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On the formation of AlSiMgCu/quasicrystal powder composite single tracks by selective laser melting

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Abstract. The process of selective laser melting (SLM) of an Al-Si-Mg-Cu powder composite with the addition of quasicrystal reinforcements under conditions of a limited powder amount was investigated. The morphology and microhardness of the obtained scan single tracks were discussed, and the optimal sintering parameters were found to be in the Linear Energy Density (LED) range 0.21-0.30 J/mm. The following SLM parameters: P = 370 W and v = 1650 mm/s given the optimal characteristics of scan single tracks geometry with less defects. The obtained composites exhibited an improved hardness with the highest values of 235 HV with the 8% of reinforcements in the powder mixture.

1. Introduction

Quasicrystal (QC) is an intermetallic compound with a long-range order, but without translational periodicity, was first discovered by D. Shechtman et al. in 1984 [1] and more than a hundred kinds of quasicrystals with different industrial applications have been developed up to date. QC are well known for their high strength and hardness, low friction coefficient, high corrosion and wear resistance [2,3] However, due to their high room-temperature brittleness, the applications of QC alloys are limited by their low workability using conventional manufacturing processes. Therefore, manufacturing of any complex shape details from QC materials is an important challenge and issue [4].

One of the possible ways to extend the potential applications of QC materials and benefit from their useful properties is to use them as reinforcement in metal matrix composite materials (MMCs) with the profit from the ductility of the matrix material. As a manufacturing method for MMCs, selective laser melting (SLM) have some obvious advantages. Amongst them are: the production of 3D components with customized geometries, ultra-fine microstructure due to the high cooling rate peculiar for the SLM process, which causes higher mechanical properties. Moreover, the metal-based reinforcements are also possible to be in-situ formed during the preparation of MMCs with strong metallurgical bonding [2,5].

Therefore, developing of Al-based QC-reinforced composite materials via SLM may be interesting for the production of lightweight metallic components with low density/high wear resistance which can be used in automotive and aviation industries [6]. Thus, in this study, Al-based QC reinforced system was selected, due to its low density and potential in-situ reaction between matrix and reinforcement.

Aluminum alloy acted as matrix material in order to obtain a high bonding strength between reinforcement and matrix, due to the high content of Al in reinforcement [3,7]. Current research aims at the investigation of optimal SLM parameters for the experimental composition of a new Al-Si-Mg-Cu powder with different contents of QC reinforcement. The objective of this work is to select the optimal printing mode considering the limited amount of available material based on the study of the formation of the scan single tracks with the investigation of their microstructure and microhardness. This method is a powerful way to rapidly investigate the behavior of new compositions for SLM and to study the effect of the parameters on the geometrical features of the molten pool.

2. Materials and methods

The initial powders for the samples fabrication were Al-Si-Mg-Cu (chemical composition: 87% Al, 10.7% Si, 0.5% Mg, 0.7% Cu, fractional amount of Mn, Ti, Fe and other impurities) alloy (D_{50} = 40 μm) powder obtained by the molten metal spraying method and gas atomized $Al_{45}Cu_{33}Fe_{22}$ QC (D_{50} = 35 μm). Before SLM, the two types of powder were blended with a 1%, 4% and 8% content of QC in the Al alloy matrix in a tumbling mixer for 120 min and dried at 80 °C for 4 h.

The SLM Solutions 280 HL 3D printer was used for selective laser melting. An aluminum–magnesium alloy (AMg5 brand, chemical composition: 94% Al, 5% Mg, 0.5% Mn, 0.2% Si, and no more than 0.1% of other impurities) was used as the substrate material. The laser spot (LP) size was was 80 μm. All samples were synthesized in a nitrogen atmosphere, and the residual oxygen content in the working area was less than 0.2 vol. % for all sample types. A powder layer of approximately 100 μm in thickness and a single pass with a laser beam was used to form scan single tracks with a length of 100 mm. The SLM printing parameters for scan single tracks were selected and varied in the following ranges: P = 250–370 W and V = 850–1650 mm/s.

Scanning electron microscopy SEM and characterization of powders were performed using a Tescan VEGA 3 scanning electron microscope with a NORAN X-ray energy dispersion spectrometer (EDX) and an element mapping attachment. Optical microscopy (OM) of scan single tracks was carried out using a ZEISS Axio Observer Z1 microscope. The microhardness of the samples was measured using a Tukon 1102 microhardness tester. The microhardness was measured at a load of 0.025 N with an indentation time of 10 seconds.

3. Results and discussion

SEM images of the composite obtained by mechanical mixing of the powder with QC particles are demonstrated in Figure 1. It can be noticed that all Al-Si-Mg-Cu particles have a quasi-spherical shape and the method used for the preparation of the composite powder do not damage the initial particles. The EDX mapping analysis showed that the reinforcement of QC particles had a normal distribution in the composite structure. Here it can be pointed out that the introduction of QC particles with non-spherical shape into the molten sprayed powder leads to reduction of its flowability [8], which is one of the key property for the SLM processes. However, in the present work only scan single tracks were considered and the influence of the QC addition on the flowability was not investigated. Based on the results obtained on the size and geometry of the particle, the initial powder was applicable for selective laser melting.

The influence of printing parameters was studied using the Linear Energy Density (LED, J/mm) calculated using equation (1):

$$LED = P / V. \tag{1}$$

where P is the laser power (W) and V is the scan speed (mm/s).

Cross-section images of the most representative single tracks within different LED ranges are presented in Figure 2. According to the scans geometry, three main process ranges were selected: LED = 0.15-0.20 J/mm, LED = 0.21-0.30 J/mm and LED > 0.35 J/mm. For different powders, the geometrical features have a similar behavior and the total scan width increases with LED values (Figure 3 (a)). The morphology of scan single tracks is dependent on the applied laser parameters by varying the thermodynamic and kinetic characteristics of the molten pool.

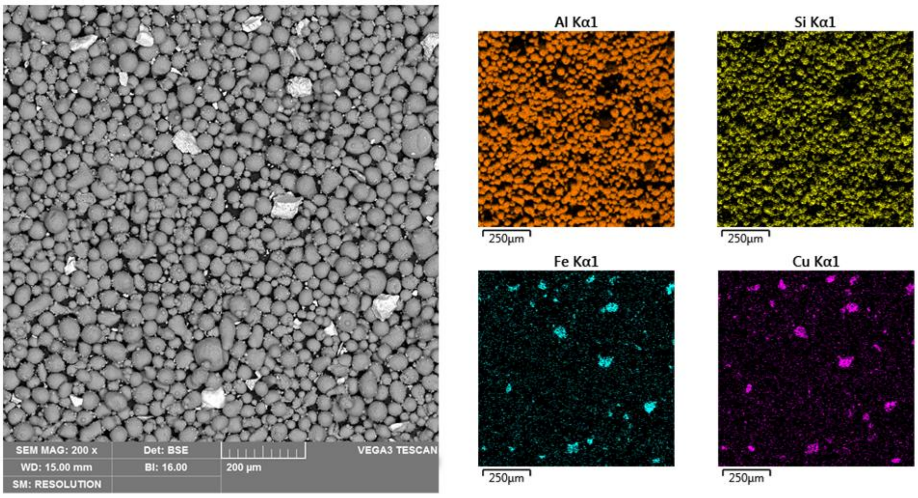

Figure 1. SEM and EDX mapping of initial powder composite after mechanical mixing

Scans in the LED range of 0.15-0.2 J/mm were not completely melted are characterized by a low penetration depth due to the low wettability and high viscosity of the melt due to the limited applied laser energy. On the other hand, deep melt pools were observed with the LED more than 0.35 J/mm with the presence of defects and pores in the structure due to the overheated molten pool and significant thermal accumulation. Study of cross-section images revealed that most suitable SLM parameters to process an Al-Si-Mg-Cu powder reinforced by QC lies in the LED range of 0.21-0.3 J/mm, taking into account the optimal characteristics of the molten pool and wetting characteristics of the melt.

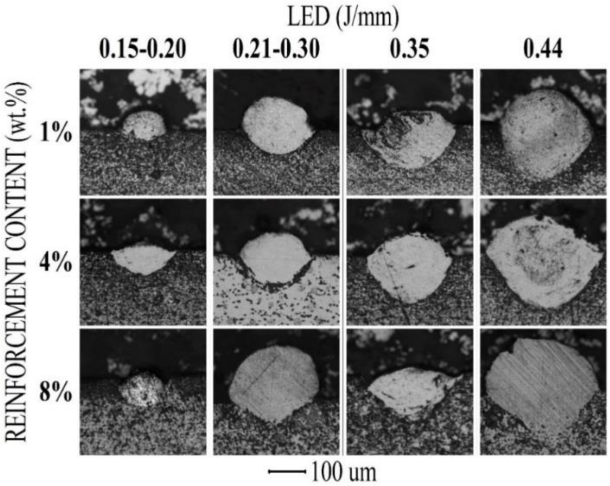

Figure 2. Cross-section images of scan single tracks

The described above was confirmed by the microhardness results, measured on the cross-sections and presented in Figure 3 (b). The microhardness of the composites with different QC content underwent a continuous increase from 159 HV to 235 HV with an increase in LED from 0.15 to 0.23 J/mm and followed by a minor changes up to LED = 0.31 J/mm. These process parameters result in increased microhardness and less defects, such as pores and micro cracks in the structure. A further increase in LED to more than 0.35 J/mm leads to a decrease in microhardness to 123 HV, which indicates the presence of microcracks and pores, which tend to lower hardness performance. But comparing to unreinforced Al-Si-Mg-Cu powder manufactured by SLM with an average microhardness value of 125 HV [7], the studied composite demonstrates an increased microhardness.

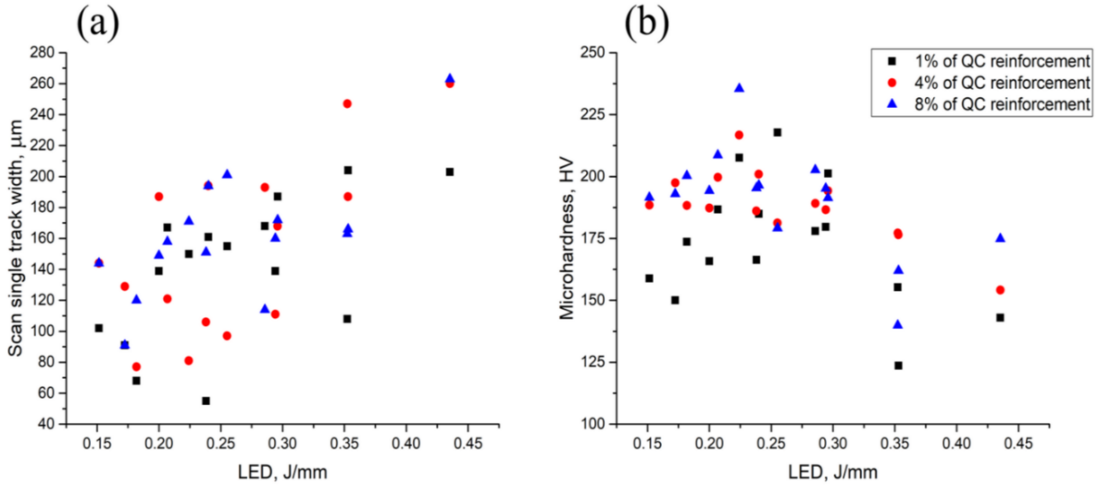

Figure 3. Influence of the LED on the (a) width and (b) microhardness of printed scan single tracks.

4. Conclusions

The formation of scan single tracks of an Al-Si-Mg-Cu powder composite reinforced with different amount of quasicrystal was studied, and the influence of selective laser melting parameters on the geometry and microhardness were investigated. The optimal process parameters were found to be in the LED range 0.21-0.30 J/mm taking into account the optimal scan single tracks geometry. The composites exhibited improvement hardness comparing to the one without QC reinforcement. The highest hardness values of 235 HV were obtained with 8% of QC reinforcements with the following SLM parameters: P = 370 W and v = 1650 mm/s. These process parameters resulted in an increased microhardness and structure with less defects throughout the material.

5. Funding

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References

[1] Shechtman D, Blech I, Gratias D, Cahn J W 1984 *Phys. Rev. Lett.* **53** 1951-1953
[2] Lu J L, Lin X, Liao H L, Kang N, Huang W D, Coddet C 2020 *Opt. Laser. Technol.* **129** 106277
[3] Kang N, Fu Y, Coddet P, Guelorget B, Liao H, Coddet C 2017 *Mater. Des.*. **132** 105-111
[4] Shadangi Y, Sharma S, Shivam V, Basu J, Chattopadhyay K, Majumdar B, Mukhopadhyay N K 2020 *J. Alloy Compd.* **828** 154258
[5] Jue J, Gua D, Chang K, Dai D 2017 *Powder Technol.* **310** 80-91
[6] Nalivaiko A Y, Arnautov A N, Zmanovsky S V, Ozherelkov D Y, Shurkin P K, Gromov A A 2020 *J. Alloy Compd.* **825** 154024
[7] Nalivaiko A Y, Arnautov A N, Zmanovsky S V, Gromov A A 2019 *Mater. Res. Express.* **6(8)** 086536
[8] Aversa A, Moshiri M, Librera E, Hadi M, Marchese G, et al. 2018 *J. Mater. Process Technol.* **255** 17-25