set up seems to be the best option for testing in a realistic, fast and simple way the worst case end use options. If specimens would be placed a bit higher above ground (i.e. like for the lap joint set up) this could reveal relationship to more practical end uses.
Regarding the situation under roof, the hanging set up is obviously the better choice for testing as realistic as possible. Both methods lead to very different results focusing on decay.
Priorities regarding the ranking of the different criteria assessed were set as follows:

1st priority: Results of outdoor testing (decay) > decay, discouloration, deformation, delamination
2nd priority: Results of lab tests

Significant difficulties or delays experienced during the fourth reporting period
No significant difficulties or delays were experienced.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 4.

Partner 5

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Contractual links to other participants

Partner 5 is a principal partner and main partner in the WP 4. Partner 5 has associated partners 9, 10 and 11, especially in the WP's 1 and 4, but also in WP's, 5 and 6.

Objectives:

- To act as a main partner in the WP 4.
- To develop and perform relevant test methods to measure durability of coated and edge sealed plywood against weathering and biodeterioration.
- To define the performance of the coated birch and spruce plywood in hazard class 3 using different modified methods (weathering and biological tests).
- To participate in the WP 1 with other partners for developing coated plywood products
- To participate in the WP 5 for analyse the condition of structure made from coated Finnish plywood and compare the results with test results from WP 4.
- Co-operate with other partners and with an associated industrial partner on the results obtained from the tests and surveys to realise optimised plywood with better performance for exterior use in WP 6.

Workplan

WP 1

In Finland phenol film coated birch and spruce plywood has been produced for a longer time. Also, a new type of coated plywood systems has been and will continue to be developed. Different type of coated spruce and birch plywood will be manufactured in WP 1 by industrial associated partners. The coatings will be e.g. phenol films, painted craft liners with polyurethane or acrylate paints, primers and topcoats. The effect of edge-sealings will be tested with two type of coated plywood using three different edge-sealing types. The related product LVL (Laminated Veneer Lumber) will also be included as a comparison material.

WP 4

4.1 Impact of coatings on laboratory and field testing results

The performance of the coated and edge-sealed plywood samples will be tested using different modified test systems in the laboratory and outdoors.

Coated panels produced in WP1 will be cut to specimens. The plywood specimens will be exposed to weathering in outside exposure conditions according to modified standard EN927-3 and using a new method, which involves mechanical loading during the exposure. Water permeability of different coating systems will be measured before and after weathering.

Different type of sample conditions will be monitored:
- sound and injured surfaces,
- treated and untreated follow-through in the samples
- mechanical stress combined with weathering.

The effect of natural weathering and the biological attack are assessed by visual inspections (every 6 months). Additionally a part of the samples are taken in to the laboratory for non-destructive tests for by partner 3 and for accelerated weathering tests and biological tests for partner 5 and for WP 2 and 3. The moisture content on samples will be monitored. Solid wood of the corresponding wood species and uncoated birch and spruce plywood will be used for comparison. Two coated panel types will be submitted to the tests in WP 2 and 3.

In order to accelerate outdoor exposure samples will be aged in laboratory using combination of water immersion and UV-ageing (modified prEN927-6). Multiple laboratory biological decay tests (EN 12038, EN 927) including mould testing will be carried out after ageing procedures. Also strength properties will be measured. The results from decay and weathering tests are compared to results from service. Final conclusions of expected service life predictions will be moved to WP 6.

4.2 Impact of durable top veneers

Timber species known for their important natural durability and their dimensional stability will be chosen in order to produce durable top veneers for plywood. The ability of wood to be glued, its machinability, as well as its supply will be taken into consideration in other WPs. A restricted choice of timber will be used to produce plywood with durable top veneer. This plywood will then be tested for their durability as in WP 2 task 2.1 and 2.2. A part of this plywood types are used as non-coated and tested as reference in WP 4.

4.3 Impact of edge-sealing

A range of edge-sealing systems will be tested in order to predict the importance of moisture penetration for two coated plywood types. Partner 1 will interrelate these results with the findings of task 3.3 on moisture controlled field exposure. In the durability tests, three different edge-sealing types are included. Water permeability of different coating systems and edge-sealings will be performed prior and after weathering and biological tests.

WP 5

5.2 Survey on exterior performance of plywood

The condition of 5 different coated plywood structures in Finland will be detected and analysed. The samples from these plywood structures will be released and transported to the laboratory, where the conditions will be studied using mechanical and microscopical technology. The results will be compared to the results from WP 4. The survey will be performed in co-operation with associated partner 9

WP 6

6.1 Methodology for testing out of ground contact, exterior usage of plywood

Partner 5 will participate to the evaluation and comparison of results from the WP 2, 3 and 4 concerning the effect of coating and edge sealing on the durability of plywood tested using different test methods. Also performance of coated plywood in relation to service classes and exposure conditions will be monitored.

6.2 Quality requirements related to exposure and service life

Test results from WP4 will be compared to outdoor survey data of coated plywood. Quality requirements of coatings and edge-sealings on spruce and birch plywood will be defined in relation to specific applications and end use targets.

6.3 Fit for purpose concept and quality marking of plywood

Based on expected service life and specific hazard identified for well defined purposes a quality labelling will be established using a fit for purpose concept of coated plywoods in co-operation with associated partners 9 - 11.

Deliverables

D1. Coated and uncoated birch and spruce plywood samples for other WPs, month 6,
D2. Preliminary test protocol to test coated plywood under laboratory conditions, month 12,
D3. Results from the accelerated laboratory weathering tests, month 12,
D5. Technical quality of different coating systems, month 18
D6. Core data of different coating systems prior to assessments, month 18
D11. A proposal for a new accelerated test method for coated exterior plywood, month 24
D17. Results on coated plywood from the exterior weathering site, month 36
D18. Final results from the laboratory tests and from the mixed tests, month 36
D19. Survey results on service-life of coated plywood in Finland, month 36.
D20. Estimation of time to failure for specific applications, month 36.
D21. Critical plywood characters influencing service life of coated plywood, month 42.
D22. Specifications for critical characteristics for exterior plywood, month 48.
D23. Evaluation criteria using methodology based on laboratory testing, month 48.
D24. Full definition of degree of exposure in relation to specific applications, month 48.
- comparison of results from WP 2, 3, 4 and 5
- evaluation criteria for lab testing and field testing for hazard class 3
- definition of degree of exposure in relation to applications
- requirements in relation to service life

Research activities during the first reporting period

WP 1

1.2. Production of coated plywood

Production of uncoated and coated spruce and birch plywood and edge sealing systems. Different type of coated spruce and birch plywood will be manufactured in WP 1 by industrial associated partners. The coatings will be e.g. phenol films, painted craft liners with polyurethane or acrylate paints, primers and topcoats. The effect of edge sealing will be tested with two type of coated plywood using three different edge sealing types.

The test material has been planned in co-operation with partners 9, 10 and 11. All materials have been delivered by partners 9 - 11.

Several different types of coated spruce and birch plywood have been produced by partners 9, 10 and 11. Edge-sealing to be used in outdoor weathering has been delivered by partner 5 to other partners.

WP 4

4.1 Impact of coatings on laboratory and field testing results

The goal of this work package is to define the performance of the coated birch and spruce plywood in hazard class 3 using different modified methods. The effect of coating types on the performance of plywood will be tested using accelerated weathering test methods developed for coated wood and the performance will also be tested using biological tests prior and after the weathering. Expected achievements are: a) new test method for coated plywood for the use class 3, b) new knowledge on the durability of coated plywood and factors affecting the durability, c) impact of coating on the durability of plywood against weathering, mould and decay to be used for the manufacturing and use of plywood.

Preliminary laboratory tests

The testing conditions of different coated plywood were first tuned and tested using preliminary laboratory tests (Stage 1). Test methods used for stage 1 were artificial weathering using QUV system and Floating - Freezing - Drying cycles (FFD). In the preliminary test, birch plywood from Finnish plywood industry was used. The materials were as following:

Birch plywood (15 mm, 9 ply), coated with phenol film (120 / 60 g)
Birch plywood (15 mm, 9 ply), coated with paint base film and water based paint (latex)
Birch plywood (15 mm, 9 ply), coated with opaque stain
Birch plywood (15 mm, 9 ply), not coated
Spruce plywood (15 mm, 9 ply), not coated (only in the FFD cycles)

The sample size was 75 x 140 mm for QUV and FFD cycles. The samples were edge sealed using edge paint TEKNOS JRM. In QUV cycles, samples with sound and injures coating were used. In FFD cycle, samples with sound and injured coating and samples having holes were used (Figure 2).

In the second stage, more material from WP 1 will be used. Coated panels produced in WP1 will be cut to specimens. Different type of sample conditions will be monitored (only for limited samples):

- sound and injured surfaces,
- treated and untreated follow-through in the samples
- mechanical stress combined with weathering.

The effect of natural weathering and the biological attack will be assessed by visual inspections (every 6 months). Also solid wood of the corresponding wood species and uncoated birch and spruce plywood will be used for comparison. For natural weathering, the sample size will be 100 x 500 mm. The samples will be edge coated with edge paint (manufactured by Teknos Oy, Finland).

<u>Preliminary test protocol to test coated plywood under outdoor conditions (field test).</u>
The preliminary field test was started in the end of June 2003 and evaluated in the end of November 2003. Sample size was 100 x 500 mm and the samples were fixed on horizontal direction. The scaffold with samples is shown in Figure 1. The materials were as following:

Birch plywood (15 mm, 9 ply), coated with phenol film (120 / 60 g)
Birch plywood (15 mm, 9 ply), coated with paint base film and water based paint (latex)
Birch plywood (15 mm, 9 ply), coated with opaque stain
Birch plywood (15 mm, 9 ply), not coated, but edge sealed
Birch plywood (15 mm, 9 ply), not coated and not edge sealed
Spruce plywood (15 mm, 9 ply), not coated and not edge sealed

Significant difficulties or delays experienced during the first reporting period
No significant difficulties occurred in the first report period. However, the manufacture of different coated plywood took more time then planned. Also selection of material in different test systems seemed to be difficult (in the project, quite many producers of plywood participate). In the biological tests, new format of edge sealing should be used.

Sub-contracted work during the first reporting period
No sub-contractor for partner 5.

Research activities during the <u>second</u> reporting period
WP 1
1.2. Production of coated plywood
Additional common uncoated plywood products have been added in the weathering tests. For the out door weathering tests in WP 4, the following different types of plywood products were selected (main optimized plywood products were included):
- Uncoated birch plywood (edge sealed and non edge sealed)
- Edge sealed samples (3 times with Teknos JRM edge sealing paint):
- Birch plywood coated with phenolic film (with 2 basic weights)
- Birch plywood coated with melamine film
- Birch plywood coated with paint base film and paint (3 types)
- Birch plywood coated with paint (3 types)
- Spruce plywood coated with phenolic film (with 2 basic weights)
- Spruce plywood uncoated and coated with transparent paint
- Spruce LVL uncoated and coated with transparent paint
- Uncoated birch plywood with larch faces
- Uncoated spruce plywood with pine heart wood faces
- Uncoated poplar plywood (2 types)
- Uncoated poplar plywood with okoumé faces,
- Uncoated poplar plywood with moabi faces
- Uncoated okoumé plywood
- Uncoated moabi plywood

1.3. Production optimised products
Main optimised coated plywood products were included in the outdoor performance test.

WP 4
4.1 Impact of coatings on laboratory and field testing results
The out door weathering tests to study the effect of coating types on the performance of plywood started at Otaniemi, Finland in May 2004. UV aging in laboratory (modified EN 927-6) started in September 2004. The first results on the performance of coated and uncoated products were obtained in December 2004. The effect of surface injuries, edge sealing and follow-through was studied using the water immersion (floating-freezing-drying cycles). Control test samples without pretreatment or weathering were prepared for biological tests (mould tests, decay tests).

4.2 Impact of durable top veneers
The outdoor weathering tests to study the effect of durable top veneer started in September 2004. The reference samples for tests on biological durability were prepared. Co-operation with the partners 1, 4 and 6 started on the tests of out door performance tests on coated plywood products.

4.3 Impact of edge-sealing
One type of edge sealing system was included in the performance test in out door weathering. Preliminary tests on the effect of different edge sealing systems were performed in the laboratory tests using soft rot fungi.

WP 5
5.1 Identification of specific exposure systems under hazard class 3
Moisture content of coated and uncoated samples in out door exposure systems after first half year period have been evaluated and compared with the critical moisture content of decay development.

5.2 Survey on exterior performance of plywood
5 different coated plywood structures in Finland were detected and preliminary analysed.

5.3 Classification of suitable plywood
The effect of coating systems for the use of different type of coated plywood for different targets was preliminary analysed.

Significant difficulties or delays experienced during the second reporting period
The optimisation of UV aging in laboratory condition for the pre treatment of samples was more complicated and delayed. The start of biological tests was delayed.

Sub-contracted work during the second reporting period
No sub-contractor for partner 5.

Research activities during the <u>third</u> reporting period

WP 4:

4.1 Impact of coatings on laboratory and field testing results

The outdoor weathering tests to study the effect of coating types on the performance of plywood continued at Otaniemi test field. The conditions of samples were evaluated on June and December 2005. UV aging schedules in laboratory (modified EN 927-6) were carried out and several different aging processes were used. Also combination of laboratory and natural weathering aging was performed. The results on the performance of coated and un-coated products after 1.5 years exposure were obtained. The effect of protecting duct bolts on different coated plywood was studied using the water immersion test and modified Cobb's method. Biological tests using weathered and un-weathered samples were performed using modified EN 12038 method and mould test method in chambers with high RH.

All results are summarized in the Technical Report of P5.

4.2 Impact of durable top veneers

The outdoor weathering tests to study the effect of durable top veneer continued in 2005 and the condition of samples were evaluated in June and December 2005. Co-operation with partners 4 and 6 was continued to evaluate the effect of different test lay-outs on the performance of uncoated plywood samples. Moisture content of samples from partner 4 was analysed using X-ray tomography of partner 5.

4.3 Impact of edge-sealing

One type of edge sealing system was included in the performance test in out door test field. Two different edge sealing systems were included in mould test and decay test EN 12038.

WP 5:

5.1 Identification of specific exposure systems under hazard class 3

Moisture content of coated and uncoated samples after one year and 1.5 year period in out door exposure have been evaluated and compared with the critical moisture content of decay development.

5.2 Survey on exterior performance of plywood

5 different coated plywood structures in Finland were detected and analysed. Results have been presented in the meeting at partner 6.

5.3 Classification of suitable plywood

The effect of coating systems and fixing systems for the use of different type of coated plywood for different targets were evaluated.

WP 6:

6.1 Methodology for testing out of ground contact, exterior usage of plywood

Partner 5 started to evaluate the effect of coating on the performance, moisture content and use of different type of coated birch and spruce plywood products. Moisture content and overall condition of the samples in different exposure systems have been measured and the results will be analysed during the next period.

6.2 Quality requirements related to exposure and service life
The comparison of test results from WP4 and outdoor survey data of coated plywood has been started. The preliminary results indicate that coatings are necessary to protect the outer veneers against water, weathering and biological attack. Especially birch plywood with phenol film and paint base film with paint are performing well. Also other critical factors affecting the service life of plywood products are protection of edges and fixing points. This is concerning especially in service conditions with high moisture hazard (use class 3.2 or more severe).

6.3 Fit for purpose concept and quality marking of plywood
The comparison of results from different test system (weathering and biological tests) is in progress. So far according to the results on different test systems, the coatings systems, birch plywood with paint base film and opaque paint or film, are protecting plywood well in conditions to be included in a wide service area of use class 3. For quality marking of plywood, wood species used as a raw material for the manufacturing plywood may have minor effect when comparing different variables. Facts such as coating type, protection of edges, a way of fixing and use of plywood structures in different exposure environment may have much bigger influence on the final service life of plywood products.

Significant difficulties or delays experienced during the third reporting period
Edge sealing systems tested were not well enough for the mould tests but performed better in decay tests. Biological tests are delayed but they will be finished during the final period.

Sub-contracted work during the third reporting period
No sub-contractor for partner 5.

Research activities during the <u>fourth</u> reporting period
WP 4
4.1 Impact of coatings on laboratory and field testing results
The out door weathering tests to study the effect of coating types on the performance of plywood finished at Otaniemi test field. The conditions of samples were evaluated on June 2006. Additional results on integrated weathering-decay tests were obtained. The final results on the performance and water permeability of coated and un-coated products after 2 years exposure were obtained. Biological tests using weathered and un-weathered samples were performed using modified EN 12038.

4.2 Impact of durable top veneers
The outdoor weathering tests to study the effect of durable top veneer continued in 2006 and the condition of samples were evaluated in June 2006. Co-operation with partners 4 and 6 was continued to evaluate the effect of different test lay-outs on the performance of uncoated plywood samples.

4.3 Impact of edge-sealing
One type of edge sealing system was included in the performance test at the out-door test field. Three different edge sealing systems were included in decay test EN 12038 and soft rot tests.

WP 5

5.1 Identification of specific exposure systems under hazard class 3

Moisture content of coated and uncoated samples during 2 year´s out door exposure have been evaluated and compared with the critical moisture content of decay development.

5.2 Survey on exterior performance of plywood

5 different coated plywood structures in Finland were selected and analysed and results have been sent to partner 6.

5.3 Classification of suitable plywood

The effect of coating systems for testing and classifying the suitable plywood for different targets has been evaluated. Evaluation of results was finished.

WP 6

6.1 Methodology for testing out of ground contact, exterior usage of plywood

Partner 5 started to evaluate the effect of coating on the performance, moisture content and use of different type of coated birch and spruce plywood products. Moisture content and overall condition of the samples in different exposure systems have been measured and the results have analysed.

6.2 Quality requirements related to exposure and service life

The comparison of test results from WP4 and outdoor survey data of coated plywood has been finished. The results indicate that coatings are necessary to protect the outer veneers against water, weathering and biological attack. Especially birch plywood with phenol film and paint base film with paint performed well. Also other critical factors affecting the service life of plywood products are protection of edges and fixing points. This concern specially in service conditions with high moisture hazard (use class 3.2 or more severe).

6.3 Fit for purpose concept and quality marking of plywood

The comparison of results from different test system (weathering and biological tests) is finished. According to the results on different test systems, the coatings systems, birch plywood with paint base film and opaque paint or film, are protecting plywood well in conditions to be included in a wide service area of use class 3. For quality marking of plywood, wood species used as a raw material for the manufacturing plywood may have minor effect when comparing different variables. Parameters such as coating type, protection of edges, the way of fixing and use of plywood structures in different exposure environment may have more influence on the final service life of plywood products.

Significant difficulties or delays experienced during the fourth reporting period

Biological tests were delayed but they were finished during the final period.

Sub-contracted work during the fourth reporting period

No sub-contractor for partner 5.

Partner 6

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Scientific team

Christiane Deval, Marcel Denance, Frédéric Simon, Patrice Rancœur, Isabelle Lebayon, Xavier Foulon, Nathalie Passedat, Patricia Collignan

Objectives

Partner 6 aims at the compilation of practical experience and service life data of plywood under outdoor exposure during several years.

Workplan

WP 5

5.1 Identification of specific exposure systems under hazard class 3

The correlation of performance against decay hazard of plywood with possibilities of increased moisture content being established over longer periods will be evaluated. Specific time-to-failure scenarios will be checked and linked to specific applications under hazard class 3.

5.2 Survey on exterior performance of plywood

This survey will provide in the collection of practical cases of external uses of plywood, identification of their production background and their exposure conditions in service.

5.3 Classification of suitable plywood

Classification of suitable plywood for outdoor use will be based on the data from well defined plywood service-life validation.

Deliverables

D4. Identification of specific exposure systems, month 12. Delivered, see Technical Report 1
D19. Survey results on service-life of different plywood types, month 36.
D20. Estimation of time to failure for specific applications, month 36.
D22. Specifications for critical characteristics for exterior plywood, month 48.

Research activities during the <u>first</u> reporting period

Christiane Deval and Marcel Denance, Construction Engineer with skills in plywood, have carried out specific research in CTBA Timber construction Pole, in order to present common conventional exposure systems, using plywood.
Marcel Denance is involved in a Research Plywood Program. He and Christiane Deval, Construction Department engineers, have been frequently consulted to carry out diagnosis on plywood construction systems, analyse disorders and flaws, and come up with rehabilitative proposals.

The proposed specific exposure systems have been presented and discussed during the Technical Project Meeting on October 9-10th 2003.

External exposures:

- Panels with 6 faces directly weather exposed: drilled cladding or advertising boards

- Panels with a directly exposed face and an interior face:
  - invisible - fixed cladding
  - in-fills in window

All results are summarized on a PowerPoint Presentation annexed in TechnRep1

Significant difficulties or delays experienced during the first reporting period
No difficulties or delays experienced during the first reporting period

Sub-contracted work during the first reporting period
No sub-contractor for partner 6.

Research activities during the second reporting period
1. During the first year three types of specific exposure systems have been defined, exposure systems under hazard class3:

- panels with 6 faces directly exposed to weather drilled cladding or advertising boards
- panels with a directly exposed face and an interior face.
  - invisible - fixed cladding
  - in-fills in window

2. Survey on exterior performance of plywood carried out according to these three types of specific exposure systems

2.1 Accelerated outdoor testing according to 3 types of specific exposure systems
At first, these 3 types of specific exposure are used for accelerated outdoor testing. Three racks representing 3 exposure scenarios have been prepared by CTBA and sent to BFH (partner 4) in Hamburg (Continental climate), to CIRAD (partner 3) in Montpellier (Mediterranean climate) and CTBA Bordeaux (partner 6) (Oceanic climate) for field testing.
Visual examination and mass loss assessment with a 0% stabilisation will be carried out according to a protocol, after two years of accelerated outdoor testing.

2.2 Assessment on exterior performance of plywood

Partner 6 looked for a collection of real sites using plywood in Façades.
The following four criteria classification was presented and discussed during Technical Project Meeting on October 9-10th 2003:

1. *Type of panel*
2. *Specific exposure systems under hazard class 3*
3. *Climate:*
    - South Continental Climate: Mediterranean climate (South Italy, Spain, South France)
    - North Continental Climate: Finland, Germany, French Mountain Climate (UV)
    - Oceanic Climate: France: Atlantic coast, the Netherlands.
4. *Age of the building site:*
    - 0 - 4 years
    - 5- 9 years
    - 10-19 years
    - 20-40 years
    - More than 40 years

In France, the CTBA has identified contacts of building sectors: constructors, experts, wood construction enterprises, plywood manufacturers.
Christiane Deval and Laurent Le Gall (ENSTIB Trainee Engineer who works 5 months at the CTBA), sent a first questionnaire, to get precise information concerning plywood façades in hazard class 3.
The aim is to collect precise information on:

- Type of panels
- Application of Panels
- Construction methods
- Coating and maintenance
- Identified risks

Collecting the information presents significant difficulties. It was difficult to find the good contacts and then to get precise information on the buildings. Partner 6 sent 120 questionnaires, only 15 questionnaires were answered.
P6 decided to get more precise information by means of site visits.
During the second work year (2004) Christiane Deval and Laurent Legall visited 20 sites using plywood in façades: drilled cladding has been selected.
The survey has been carried out in North Continental Climate (East and Central France, and Switzerland), and Oceanic Climate.
The age of the building sites was up to 20 Years.

The site visit program was presented during the PLYBIOTEST progress meeting in Hamburg 4-5 November 2004, the supporting PowerPoint Presentation is annexed to Technical Report 2.

Significant difficulties or delays experienced during the second reporting period
No difficulties or delays experienced during the second reporting period.

Sub-contracted work during the second reporting period
No sub-contractor for partner 6.

Research activities during the third reporting period
In 2005 the site visit program is carried out by Christiane Deval. A restricted choice of building sites is assessed. The selection is done by the age of the panel. Building sites more than 10 years old are researched in priority.

Two examples:
Very interesting examples are assessed with 30 year old plywood in maritime pine. The building present maritime pine plywood and maritime pine solid wood exposed in the same conditions, in ground contact (more than 30 years old). Some softened pieces of solid maritime pine have been replaced by maritime pine plywood, where as the maritime pine plywood is still intact.
Two buildings using spruce LVL in hazard class 3 have been assessed. These façades in hazard class 3 are directly weather exposed. No biological decay on this façades but a lot of cracking. A heavy maintenance is necessary after 7 years.

Data base of assessments on exterior performance of plywood

In 2005 a database has been made by CTBA. It has been done according to the CTBA Durability database model. This specific database is an internal one. Xavier Foulon has developed this database. Christiane Deval is in charge of the development (50 survey documents until now)
A survey template document in English has been handed over to all partners.

Participating in WP 3: Field test method

In 2005 Isabelle Lebayon and Nathalie Passedat have participated in WP3. Martin Haupt (P4) asked for assistance to have a system exposed in Oceanic Conditions.
They assessed wood staining fungi and wood decaying fungi according to TS12037. The results are given in annex.

Plybiotest meeting preparation

Laurence Podgorski, Christiane Deval, and Patricia Collignan as a secretary prepared the fifth Project Co-ordinating Committee (PCC) meeting and Technical Project Meeting (to be held in BORDEAUX January 16-17, 2006)

Significant difficulties or delays experienced during the third reporting period
No difficulties or delays experienced during the third reporting period

Sub-contracted work during the third reporting period
No sub-contractor for partner 6.

Research activities during the fourth reporting period

WP 3: Field test method

In 2006 Isabelle Lebayon, Nathalie Passedat and Virginie Latournerie have participated in WP3 after Martin Haupt (P4) asked for assistance to have a system exposed in Oceanic Conditions. They assessed wood staining fungi and wood decaying fungi according to TS12037. The results are sent to BFH (Partner 4).

WP 5

5.1 Identification of specific exposure systems under hazard class 3

Specific exposure systems:

- panels with 6 faces directly exposed to weather drilled cladding or advertising boards
- panels with a directly exposed face and an interior face.
  - invisible - fixed cladding
  - in-fills in window

The correlation of performance against decay hazard of plywood with possibilities of increased moisture content being established over longer periods was evaluated. Specific time-to-failure scenarios are checked and linked to specific applications under hazard class 3.

Hazard class 3 Plywood has been checked during the Survey on exterior performance of plywood.

Very little plywood in hazard class 3 situations presents decay. We looked for specific exposure of plywood under hazard class 3b or 4.

5.2 Survey on exterior performance of plywood

In 2006 the site visit program was continued by Christiane Deval. A restricted choice of building sites was assessed. The selection was done by the age of the panel. Building sites more than 10 years old were researched in priority.

Christiane Deval assessed a few others building sites, and compiled the information on plywood in exterior constructions in the database.

A survey template document in English has been handed over to all partners. The other partners are using this concept in a slightly modified version for their inventory.

CTBA (P6) received data from UGHENT (P1), UNITO (P2), and VTT (P5). This information has been studied by Christiane Deval and compiled in the data base.

Very interesting examples that were assessed are examples with 30 year old plywood made of maritime pine and okoumé.

Several buildings using spruce and birch plywood and spruce LVL in hazard class 3 situations have been assessed. All these façades in hazard class 3 are directly weather exposed. Some parts of the façades are hazard class 4 situations.

Some “Non qualified Plywood” has been assessed too, Ghent University provided examples and CTBA integrated the assessment in the first part of the study.

A database has been made by CTBA. It has been done according to the CTBA Durability database model. This specific database is an internal one. Xavier Foulon has developed this database. Christiane Deval has been in charge of the development
In 2006 CTBA (P6) assessed 10 more building sites, helped UNITO (P2), VTT (P5) and Ghent University (P1) to do their own survey according to the survey template document, collected data from the three partners and integrated all the documents (survey document and photos) in the database.
A total of 75 building sites have been assessed, representing a total of 2075 plywood panels. Among these building sites, 60 sites have been assessed by CTBA, representing 1780 plywood panels.

Plywood constructions described by CTBA are mainly situated in France, Switzerland, Netherlands, and Finland.
Those described by UNITO are situated in Italia (Alpine climate)
Those described by VTT are situated in Finland
Those described by Ghent University are situated in Belgium and The Netherlands

CTBA collected the survey template documents in the database. 2 types of documents have been included:

- A complete survey template document for CTBA,
- and a slightly modified version for VTT, Ghent University and UNITO.

All the assessments entered in the database present relevant information about plywood durability in hazard class 3 situations.

As presented in the January 2006 meeting, the survey results have been studied according to the following criteria:

Little changes occurred to integrate major of the results.

Criterion N°1: 5 plywood types
- birch (or birch-spruce combi) plywood
  - 10 mm / 7 plies, 12 mm / 9 plies, 15 mm / 11 plies
- spruce plywood
  - 10 mm / 7 plies, 12 mm / 9 plies, 15 mm / 11 plies
- spruce LVL
- okoume plywood
  - 8 mm / 5 plies, 12 mm / 7 plies, 18 mm / 9 plies
- pine plywood
  - 8 mm / 5 plies, 15 mm / 7 plies, 25 mm / 9 plies
- low quality panel (meranti…)

Criterion N° 2: Specific exposure systems under hazard class 3

Drilled cladding is 1 of the three exposure set ups as integrated in the CTBA field test. Drilled Cladding: panels hanging with six faces directly weather exposed have been selected as exposure type assessed in the survey. This type of exposure is very similar to the "freely hanging plywood panel, set up A" of partner 1.

Criterion N° 3: Climate

- Assessment on exterior performance of plywood are carried out according to two types of European climate
- North Continental Climate:
  - – Finland, Germany, France Mountain Climate (UV)
  - – Switzerland: 30 Building sites
- Oceanic Climate:
  - – France: Atlantic cost, Netherland, Belgium (40 Building sites)

- Mediterranean climate
  - – No interesting building sites have been found

Criterion N° 4: age of the building sites

- Assessment on exterior performance of plywood are carried out according to the following service lives:
  - 0 - 4 years
  - 5 - 14 years
  - 15 - 24 years
  - More than 25 years

In December 2004, 2005 and 2006 the general conditions of the plywood panels of the building sites recorded have been evaluated.
The occurrence of blue stain and wood destroying fungi has been recorded.
The different types of decay inventoried are:

- panel deformations (bending)
- weathering features (delamination, crack formation, defibrillation, discoloration, erosion moisture traces, blue stain fungi)
- damage by wood destroying fungi (softened or decayed panel)

Looking for decay, CTBA has registered and assessed 60 buildings sites using plywood

- Rot has been detected in only 1,2 % of the 1700 assessed plywood panels
- These results occurred in:
  - – 5 types of plywood
  - – Major in hazard class3 situations (80%)
  - – In continental and oceanic climates
  - – From 0 to 30 years old

The results of the evaluation are presented in Figures 1 and 2.

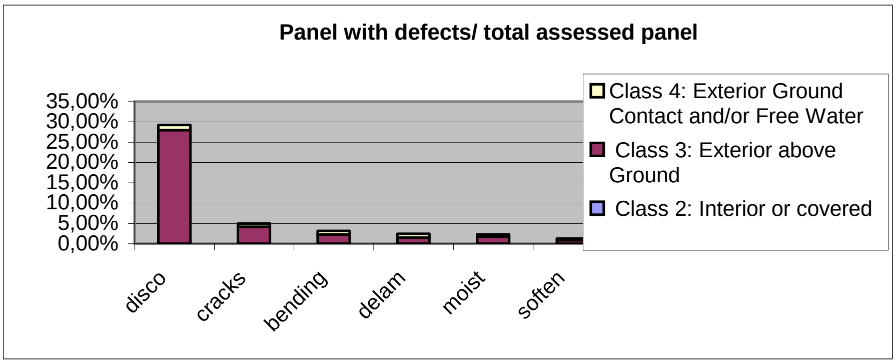


Figure 1 Panels with defects / total assessed panels by type of defects

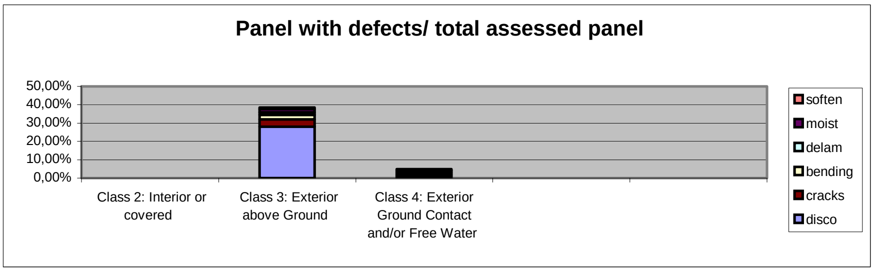


Figure 2 Panels with defects / total assessed panels by Hazard Class 2, 3 and 4

Main defects detected are:

- Discoloration, crack formation, bending, delamination, moisture traces and wood destroying fungi.

Cracks, delamination and softening decay are linked to the previous durability of the panel. The project is linked with the durability of plywood; CTBA now focuses the study on Crack formation, delamination and softening decay.

CTBA integrated results from Ghent University, VTT and UNITO.

Looking for decay, the four partners have registered and assessed 75 buildings sites using plywood.
Wood destroying fungi have been detected in only 1,5 % of the 2000 assessed plywood panels.

These results were registered by CTBA, Ghent University, UNITO and VTT and occurred in:

- 5 types of plywood and 1 type of non qualified product
- Major in hazard class 3 situations (81%)
- In continental and oceanic climates
- From 0 to 30 years old

This shows clearly the durability of plywood in Hazard class 3 situations (service life exceeding 30 years of outdoor use).

Results of this evaluation are presented in Figures 3 to 6.

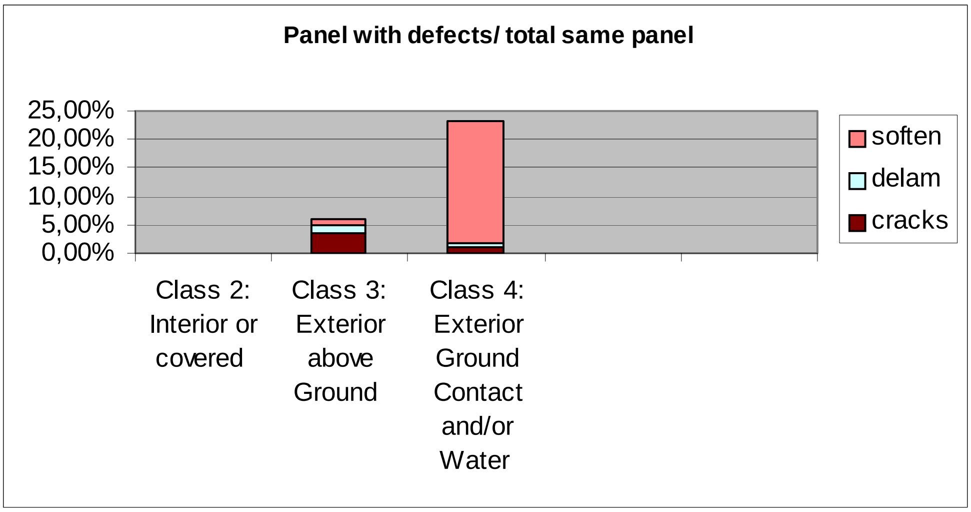


Figure 3 Panels with defects / total assessed panels by hazard class

Looking for decay, we registered and assessed 75 buildings sites around 2075 panels:

- – 81 % in hazard class 3 situations
    - • 1,45 % delamination, 0,9 % softened
- – 1,7 % in hazard class 4
    - • 21,6 % softened

The results clearly show that soft rot is linked to hazard class 4 situations.

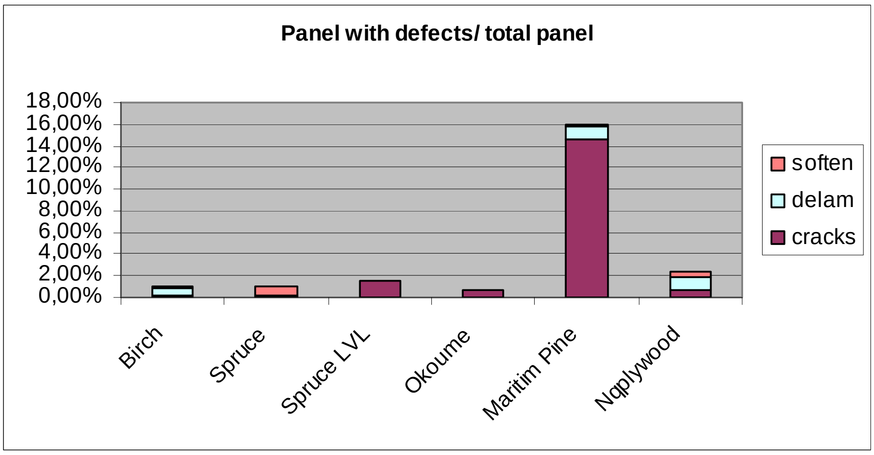


Figure 4 Hazard Class 3 situations, panels with defects / total assessed panels by type of panel

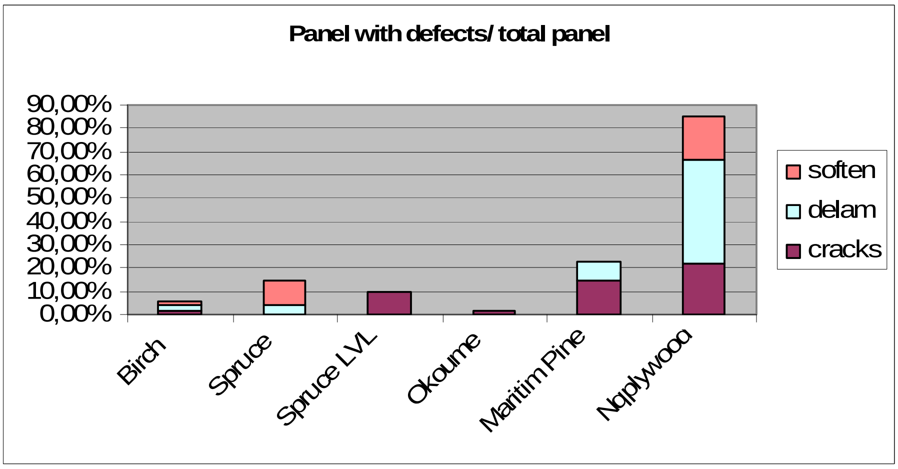


Figure 5 Hazard Class 3 situations, panels with defects / total assessed panels of the same category by type of panel

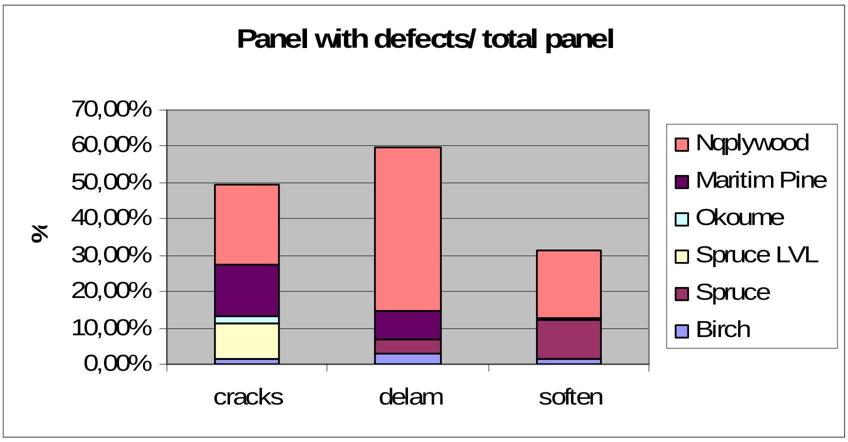


Figure 6 Hazard Class 3 situations, panels with defects / total assessed panels of the same category by type of decay.

Non qualified plywood, meranti plywood (plies with different thickness, gluing defects…) represent only 60 plywood panels among a total of 2075 assessed plywood panels. 18% presents wood decaying fungi, 45% shows delamination.

The results clearly show that durability of plywood is linked to the quality of the processing (raw material, machining and gluing quality…). CE marking involved Initial Type Testing and Factory Production Control: part of the durability assessment.

Partner 6 now focused the study on well defined plywood (without non qualified plywood).
Results of this evaluation are presented in Figures 7 to 9.

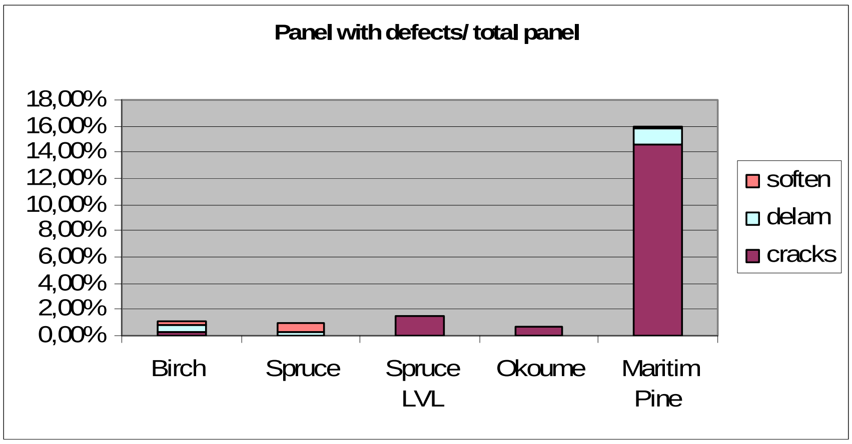


Figure 7 Hazard class 3 situations, panel with defects/total assessed panels by type of panel.

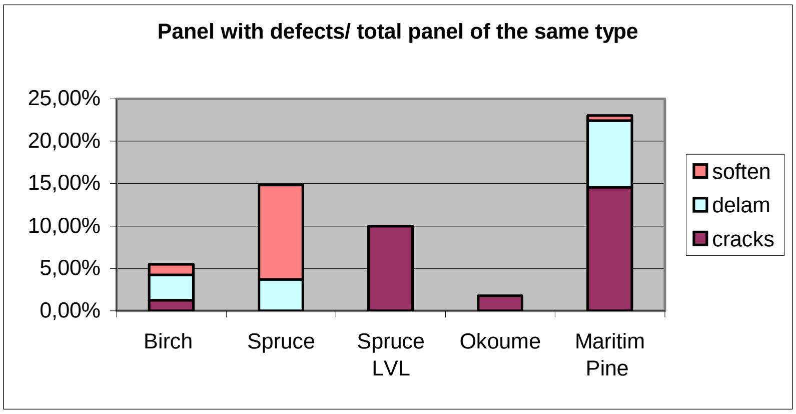


Figure 8 Hazard class 3 situations, panel with defects / total assessed panels of the same category by type of panel.

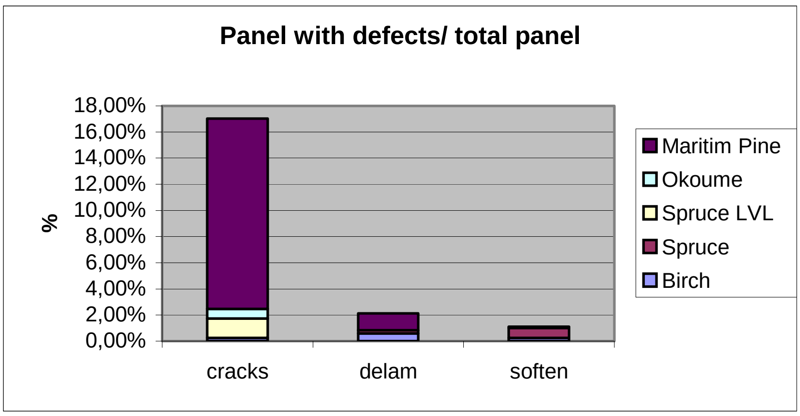


Figure 9 Hazard class 3 situations, panel with defects / total assessed panels of the same category by type of decay.

Looking for decay rot has been detected in only 1,5 % of the 2000 assessed plywood panels. It has been detected in spruce, birch, and maritime pine plywood.
Rot has been detected in 0,9% of the assessed plywood in hazard class 3 situations, some very early (from 5 -10 years old) causes are:

– Interstitial condensation due to non ventilated air space;
– Infill non continuous draining or coating with no vapour permeability;
– In that case it can bring to plywood decay before 3 years if plywood is frequently wet and can't get dry very quickly.

These hazard class 3.2 situations have to be identified.

Under other hazard class 3 conditions, long service lives have been detected.

In hazard class 4, in 21% of the assessed plywood rot has been detected. Causes are:

– Exterior in ground contact or contact with water
– In that case it brings to plywood decay within 5-10 years depending on the exposure and « local conditions »

These results clearly confirm the durability of plywood in Hazard class 3 situations, especially for plywood panels with an efficient Factory Production Control.

Plywood durability has been studied according to 4 criteria:

- Plywood types
- Hazard class situations
- Climate
- Age of the building sites

Plywood types
In the survey okoumé and martime pine plywood are less decayed than the others in hazard class 3 conditions.
Partner 6 was able to assess examples of panels having long service lives (30 years old and more)
Spruce and maritime pine plywood and spruce LVL are the most vulnerable to crack formations.
End-users shall be informed of this particular evaluation.

Hazard class situations
Hazard class seems to be the most influential parameter

Climate
Climate has an influence as one of the "local conditions" parameters. The other "local conditions parameters" have been presented and discussed during the December 2006 progress meeting in Ghent.
They are detailed in the next paragraph.

Age of the building site
Age of the building is an important parameter influencing the rate of decaying, especially acting with one of the other parameters.

5.3 Classification of suitable plywood

Data gathered during the survey study mentioned above.
As presented and discussed during the last PCC meeting in Ghent.

Suitable plywood shall be defined for hazard class 3 situations, and hazard class 3.1 and 3.2 situations shall be defined very precisely.

3.1 Exterior, protected, occasionally wet:

- Can dry out very quickly; implies ventilated air space, continuous draining systems for infills in windows or wood assembly

3.2 Exterior, unprotected, frequently wet:

- Can't dry out very quickly because of ventilated air space, continuous draining systems for infills in windows or wood assembly, interstitial condensation

Coated plywood: In Hazard class 3 or 4, coated plywood can be decayed if the coating has no water-vapour permeability.

- Well performing coating implies a durable coating with a good water-vapour permeability, and appropriate maintenance with EN 927 classified coatings.

In Hazard class 3 or 4, film faced plywood can be decayed if the lay up has no water-vapour permeability.

Good quality panel shall have good quality control.
Cracks are detected in spruce LVL and pine plywood when the thickness of the plies is maximal. End-users shall be informed of this particular evolution
Delamination can be detected very early (0-4 year panels). These defects can cause decay in plywood under exterior unprotected conditions (3.2).
Delamination can lead very quickly to decay by wood destroying fungi, especially under exterior unprotected conditions (3.2).
Quality control shall be efficient: raw material, machining, gluing…

CE marking involves Initial Type Testing and Factory Production Control in plywood production, which is part of the durability assessment.

WP6
6.2 Quality requirements related to exposure and service life

Data gathered during the survey study mentioned above.

To increase plywood service life in outdoor out of ground contact applications a good 3.1 and 3.2 hazard class definition is necessary.

According the survey, and taking account of the state of art:

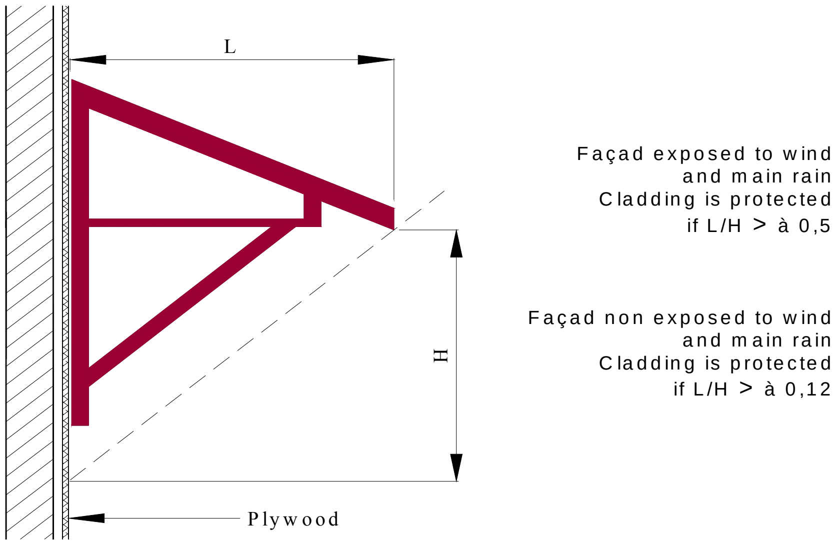
- Use class 3 covered situation (fig 9) according to the survey

For façades exposed to main rain and wind: L/H > 0,50
For façades not exposed to main rain and wind: L/H > 0,12

- Use class 3 non covered situation
  Non covered situations divided into:
  Frequently wet and can dry very quickly (dry or cold climate and secured design)
  Frequently wet and can't dry very quickly (wet climate and non secured design)

- Exposure situations have to be considered depending on the climate and local situations:
  Façades exposed to main rain and wind:
  For example the main rain exposure for the oceanic climate in France is West exposure

EXPOSURE SITUATIONS



Recommendations for design and installation:

- The work includes the details (connection, Joint...) should be designed in order to avoid water penetration behind the plywood, or interstitial condensation (it can bring to plywood decay very quickly)

- For infills in windows, with continuous draining systems:
  - Service life can reach 30 years and more

- For cladding, should be designed:
  - Walls: The wall itself already meets the necessary air tightness
  - Subframe: intermediate assembly of vertical and/or horizontal, wood or metal profiles, located between the skin and the substrate

- Cladding element: plywood assessed for biological durability for use class 3.1 or 3.2
  - Air space between cladding and the backing wall
  - Ventilated air space
    - Breathing membrane: Membrane placed in the cladding kit to ensure airtightness of the wall
    - Cladding fixings, and cladding fixing densities
    - Cladding dimensions (length, height, thickness)

Recommendations for maintenance and repair of the works:

- Maintenance includes repairs to localised damaged areas due to accidents

- The application of various products of paints for stained or painted plywood (maintenance to be carried out with EN 927 classified products)

6.3 Fit for purpose concept and quality marking of plywood

Data gathered during the survey study mentioned above.

Comments and proposal: Fig 9 of the Ghent University proposal (coordinator):

- Covered situations
  - Use class 3 covered situation according to the survey:
    - For façades exposed to main rain and wind : L/H >0,50
    - For façades not exposed to main rain and wind: L/H >0,12
- Non covered situations divided into
  - Frequently wet and can dry out very quickly (dry or cold climate and secured design)
  - Frequently wet and can't dry out very quickly (wet climate or non secured design)

Covered situations and secured design:
- All type of exterior plywood: expected service life 30 years and more

Non covered situations part 1:
- Frequently wet and can dry very quickly (dry or cold climate and secured design)
  - Expected service life 30 years and more for "durable plywood"

Non covered situations part 2:
- Frequently wet and can't dry out very quickly (wet climate or non secured-design)
  - Expected service life 10 years for "durable plywood"

For "durable plywood", when 30 years service life is expected: periodic building inspections should be recommended leading to appropriate maintenance and repair (painting EN 927 classified products, edge sealing, local repair…)

Classification of suitable plywood for outdoor use will be based on the data from well defined plywood service-life validation.

Deliverables
D4. Identification of specific exposure systems, month 12.
Completed, see above.

D19. Survey results on service-life of different plywood types,
Completed, see above.

D20. Estimation of time to failure for specific applications
Completed, see above.

D22. Specifications for critical characteristics for exterior plywood,.
Completed, see above.

Significant difficulties or delays experienced during the fourth reporting period
No difficulties or delays experienced during the fourth reporting period

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 6.

Partner 7

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Scientific team

Prof. Castellini, N. Azzi, G. Brocchieri, A. Braglia, E. Lanfredini, E. Sanguanini, G. Aroldi, F. Lini, S. Lodi, M. Marangoni.

Objectives

- Production of different panel types: MUF poplar plywood, poplar LVL and exotic plywood with different veneer thickness/lay-up; poplar plywood with treated glue lines.
- Development of MUF glued poplar plywood with surface protection (overlaid by phenolic film, resin coated and/or edge painted) and with faces made of veneer of durable wood species or with mixed layers (combi).
- Production of plywood with durable top veneers.
- Production of optimised plywood types.

Workplan

WP 1

1.1 Production of non-coated exterior plywood

Partner 7 will produce some types of poplar plywood for exterior use based on a melamine-urea-formaldehyde resin adhesive (type BFU100) with different veneer thickness (1-3 mm) and plywood thickness (10-20 mm), with different poplar clones (I 214, Robusta and Beaupré). The related product poplar LVL (Laminated Veneer Lumber) will also be produced.

1.2 Production of coated exterior plywood

Partner 7 will produce plywood coated with resin or phenol impregnated paper coatings or with faces made of veneer of durable wood species or with mixed layers (combi-plywood).

1.3 Production of optimized products

Based on results obtained during the course of the project "optimized" plywood will be produced by partner 7.

Deliverables

The following deliverable was covered:
D6. All plywood material available for testing, month 24

Research activities during the first reporting period

Panguaneta produced following plywood types and delivered them to Ghent University:

- Poplar plywood, 15mm/7plies, uncoated, UMF, 6 panels, size 2500mm x 1220mm x 15mm
- Poplar plywood, 18mm/9plies, uncoated, UMF, 6 panels, size 2500mm x 1220mm x 18mm

- Plywood with top veneers Okoumé, inner veneers Poplar, 18mm/9plies, uncoated, UMF, 6 panels, size 2500mm x 1220mm x 18mm

Significant difficulties or delays experienced during the first reporting period
No delays were experienced during the first reporting period.

Sub-contracted work during the first reporting period
No sub-contractor for partner 7.

Research activities during the second reporting period
Discussion and research performed on selecting and producing optimized plywood. Material was provided to partner 2.

Significant difficulties or delays experienced during the second reporting period
No delays were experienced during the second reporting period.

Sub-contracted work during the second reporting period
No sub-contractor for partner 8.

Research activities during the third reporting period
The work carried out by Panguaneta included the production in July 2005 of a first set of industrial optimised panels with the support of partner 2 (UNITO). The optimised plywood produced are listed below:

- poplar I 214 plywood UMF + wolsit glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick
- poplar I 214 plywood UMF + tannin glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick
- poplar I 214 plywood UMF + resorcinol glued, nominal thickness 18/9 mm made with veneers of 2.1 mm thick

These optimised panels were bonded with a standard UMF (melamine-urea-formaldehyde) resin mixture suitable for gluing wood-based panel for use in humid conditions.
In the same period Panguaneta produced another set of optimised panel, on the basis of the indications of partner 2:

- maritime pine plywood UMF glued, nominal thickness 17/7 mm made with veneers (from Smurfit-France) of 2.5 mm,
- paulownia plywood UMF glued, nominal thickness 18/9 mm made with veneers of 2.1 mm,
- oak plywood UMF glued, nominal thickness 15/9 mm made with veneers of 1.8 mm.
- poplar plywood (raw) PF glued (clone I-214), nominal thickness 18/9 mm made with veneers of 2.1 mm,
- poplar plywood (clone I-214) as above but phenolic film faced,
- poplar plywood (raw) UMF glued (clone I-214), nominal thickness 15/11 mm made with veneers of 1.4 mm,
- poplar plywood (raw) PF (phenol formaldehyde) glued, nominal thickness 18/9 mm, made with veneers of 2.1 mm thick,
- poplar plywood (clone I-214) as above but phenolic film faced.

Significant difficulties or delays experienced during the third reporting period
No delays were experienced during the third reporting period.

Sub-contracted work during the third reporting period
No sub-contractor for partner 7.

Research activities during the fourth reporting period
Panguaneta attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Significant difficulties or delays experienced during the fourth reporting period
No delays were experienced during the fourth reporting period.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 7.

Partner 8

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Scientific team

Johan Pastuer, Filip Agneessens, Uwe Herman

Objectives

Coblo is experienced in the production of thick poplar plywood. Evaluation of the impact of moisture control in the interior plies on the service life in outdoor conditions can be considered a main topic for product improvement.

Workplan

WP 1

Partner 8 will mainly produce poplar plywood for better understanding the role of moisture on the time to failure both in laboratory and outdoor testing including the impact on strength. Combinations of different wood species and plywood coatings will also be provided to allow identification of important parameters steering the results and the impact of these.

Deliverables

The following deliverable was covered:
D6. All plywood material available for testing, month 24

Research activities during the first reporting period

Coblo produced following plywood types and delivered them to Ghent University:

- Poplar plywood, 15mm/11plies, uncoated, UMF, 6 panels, size 2500mm x 1220mm x 15mm
- Poplar plywood, 20mm/9plies, uncoated, UMF, 6 panels, size 2500mm x 1220mm x 20mm

Significant difficulties or delays experienced during the first reporting period

No delays were experienced during the first reporting period.

Sub-contracted work during the first reporting period

No sub-contractor for partner 8.

Research activities during the second reporting period

Discussion and research performed on selecting and producing optimized plywood.

Significant difficulties or delays experienced during the second reporting period

No delays were experienced during the second reporting period.

Sub-contracted work during the second reporting period

No sub-contractor for partner 8.

Research activities during the third reporting period
Selection of optimized plywood and specific production.

Significant difficulties or delays experienced during the third reporting period
No delays were experienced during the third reporting period.

Sub-contracted work during the third reporting period
No sub-contractor for partner 8.

Research activities during the fourth reporting period
Coblo attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Significant difficulties or delays experienced during the fourth reporting period
No delays were experienced during the fourth reporting period.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 8.

Partner 9

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Scientific team

Jouko Veistinen, Tero Nokelainen, Kasperi Sokka, Pekka Juutistenaho, Jussi Ekman

Objectives

To produce LVL and coated spruce and birch plywood products for exterior use to be tested in WP 4. To participate in the WP 6.

Workplan

WP 1

1.2 Production of coated plywood

Coated birch plywood (ply thickness 1.5 mm) and spruce plywood (ply thickness 1.5 and 3 mm) will be manufactured to be assessed in other WPs. Part of the boards will be coated with phenol film or with painted craft liner or with primers and topcoats In addition new developments combining standard core plywood and durable or modified top veneers will be prepared. Choice of different edge sealing technologies will be studied.
Partner 9 will focus on spruce plywood using different veneer thickness, LVL and plywood having durable top veneers.

1.3 Production of optimised products

Based on the results obtained from the preliminary tests conduced on the commercially used plywood and on those with special lay-ups and surface protections, the partner will be able to realise optimised plywood products with better performance for exterior use.

WP 6

6.3 Fit for purpose concept and quality marking of plywood

Based on expected service life and specific hazard identified for well defined purposes a quality labelling will be established using a fit for purpose concept in co-operation with other partners.

Deliverables

The following deliverable was covered:
D1. Coated and uncoated birch and spruce plywood samples for other WPs, month 6.

Uncoated and coated + edge-sealed Finnforest Spruce and softwood plywoods and uncoated and coated Kerto-Q-LVL panels has been delivered to laboratories in Ghent, Belgium and VTT, Finland.

Research activities during the first reporting period

Finnforest Corp has produced and delivered the following plywoods and LVL-panels to the laboratories:

- *To GHENT University, Belgium*:
  - Finnforest Spruce softwood plywood, 15mm/5ply, sanded, uncoated, 6 panels, size 2440mm x 1220mm x 15 mm
  - Kerto-Q-LVL panels 27mm/9ply, unsanded, uncoated, 6 panels, size 2400mm x 900mm x 27mm
  - Coated Kerto-Q-LVL panels 27mm/9ply, one side coated, 6 panels, size 2400mm x 900mm x 27mm

  Later on week no 6 /. 2004:
  - Softwood plywood, 15mm/11ply, sanded, uncoated, 6 panels, size 200mm x 2400mm x 15mm

- *To VTT, Finland:*

  Thick veneer plywood:
  - Finnforest Spruce softwood plywood, 15mm/5ply, sanded, uncoated, 6 panels, size 2440mm x 1220mm x 15mm
  - Overlaid Finnforest Spruce softwood plywood, 15mm/5ply, overlaid with phenolic film 145 g/m^2, 2 sided, edge sealed, 6 panels, size 2440mmx1220mmx15mm
  - Finnforest Spruce softwood plywood, 15mm/5 ply, surface veneers heartwood of Finnish pine, sanded, uncoated, 6 panels, size 2440 mm x1220mmx 15mm

  Thin veneer plywood:
  - Softwood plywood, 15mm/11ply, sanded, uncoated, 6 panels, size 1200mm x 2400mm x 15mm,
  - Overlaid softwood plywood, 15mm/11ply, overlaid with phenolic film 40/120g/m^2, 2 sided, edge sealed, 6 panels, size 1200mm x 2400mm x 15mm
  - Overlaid softwood plywood, 15mm/11ply, overlaid with phenolic film 80/220 g/m^2, 2 sided, edge-sealed, 6 panels, size 1200mm x 2400mm x 15mm.

  - Kerto-Q-LVL panels, 27mm/9ply, unsanded, uncoated, 3 panels, size 2400mm x 900mm x 27mm
  - Coated Kerto-Q-LVL panels, 27mm/9ply, one side coated, 3 panels, size 2400mm x 900mm x 27 mm

All the plywood produced are PF glued.

Significant difficulties or delays experienced during the first reporting period
No delays were experienced during the first reporting period

Sub-contracted work during the first reporting period
No sub-contractor for partner 9.

Research activities during the <u>second</u> reporting period
Discussion and research performed on selecting and producing optimized plywood.

1. Finnforest has inspected surfaces of facade plywoods of several buildings and the condition of overlaid, transparent plywood surfaces in some other exterior applications.

Surfaces of old traffic signs made of paper faced birch plywood have been inspected as well.

2. Finnforest has delivered more reference material to Partner No 4 /BFH Hamburg: Finnforest Spruce softwood plywood 15 mm/5 ply PF glued, spruce veneers 2,6 mm, spruce veneers 1,4 mm and spruce and birch peeler logs.

Significant difficulties or delays experienced during the second reporting period
No delays were experienced during the second reporting period.

Sub-contracted work during the second reporting period
No sub-contactor for partner 9.

Research activities during the <u>third</u> reporting period

- Finnforest inspected surfaces of facade plywood of several buildings and the condition of old floor plywood in vehicles.
- Finnforest produced and delivered optimized plywood to Ghent University. It concerns birch plywood with 2.4 mm birch veneers.
- Finnforest organized in May an excursion to Pohjola football stadium in Vantaa where the participants of the fourth Project Co-ordinating Committee of Plybiotest project could inspect the condition of overlaid plywood and overlaid Kerto-LVL-panels in the construction of this football stadium.

Significant difficulties or delays experienced during the third reporting period
During the summer of 2005 there was a two months long strike in Finnish forest industry and in wood procurement. Unfortunately we could not procure any aspen logs for producing Finnish aspen plywood for tests in Ghent University.

Sub-contracted work during the third reporting period
No sub-contractor for partner 9.

Research activities during the <u>fourth</u> reporting period
Finnforest attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Significant difficulties or delays experienced during the fourth reporting period
No delays were experienced during the fourth reporting period.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 9.

Partner 10

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Scientific team

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Objectives

To produce coated birch plywood products uncoated and coated plywood with phenol impregnated or melamine impregnated films to be tested in WP 4.

Workplan

WP 1

1.2 Production of coated plywood

Normal coated birch plywood (ply thickness 1.5 mm) and uncoated birch plywood will be manufactured to be assessed in other WPs. In addition new developments combining standard core plywood and durable or modified top veneers will be prepared. Phenol films, primers and topcoats will be used as coating types.
Partner 10 will focus on birch plywood having durable top veneers and coatings.

1.3 Production of optimised products

Based on the results obtained from the preliminary tests conduced on the commercially used plywood and on those with special lay-ups and surface protections, the partner will be able to realise optimised plywood products with better performance for exterior use.

Deliverables

The following deliverable was covered:
D1. Coated and uncoated birch and spruce plywood samples for other WPs, month 6.

Research activities during the first reporting period

Test boards have been made and delivered for testing to the laboratories VTT Building and Transport and Ghent University.

Significant difficulties or delays experienced during the first reporting period

No significant delays were experienced during the first reporting period.

Sub-contracted work during the first reporting period

No sub-contractor for partner 10.

Research activities during the second reporting period

Discussion and research performed on selecting and producing optimized plywood.

Significant difficulties or delays experienced during the second reporting period
No significant delays were experienced during the second reporting period.

Sub-contracted work during the second reporting period
No sub-contractor for partner 10.

Research activities during the third reporting period
Selection of optimized plywood and specific production

Significant difficulties or delays experienced during the third reporting period
No significant delays were experienced during the third reporting period.

Sub-contracted work during the third reporting period
No sub-contractor for partner 10.

Research activities during the fourth reporting period
Koskisen attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Significant difficulties or delays experienced during the fourth reporting period
No significant delays were experienced during the fourth reporting period.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 10.

Partner 11

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Scientific team

Esa Lappalainen, Ilkka Seppänen

Objectives

Partner 11 will concentrate on the production of painted craft liner coated plywood and different edge sealing systems.

Workplan

WP 1

1.2 Production of coated plywood

Coated birch plywood (ply thickness 1.5 mm) and spruce plywood (ply thickness 3.0 mm) will be manufactured to be assessed in other WPs. Part of the boards will be coated with phenol film or with painted craft liner or primers and topcoats. Choice of different edge sealing technologies will be studied. For the durability tests, three different edge-sealing types will be used.

Partner 11 will focus on birch plywood and spruce plywood having different painted surfaces. The edge-sealing was concentrated in Ghent.

1.3 Production of optimised products

Based on the results obtained from the preliminary tests conduced on the commercially used plywood and on those with special lay-ups and surface protections, the partner will be able to realise optimised plywood with better performance for exterior use.

Deliverables

The following deliverable was covered during the first reporting period:

D1. Coated and uncoated birch and spruce plywood samples for other WPs, month 6.

Research activities during the first reporting period

- The crude birch and spruce plywood panels were taken from the ordinary production line.
- The craft liner papers were hot-pressed on plywood. Alternatively other panels were fine sanded.
- All the panels were paint-coated (wood preservatives, primers, top coating) on the automatic painting line.
- Because the paint types were changed many times in the painting line, a lot of panel material was used for the optimization of painting conditions.

Significant difficulties or delays experienced during the first reporting period

The panels were coated on the ordinary painting line, which was difficult to reserve for test trials for longer time. Thus, the optimization for each paint treatments was made rather fast. For this reason the coating quality in the longer production use can be in the average slightly higher.

Sub-contracted work during the first reporting period
No sub-contractor for partner 11.

Research activities during the <u>second</u> reporting period
Discussion and research performed on selecting and producing optimized plywood.

Significant difficulties or delays experienced during the second reporting period
No significant delays were experienced during the second reporting period.

Sub-contracted work during the second reporting period
No sub-contractor for partner 11.

Research activities during the <u>third</u> reporting period
Delivered to VTT, Helsinki, Finland:

- WISA-Die Birch BB, birch plywood panels, MUF glued, non-coated, size 15 x 1200 x 1200 mm, amount 4 panels

Delivered coated plywood panels to University of Ghent, Belgium:

- Warkaus Floor Grating, birch plywood, size 35 x 1500 x 1500 mm, 6 panels

- WISA-Multiwall White, birch plywood, size 15 x 1200 x 2400 mm, 6 panels

- WISA-SP Eco, birch plywood, size 15 x 1200 x 2400 mm, 6 panels

- WISA-Container Floor, birch plywood painted by Teknopox 210 epoxy paint, gray, size 28 x 1220 x 2440 mm, 6 panels

Delivered combi and mirror plywood panels with or without Xyligen to Ghent Belgium:

- WISA-Combi BB plywood, (birch and spruce, without Xyligen 25 F treatment), non-coated, size 15 x 1200 x 2400 mm, 6 panels

- WISA-Form Combi plywood, dark brown, (birch and spruce, without Xyligen 25 F treatment), flat phenol formaldehyde film on both side, size 15 x 1200 x 2400 mm, 6 panels

- WISA-Mirror BB plywood, (birch and spruce, with Xyligen 25 F treatment), non-coated, size 12 x 1200 x 2400 mm, 6 panels

- WISA-Wire/Film Mirror plywood, (birch and spruce, with Xyligen 25 F treatment), PF wire film on one side, flat PF film on the other side, size 12 x 1200 x 2400 mm, 6 panels

Significant difficulties or delays experienced during the third reporting period
No significant delays were experienced during the third reporting period.

Sub-contracted work during the third reporting period
No sub-contractor for partner 11.

Research activities during the fourth reporting period
UPM-Kymmene attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Significant difficulties or delays experienced during the fourth reporting period
No significant delays were experienced during the fourth reporting period.

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 11.

Partner 12

Name: **ALLIN**
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e-mail: allin-sa@allin.fr

Scientific team

François Allin, Texier, Laurent, Rondonnet

Objectives

The company Allin is experienced in the use of durable top veneers on poplar plywood and will optimise this product in view of increased service life under exterior use.

Workplan

Durable top veneer poplar plywood will be manufactured for assessment under other WPs. Different pure poplar plywood types will also be provided.
Optimised products will be produced based on results obtained with these board types.

Deliverables

The following deliverable was covered:
D6. All plywood material available for testing, month 24

Research activities during the first reporting period

Four different types of plywood have been produced and delivered to Ghent University (P1):

- Plywood with top veneers okoumé, inner veneers: length okoumé, cross poplar, 15mm/7plies, 6 panels, uncoated, size: 2500mm x 1220mm x 15mm
- Plywood with top veneers okoumé, inner veneers poplar, 15mm/7plies, 6 panels, uncoated, size: 2500mm x 1220mm x 15mm
- Okoumé plywood, 15mm/7plies, 6 panels, uncoated, size: 2500mm x 1220mm x 15mm
- Plywood with top veneers moabi, inner veneers poplar, 15mm/7plies, 6 panels, uncoated, size: 2500mm x 1220mm x 15mm

Significant difficulties or delays experienced during the first reporting period

No delays were experienced during the first reporting period

Sub-contracted work during the first reporting period

No sub-contractor for partner 12.

Research activities during the second reporting period

Discussion and research performed on selecting and producing optimized plywood.

Significant difficulties or delays experienced during the second reporting period

No delays were experienced during the second reporting period

Sub-contracted work during the second reporting period

No sub-contractor for partner 12.

Research activities during the <u>third</u> reporting period
Selection of optimized plywood and specific production

Significant difficulties or delays experienced during the third reporting period
No delays were experienced during the third reporting period

Sub-contracted work during the third reporting period
No sub-contractor for partner 12.

Research activities during the <u>fourth</u> reporting period
Allin attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Significant difficulties or delays experienced during the fourth reporting period
No delays were experienced during the fourth reporting period

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 12.

Partner 13

Name: **SMURFIT ROL PIN**
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Tel.: +33 5 58044242, Fax: +33 5 58044253
e-mail: marc.vincent@fr.smurfitgroup.com, Serge.rouger@fr.smurfitgroup.com

Scientific team

M. Vincent, S. Rouger, Seguin, Lassagne

Objectives

The company Smurfit Rol Pin is experienced in the production of maritime plywood using different combinations of veneer thickness. Impact of heartwood content and plywood lay-up on increased service life under outdoor conditions is envisaged.

Workplan

A range of plywood compositions will be supplied to the other WP's including variations in veneer thickness, maritime pine heartwood/sapwood ration and the incorporation of hardwood species.

Deliverables

The following deliverable was covered:

D6. All plywood material available for testing, month 24: delivered 4th quarter 2003

Research activities during the <u>first</u> reporting period

Sorting of various thickness maritime pine veneers. Manufacturing of panels bonded with PF glue. Control production parameters.

Smurift Rol Pin produced and delivered following plywood type to Ghent University:

- Maritime Pine plywood, 17mm/7plies, uncoated, PF, 6 panels, size 2500mm x 1250mm x 17mm

Significant difficulties or delays experienced during the first reporting period

No delays were experienced during the first reporting period

Sub-contracted work during the first reporting period

No sub-contractor for partner 13.

Research activities during the <u>second</u> reporting period

Discussion and research performed on selecting and producing optimized plywood.

Smurfit Rol Pin produced and delivered following optimized plywood types to be distributed by Ghent University:

- Maritime Pine plywood groove, 15mm/7plies, uncoated, PF, 6 panels, size 2500mm x 1250mm x 15mm
- Maritime Pine plywood treated high temperature, 15mm/7plies, uncoated, PF, 6 panels, size 2500mm x 1250mm x 15mm

- Maritime Pine plywood treated preservative product by vacuum and pressure, 15mm/7plies, uncoated, PF glued, 6 panels, size 2500mm x 1250mm x 15mm
- Maritime Pine plywood 15mm/7plies, coated with phenolic film, PF, 6 panels, size 2500mm x 1250mm x 15mm

Significant difficulties or delays experienced during the second reporting period
No delays were experienced during the second reporting period

Sub-contracted work during the second reporting period
No sub-contractor for partner 13.

Research activities during the <u>third</u> reporting period
Selection of optimized plywood and specific production

Significant difficulties or delays experienced during the third reporting period
No delays were experienced during the third reporting period

Sub-contracted work during the third reporting period
No sub-contractor for partner 13.

Research activities during the <u>fourth</u> reporting period
Smurfit Rol Pin attributed time and effort to come to the final outcome by discussing with the coordinator mainly through the FEIC technical group the implementation of the results.

Significant difficulties or delays experienced during the fourth reporting period
No delays were experienced during the fourth reporting period

Sub-contracted work during the fourth reporting period
No sub-contractor for partner 13.

4. PROJECT MANAGEMENT AND COORDINATION

First reporting period

- 1st Project Coordinating Committee (PCC) meeting in Helsinki, Finland (24th of January 2003)
- 2nd Project Coordinating Committee (PCC) meeting in Sabbioneta, Italy (9-10th of October 2003)
- Extra meeting for partners 2 (UNITO) and 3 (CIRAD) in Montpellier (20th of November 2003)
- 4 extra meetings between the Finnish partners:
    - 14th of January 2003, Helsinki
    - 21st of March 2003, Helsinki
    - 30th of September 2003, Helsinki
    - 25th of November 2003, Helsinki

Second reporting period

- Extra meeting for scientific partners in Montpellier, in France (15th of September 2004)
- 3rd Project Coordinating Committee (PCC) meeting in Hamburg, Germany (4-5th of November 2004)
- 2 extra meetings between the Finnish partners:
    - 9th of February 2004 Helsinki, Finland
    - 10th of May 2004 Helsinki, Finland

Third reporting period

- 4th Project Coordinating Committee (PCC) Meeting in Hämeenlinna, Finland (23rd – 25th of May 2005)

- Extra meetings between the Finnish partners:

    - 4th of February 2005, Rajamäki, Finland
    - 9th of May 2005, Helsinki, Finland

- Extra meeting between the coordinator (partner 1) and Smurfit Rol Pin (partner 13) (3rd of February 2005), Labouheyre, France.

- Extra meeting between the coordinator (partner 1) and Allin (partner 12) (4th of February 2005), Le Vanneau, France.

Fourth reporting period

- 5th Project Coordinating Committee (PCC) Meeting and Technical project meeting in Bordeaux, France (16th – 17th January 2006)

- 6th Project Coordinating Committee (PCC) Meeting and Technical project meeting in Valencia, Spain (14th June 2006)

- 7th Project Coordinating Committee (PCC) Meeting and Technical project meeting in Ghent, Belgium (11th – 13th December 2006) – Final meeting.

Each project coordination meeting (PCC) resulted in a compilation of discussions in a meeting report (minutes) which were included on the project website alongside presentations given by the different partners.

Additional meetings of coordinator partner 1 (UGENT) for implementation / discussion with industry

Brussels, Belgium, 31 January 2007, FEIC technical working group meeting.

Paris, France, 13 November 2007, meeting with Bernard Chevaldonnet (FEIC).

Montpellier, France, 21 November 2007, meeting with partner CIRAD.

Milan, Italy, 14 February 2008, meeting with partner UNITO.

Paris, France, 8 April 2008, meeting with Bernard Chevaldonnet (FEIC).

Brussels, Belgium, 13 May 2008, meeting with FEIC Technical Group.

Ghent, Belgium, 22 September 2008, meeting with Kris Wijnendaele and Bernard Chevaldonnet (FEIC).

Hanover, Germany, 8 October 2008, meeting with FEIC Technical Group.

5. EXPLOITATION AND DISSEMINATION ACTIVITIES

The project's website has been updated with a new URL-address (www.plybiotest.be), a password-protected part containing relevant publications issued by the project-partners, and a group photo taken during the Sabbioneta meeting. The website contains an introduction to the project's objectives, the expected achievements, the workplan, a presentation of each partner and links to all partner's websites.

Presentation material and quality illustration introducing a non-specialist audience to the project's objectives and field of interest can be found respectively on the websites of project's partners. Links to these websites can be found on the project's website (www.plybiotest.be).

The ongoing project has been discussed both in meetings (twice a year) at CEN TC38 WG23 and via FEIC-meetings also related to CEN TC112 WG2. This way both Standardisation Committees and the industrial platform were involved.

A compilation of results have been produced as an Implementation document. This allowed thorough discussion with the industry and among project partners. This document as well as a brainstorming document was finalized by the second half of 2008 and will suit as basis for implementation of results in enhanced test methods, new and further complemented European standard as well as basis for additional industrial and institute research projects. The final version of the Implementation document is dated 15 June 2008 and the Brainstorming document 15 May 2008.

Following papers/presentations were produced with the results from the plybiotest project (sorted on year of publication):

Faraji, F., Thévenon, M.F. and Thibaut, B. (2004). Evaluation of the natural durability and ultrasonic method for decay detection of some European hardwood and softwoods species. *The International Research Group on Wood Preservation*, 07-10/06, Ljubljana, Slovenia. Doc IRG/WP04-10537, 12 pages.

Faraji, F., Thévenon, M.F., Grill, J. and Thibaut, B. (2004). Evaluation of the natural durability of plywoods made of mixed durable and non-durable timbers, and ultrasonic methods to detect fungal decay. Colloque Sciences et Industries du Bois, 2-4/11, Ecole Nationale Supérieure des Technologies et des Industries du Bois, Epinal, France.

De Smet, J., De Windt, I. and Van Acker, J. (2006) L-joint based testing for service life prediction of exterior plywood in out of ground contact conditions *The International Research Group on Wood Preservation*, Stockholm, IRG/WP06/20342, 16 pages.

De Smet, J. and Van Acker, J. (2006) Testing methodology and CE-marking for biological performance of plywood for exterior construction purposes. Proceedings of the Cost Action E44 – E49 Conference in Valencia, Spain on "Wood resources and panel properties" (Editors: J. Van Acker, M. Irle and J.-V. Oliver, ISBN 94-95077-24-8), 189-199.

Van Acker, J., De Smet, J. and De Windt, I. (2006) Service Life Performance of Plywood in View of CE-Marking for Biological Durability. 5th European Wood-based Panel Symposium, Hanover, Germany, 4-6 October 2006, 12 pages

Van Acker, J. and De Smet, J. (2007) Moisture dynamics of plywood in exterior applications as a basis for service life prediction. COST Action E37 –Florence (Italy), 5-6 November and Proceedings of Proceedings of the International Panel Products Symposium (IPPS), Cardiff, UK (Editor M. Spear, ISBN 978-1-84220-097-1), 47-60.

Van Acker, J. and De Smet, J. (2007) Service life prediction of plywood. *The International Research Group on Wood Preservation*, Stockholm, IRG/WP07/20367, 10 pages.

Van den Bulcke, J. and Van Acker, J. (2008) Time resolved analysis of the moisture dynamics of plywood. Proceedings of the Cost Action E37 Final Conference in Bordeaux, France: "Socio-economic perspectives of treated wood for the common European market" (Editors: J. Van Acker and R.-D. Peek, ISBN 9789080656505), 65-75.

Viitanen, H., Nurmi, A., MetsäKortelainen, S., Jämsä, S. and Paajanen, L. (2008) Effect of Coatings on the Performance and Durability of Birch Plywood – Results after Outdoor Weathering and Accelerated Decay Resistance Assessments. Proceedings of the International Panel Products Symposium (IPPS), Espoo, Finland, 335-340.

Van Acker, J. and Van den Bulcke, J. (2008) Time of wetness as indicator for service life prediction of plywood in use class 3 applications. 6th European Wood-based Panel Symposium, Hanover, Germany, 8-10 October 2008, 15 pages.

6. ETHICAL ASPECTS AND SAFETY PROVISIONS

There are no specific ethical aspects involved in this project. Safety provisions are primarily related to laboratory fungal testing and industrial safety measures to produce plywood for testing.