REALIZATION AND CHARACTERIZATION OF AlSiMg/SiC COMPOSITES BY DIRECT METAL LASER SINTERING

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Abstract
Many materials have been processed successfully and many reports are available in literature on the Direct Metal Laser Sintering (DMLS) of iron and steels, superalloys, Ti and Al alloys. Recently, also processing of composite materials has attracted interest due to the potential of the process in freeform fabrication of intricate articles in a reduced production cycle.
In this paper are summarized the main results for the realization of AlSiMg/SiC composites by DMLS: it was fundamental to study the laser sintering parameters, like laser energy and scanning speed, to obtain sintered specimens with density near to the theoretical one. The resulting composites were then investigated through optical and electron microscope.

1 Introduction
Additive Manufacturing (AM) of metal end-usable parts is well recognized as an interesting substitute to other conventional or unconventional processes for medium batch production, thanks to its capability to produce complex shapes and integrated parts towards highest strength to weight ratio [1]. As a matter of fact, additive technologies directly translate virtual three-dimensional (3D) models into physical parts in a quick and easy process. Basically the data is sliced into a series of thin sections then combined into the AM machine, adding them together in a layer by layer sequence [2]. Among the main European companies that have put on the market machines based on laser systems for direct melting of metal powders, EOS GmbH has been recognized as the market leader after the introduction in 2004 of the EOSINT® M270 Direct Metal Laser Sintering (DMLS) machine [3,4]. By means of a high energy focused laser beam a localized region of a very thin layer (from 0.02 to 0.06 mm) of metal powder directly fuses: it is possible to obtain directly 3D metallic components near full density with minimal post processing requirements. Moreover, if in the past the issues related to the atmosphere in the building chamber and the safety risk limited the availability of materials to bronze-based or steel powders [5-7], recent development allowed to extend the range of available materials to Cobalt–Chromium, Titanium and lastly Aluminum alloys. Aluminium alloys as lightweight materials are very attractive for the production of parts that

require good mechanical properties in combination with a low weight. Recently EOS Gmbh has introduced on the market an AlSi10Mg alloy, a typical casting alloy, similar to die cast A360.0 alloy. The alloy combination of aluminum, silicon and magnesium results in a significant increase in strength [8]. However for high-demanding applications, like in automotive and aerospace industries, it is necessary to improve its stiffness, hardness and high temperature properties: this can be done employing some reinforcements, like discontinuous particles of silicon carbide. As a matter of fact Al-SiC metal matrix composites (Al-MMCs) are now widely used in many fields: from brake drums and cylinders liners of automobiles, to structural parts of aerospace like rotor vanes and plates. There are several methods, such as powder metallurgy, squeeze casting, stir casting to fabricate such composites, nevertheless these conventional techniques are expensive and not suitable for small volumes and complex shapes. In the recent past different research groups investigated the feasibility to employ DMLS to obtain Al-based MMCs [9-12]. In this work an EOSINT® M270 Xtended has been employed to realize MMCs using commercial AlSi10Mg and SiC powders respectively of micrometric and sub-micrometric size. The powders have been simply mixed using a ball milling system and then processing has been carried out in an Ar atmosphere using different laser energies at different scanning speeds to realize geometric regular samples. After polishing the composites density was measured and the resulting microstructures were analyzed by optical and electron microscopy.

2 Materials and methods

The aluminum powder alloy used in this work is a gas atomized one, furnished by EOS Gmbh (Germany). It has a nominal density of 2.68 g/cm^3, and its composition is reported in Table 1. As previously stated the AlSi10Mg is a typical casting alloy used for example for parts with thin walls and complex geometry. In the data sheet the producer guarantees that all the particles have a dimension lower than 63 μm, with an average of 40 μm.

Element	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Ti**	**Al**
Weight%	9-11	≤0.55	≤0.05	≤0.45	0.2-0.45	≤0.15	reminder

Table 1. Processing parameters employed for the realization of the composites cubic samples

On the other hand the ceramic powder is α-SiC powder from H.C. Starck UF-15 (15 m^2/g) with a density of 3.2 g/cm^3 and a mean particle size of 0.55 μm.

The experimental investigation started with the as-received powders characterization by means of a Field Emission Scanning Electron Microscope (FESEM, Zeiss SupraTM 40) in order to evaluate their shape, size and distribution. In the SEM images reported in Figure 1 it can be noted that: the aluminum alloy particles are spherical and quite regular in shape, ranging in dimensions from 1 to 45 μm (Figure 1a), in accordance with the producer; on the other hand SiC particles have an angular shape and show a small tendency to agglomerate (Figure 1b).

To realize the composite it was choose to use 10% in weight of SiC, mixing the powders by means of a ball milling system in ceramic jars, without any grinding medium, for 48 hours. Subsequently they were dried for removing any humidity and sieved with a mesh of 63 μm before putting them in the DMLS machine. The processing has been carried out in an Ar atmosphere using a powerful Yb (up to 200W) fiber laser with a spot size of 0.1 mm able to be tuned to different energies at different scanning speeds. As a result 10 cubic shaped samples of 15 mm per side were realized, following a matrix generated by the above mentioned parameters as summarized in Table 2.

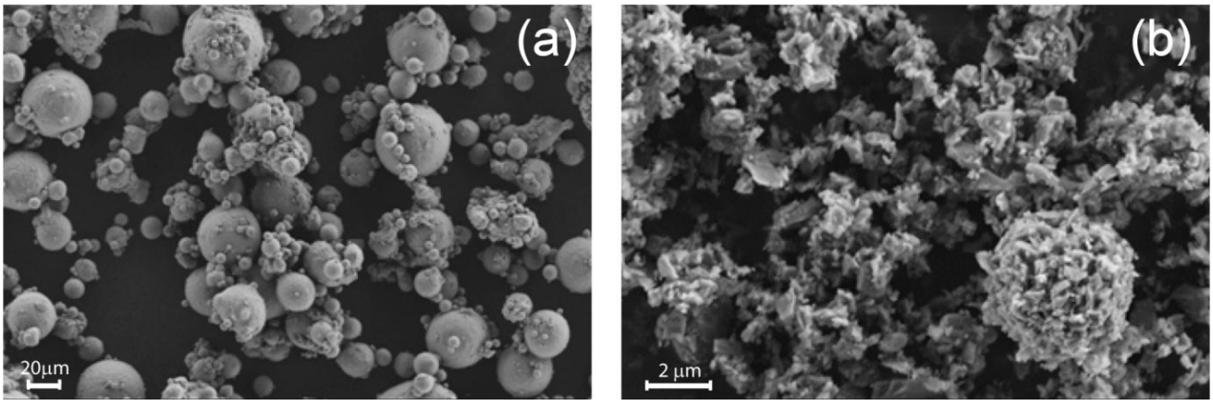

Figure 1. SEM images of the as-received commercial powders: AlSi10Mg0.3 on the left (a) and SiC on the right (b)

	Scanning Speed (mm/s)				
Laser Power (W)	**900**	**800**	**700**	**600**	**500**
195	N. 1	2	3	4	5
180	6	7	8	9	10

Table 2. Processing parameters employed for the realization of the composites cubic samples

After removal from the building platform, the geometric density of the sample was evaluated taking into account the rule of mixture for the theoretical AlSiMg/SiC 10wt% density reference. For metallography, the sintered samples were sectioned in parallel to the building platform (parallel to XY plane) and along the building direction (Z axis), so along the thickness, and polished down to 1 µm diamond paste. The microstructure was studied by optical and scanning electron microscopy (FESEM).

3 Results

As can be observed at FESEM the mixing of the powders allows to obtain round AlSiMg particles covered by a sort of "fluff" made of SiC particles (Figure 2b), while the mean size and the morphology of the particles remain virtually the same (see Figure 2a). This is very important for the DMLS process, in which a fundamental parameter is the thickness of the powder layer that the recoater-blade spread onto the building platform each time up to the desired height of the samples.

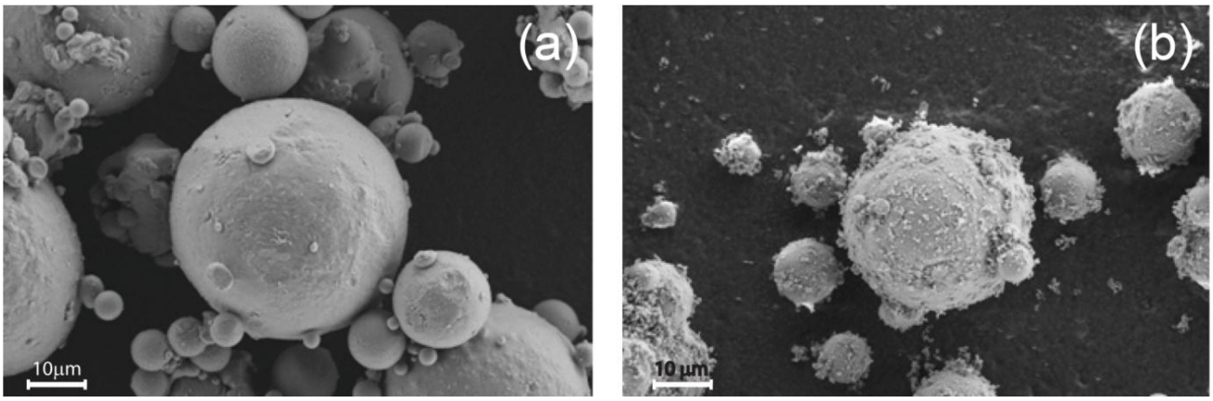

Figure 2. SEM images of AlSi10Mg0.3 powders before (a) and after (b) mixing in ball milling with SiC the left (a) and SiC on the right (b)

So in this work it was used the value of 30 μm as layer thickness, the same of standard EOS AlSiMg. However the so realized particles, due to the new surface aspect, have a different behavior in terms of flowability, causing some problems during the additive process.
In figure 3 is reported a picture showing the cubic composites samples realized on the aluminum building platform: the number reported on the top surface is related to the parameters employed for each sample, as already indicated in Table 2.

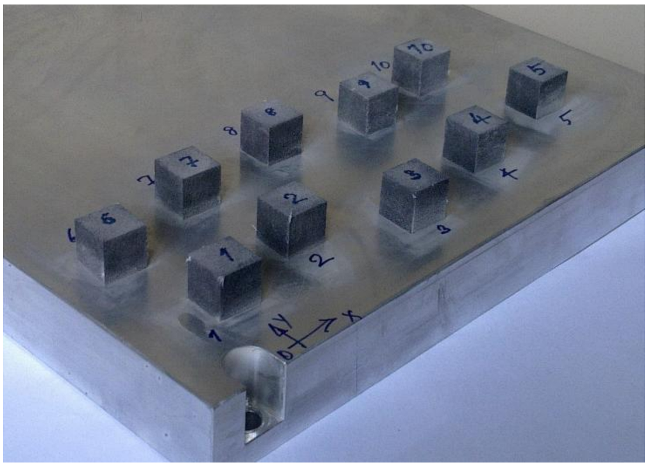

Figure 3. The AlSiMg/SiC composites samples realized on the building platform (XY plane): the numbers corresponds to a different combination of processing parameters, as indicated in Table 2

The measured average density of the samples was 2.6 g/cm^3, and taking into account a theoretical value of 2.73 g/cm^3, it means a mean porosity of around 5%. It should be noted that many samples suffered of cracks formation, a common problem of Al based MMCs by DMLS, as reported in literature [12].
The microstructure illustrated in the optical micrographs of Figure 4, taken from a polished sample after etching with Weck’s reagent, is characterized by individual laser scan lines easily distinguishable, typical of this process: rapid cooling in DMLS creates very small grain sizes, and subsequent layer deposits only partially re-melt the previously deposited layer.
The black arrow in Figure 4b indicates the building direction (Z axis).

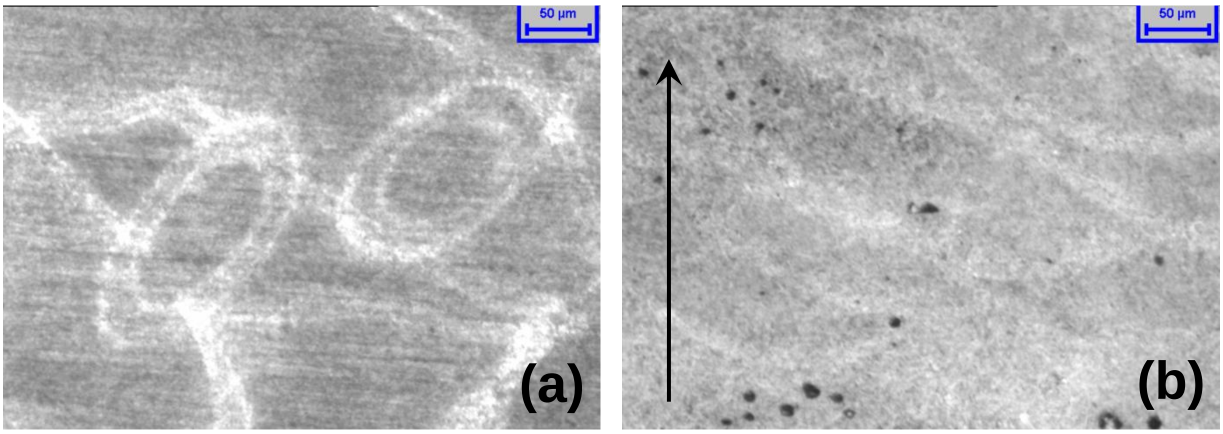

Figure 4. Optical image of AlSiMg/SiC composite microstructure after polishing and etching with Weck’s reagent: a section parallel to the building platform (XY) on the left (a); a section along the building direction (Z axis) indicated by the arrow, on the right (b)

Some porosity is visible in the section along the building direction, but the pore dimension is very fine and the bigger ones are always below 100 μm.
In Figure 5 the same section (along Zaxis) was observed at FESEM: going to higher magnification allows to appreciate the very fine dendrites that form, due to the extremely rapid solidification after the laser local melting and related to the local heat-flow direction (figure 5a). It is possible to detect also some small agglomerate of SiC grains (figure 5b) that probably arise from the mixing step.

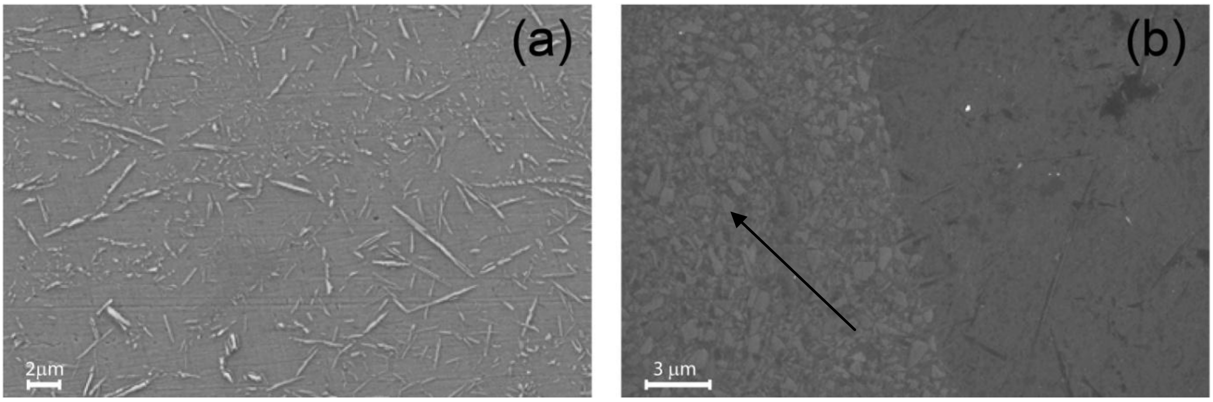

Figure 5. FESEM images of AlSiMg/SiC composite microstructure after polishing in a section along the building direction (Z axis): on the left (b) some SiC agglomerates are indicated by a black arrow

4 Conclusions

AlSiMg/SiC-10%wt. composites were fabricated by DMLS using different parameters in terms of scanning speed and power of the laser source. The powders employed were simply prepared starting from commercial ones and mixed by ball milling without the grinding means. Microscope analyses reveal a very fine microstructure for the final composites, with little porosity (densities up to 95 were obtained) more concentrated in the section taken along the building direction (Z axis) than in the one parallel to the XY plane. This is probably due to the lower flowability of the composite powder with respect to the AlSiMg starting one.

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