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Abstract

Laser Powder Bed Fusion (LPBF) is an Additive Manufacturing (AM) process that allows the production of fully dense near net shape metal components using 3D CAD data as digital information. Despite the strong interest in this innovative technology, nowadays, only a few alloys can be processed by LPBF processes. There is therefore a strong interest in the development of new alloys especially designed for AM. In the present study the microstructure and the mechanical properties of three new aluminium alloys were investigated by means of laser single scan tracks experiments. In particular the new compositions were obtained by adding copper and silver to an AlSi10Mg powder and using a Al-Er pre-alloyed powder. The geometrical features and the microstructure of the scans were investigated and compared with the AlSi10Mg ones.

Introduction

Laser Powder Bed Fusion (LPBF) is a powder bed Additive Manufacturing (AM) technology that, due to the extremely high cooling rates (10^{3-8} K/s [1]), belongs to the Rapid Solidification (RS) process class. Nowadays, as only a few commercial casting alloys are available for this technology, there is a strong interest in the development of new alloy compositions that can take advantages of the rapid cooling that arises during the LPBF building process. Recently in fact some research works focused on the development of new alloy compositions especially designed for this innovative production technology [2–4]. An alloy specifically designed for AM processes should be characterised by a fine melting range and a good fluidity in the molten state in order to avoid the liquation cracking phenomenon [5,6]. Moreover, it should contain alloying elements that can take advantage of the rapid cooling by forming supersaturated solid solutions and metastable phases coherent with the matrix.

Previous studies demonstrated that the introduction of Transition Metals (TM) on the microstructure and of rapidly solidified aluminium alloys allows an increase in the mechanical properties due to highly dispersed intermetallic particles [7,8]. In particular, the effect of copper and silver on the microstructure and the properties of Al alloys was investigated in previous studies [9–14]. Matsuda et al. for example investigated and compared the precipitates that form due to the addition of Cu and Ag to an Al-Mg-Si alloy [11]. Nakamura demonstrated that Ag enters the composition of the β' phase and modifies its lattice parameter [9]. Kubota et al. studied the properties of Ag/Cu modified Al-Mg-Si alloy showing that Cu is more effective on the strength increase while Ag and Cu have a similar effect on the elongation [12].

Previous studies focused also on the introduction of Rare Earth (RE) elements to aluminium showing that these elements lead to the refinement of the microstructure, the precipitation of coherent phases and to a strong increase in the mechanical properties [15]. Among RE elements, erbium showed to have an important strengthening effect as it forms the $L1_2$ Al_3Er phase which has a lattice parameter very similar to the Al one [16]. The effect of this alloying element on the microstructure and the properties of an aluminium alloy was assessed by Colombo et al. who demonstrated that Er causes the refinement of the A356 microstructure and the increase in its mechanical properties [18]. Wen et al. demonstrated in fact that Er is particularly effective in increasing the high temperature strength of Al alloys and that the addition of only 0.2% wt Er to an Al-Mg-Mn-Zr alloy allows a 50% increase in the yield strength [17].

However these studies were carried out on samples produced by conventional technologies such as casting and hot rolling. To date, to the best of our knowledge, no study was carried out on the effect of the introduction of these elements in AM samples**.**

In the present study the LPBF processability of Al-Si-Mg-Cu, Al-Si-Mg-Ag and Al-Er alloys was investigated. In order to reduce the material consumption, in this preliminary phase, laser single scan tracks (SSTs) were performed in order to have a first insight on the processability and the properties of these new compositions.

Materials and methods

An EOS M270 Dual Mode system was used to build all the samples. This machine uses an Yb fiber laser with a power up to 200 W and a scan speed up to 7000 mm/s; the whole process is carried out in Ar atmosphere on an heatable platform.

A gas atomised AlSi10Mg powder provided by EOS GmbH was dry mixed with 4%wt Cu and 0.5%wt Ag particles provided by Sandik AB and Topcast Srl, respectively, in order to obtain an AlSi10Mg+Cu and AlSi10Mg+Ag powder batches. The nominal composition of the mixed powder batches are reported in Table 1. The pre-alloyed Al-3%Er gas atomised powder was provided by Nanoval GmbH. Field Emission Scanning Electron Microscope (FESEM) micrographs of AlSi10Mg and Al3%Er particles, reported in Fig. 1, show that in both cases the particles have a spherical shape suitable for the LPBF process, however both powders contain some satellites. Finer particles were present in the Al3%Er pre-alloyed powder batch.

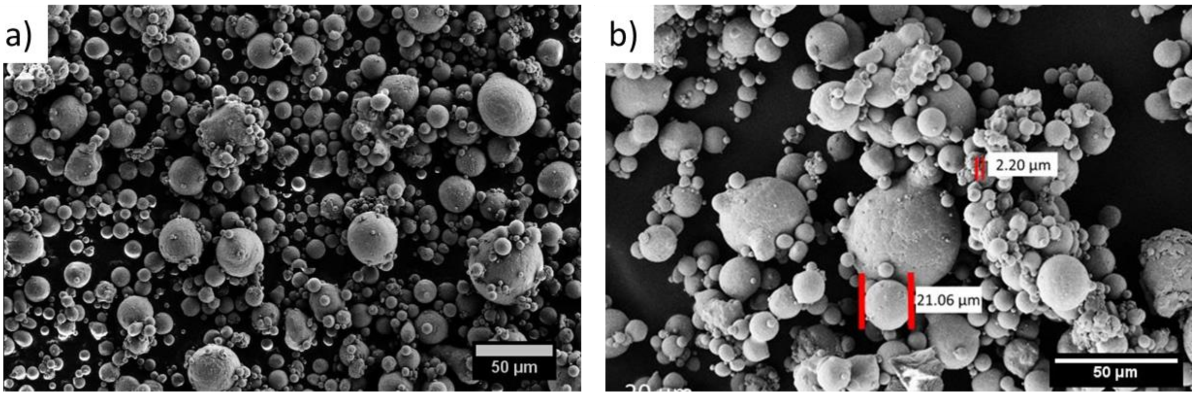

Figure (FESEM) micrographs of a) AlSi10Mg and b) Al3%Er

Table 1 Nominal chemical composition of the powder batches used

	Si	Fe	Mn	Mg	Zn	Ti	Cu	Ag	Others
AlSi10Mg	9.0-11.0	<0.55	<0.45	0.20-0.45	<0.10	<0.15	-	-	<0.05
AlSi10Mg+Cu	8.6-10.6	<0.55	<0.43	0.19-0.43	<0.10	<0.14	4	-	<0.05
AlSi10Mg+Ag	9.0-10.9	<0.55	<0.45	0.20-0.45	<0.10	<0.15	-	0.5	<0.05

Laser single scan tracks were produced on a EOS modified building platform as described in previous works [19,20]. In order to simulate as much as possible a real LPBF process, for each powder batch the SSTs were built on substrates with a composition similar to the powder. For the AlSi10Mg+Ag and AlSi10Mg+Cu single scan tracks AlSi10Mg substrates were used while for Al3%Er ones pure Al was selected.

The building parameters, selected on the basis of the results obtained by previous works, were varied in the ranges reported in Table 2 [19,20].

Table 2 Ranges of building parameters used

	Power	Scan speed	Layer thickness

	(*P*)	(*v*)	(*t*)
Min	100 W	300 mm/s	50 µm
Max	195 W	1500 mm/s	

The single scan tracks obtained with the three compositions were at first observed on top by a Leica DMI 5000 microscope in order to assess the melt pool stability. All the scan were then cut mounted and polished in order to observe the beads cross sections. The geometrical features of the melt pool were measured using the Image J software.

Results and discussion

The on top optical micrographs were used to build the process windows reported in Fig. 2. The different SSTs morphologies identified in previous studies are reported in Fig. 2 c).

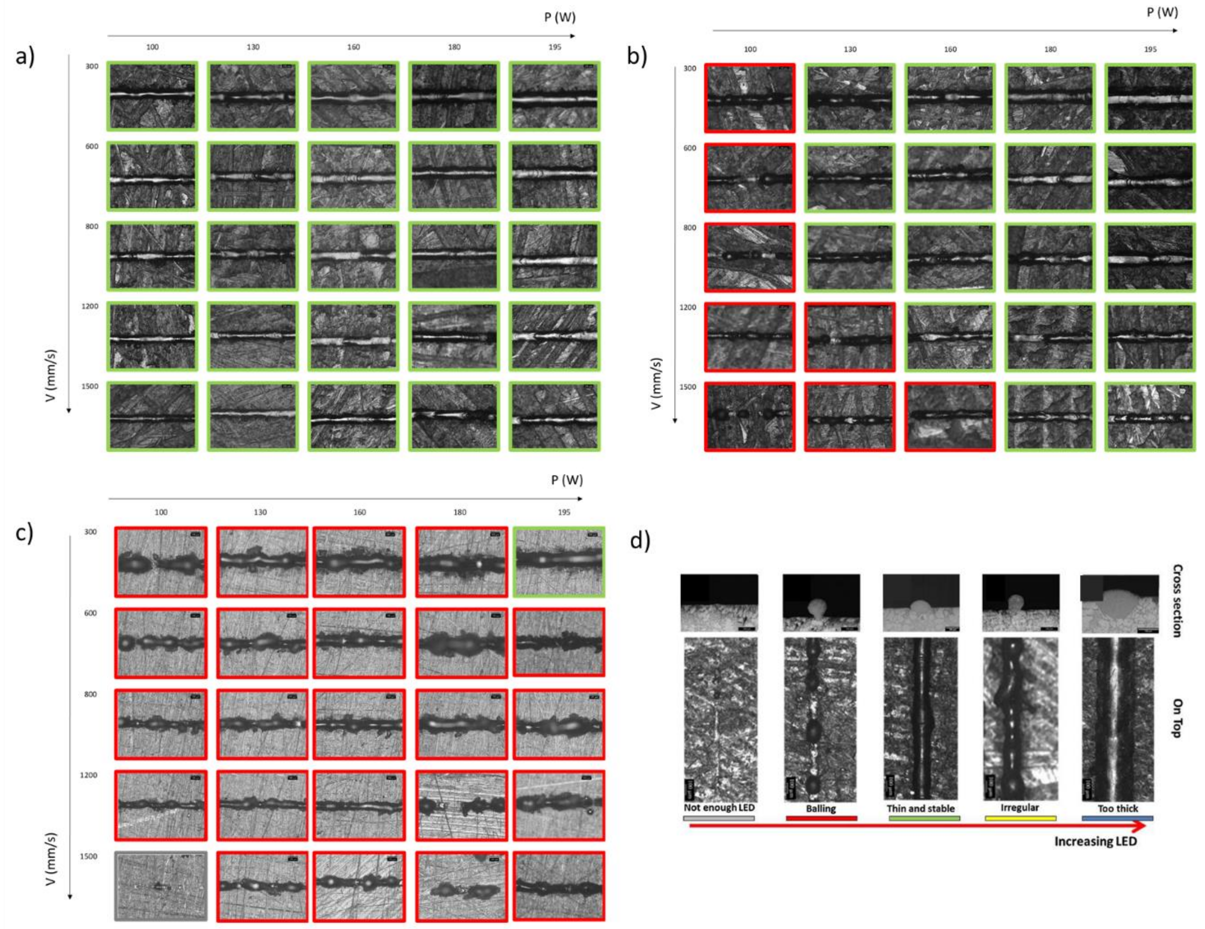

Figure 1 Process windows of a) AlSi10Mg+Ag, b) AlSi10Mg+Cu, c) Al3%Er and d) scan morphologies (colours indicate the scan morphology)

With the AlSi10Mg+Ag powder batch stable and continuous scan tracks can be obtained with all the building parameters used in this study. This powder has in fact a processability very similar to the AlSi10Mg one [19]. On the contrary, the AlSi10Mg+Cu SSTs are not stable with all the process parameters. Scan tracks built with low power and high scan speed values are in fact characterised by some balling. This instability is probably due to the large quantity of Cu particles characterised by a high reflectivity [21]. Finally, the process map of the Al3%Er powder revealed that this alloy is scarcely processable by LPBF. Most of the SSTs display the morphology typical of the balling phenomenon. Some SSTs were discontinuous or detached from the building platform suggesting a poor penetration in the substrate. Only the scan built with the highest power and the lowest scan speed values showed to have a continuous morphology. This suggests that the melt pool instability of this powder is due the low powder laser absorption which is probably caused by the lack of Si, responsible for the laser absorption in Al-Si alloys [19]. This preliminary on top analysis suggests that this composition need to be modified in order to be processable by LPBF; in particular elements with a higher laser absorption must be added.

The cross section images of the scan built with the standard AlSi10Mg standard parameters (P=195 W and v=800 mm/s), reported in Fig. 3, confirm the results obtained by on top micrographs. The AlSi10Mg+Ag melt pool is dense and has a regular shape. On the contrary AlSi10Mg+Cu melt pool is characterised by an irregular shape and by the presence of some pores suggesting some scan track instability. Fig. 3 c) clearly shows that in this case no penetration in the substrate was observed, the melt pool lays in fact on the substrate and is strongly asymmetrical.

The dimensions melt pool obtained with 195 W and 800 mm/s, calculated according to the schematic representation reported in Fig. 3 d), are reported in Table 3. The scan width (*W*) only slightly varies while the scan height (*H*), depth (*d*), growth (*g*) and angles (*α*) seem to be strongly affected by the powder properties.

Finally, it is interesting to underline that, due to a strong balling behaviour, in the Al-3%Er melt pool the scan is higher than the layer thickness (50 µm). In a real LPBF process this will cause the hindering of the recoater movement and the interruption of the building process.

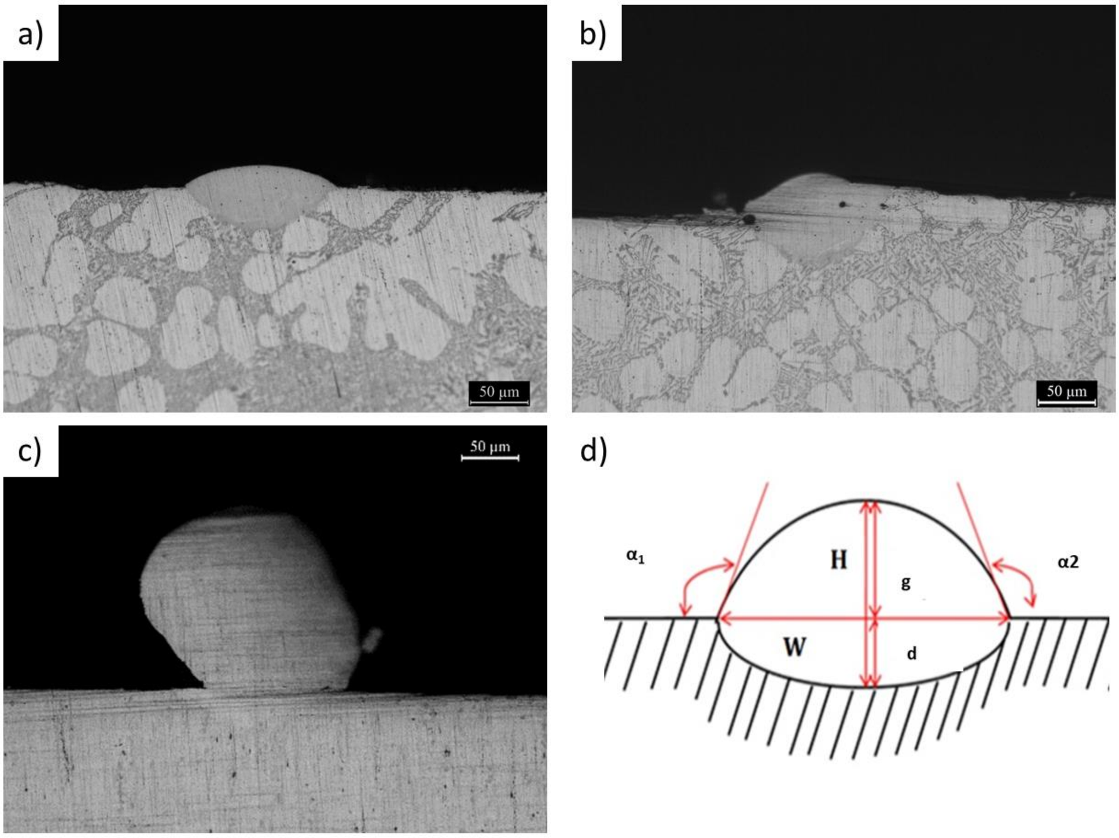

Figure 2 Optical micrographs of a)) AlSi10Mg+Ag, b) AlSi10Mg+Cu, c) Al3%Er melt pools built with P=195 W and v=800 mm/s and d) schematic representation of a melt pool cross section with the most significant dimensions.

Table 3 Melt pool dimensions of the scans

	W (µm)	H (µm)	D (µm)	G (µm)	α_1 (µm)	α_2 (µm)	α_{mean} (µm)
AlSi10Mg+Ag	132.8	55.4	36.8	18.6	147.3	148.0	147.7
AlSi10Mg+Cu	144.0	65.4	39.7	22.9	143.9	165.0	154.5
Al3%Er	122.4	154.1	0.0	152.5	61.7	48.4	55.1

Conclusions

In this work the LPBF processability and the properties of three new alloy compositions were evaluated by performing single scan tracks. The results show that it was possible to produce SSTs with all powder batches without critical issues such as cracks. However, the three powders are characterised by different laser absorption and present therefore different scan morphologies.
The observation of the scan tracks highlight the importance of the selection of the building parameters for a successful LPBF process.
Finally, the study of the Al3%Er scan suggests that the composition of this powder must be modified by the introduction of some elements with a high laser absorption.

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