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An investigation on selective laser melting of Al-Cu-Fe-Cr quasicrystal: From single layer to multilayers

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ABSTRACT

In this study, the effects of processing parameters on the microstructure of Al-Cu-Fe-Cr quasicrystalline (QC) coatings fabricated by selective laser melting (SLM) are investigated. A qualitative analysis on the XRD patterns indicates that the phase composition for the SLM processed coating mainly consisted of Al-Cu-Fe-Cr quasicrystals and α-Al (CuFeCr) solid solution, and with increasing laser energy input or coating thickness, the volume fraction of QC i-$Al_{91}Fe_4Cr_5$ reduced and those of QC d-$Al_{65}Cu_{20}Fe_{10}Cr_5$ and crystalline θ-Al_2Cu increased. The formation of cracks during the coating building procedure from single layer to multilayers is also discussed. For the coatings with the same layer number, the pores and balling particles diminish as laser power increases, due to the growth of melting degree. At the early stage of fabrication, with increment of layer number (or coating thickness), pores and balling particles decrease considerably because the molten pool solidified more "slowly". However, after the layer number increases continuously from 10 to 20, the porosity no longer decreases, and some big size pores, micro-cracks and fractures appear, especially for the sample obtained at lower laser power. A wavy-like pattern composed chiefly of Al and QC phases, is formed at the interfacial region between substrate and coating due to Marangoni effect.

1. Introduction

As intermetallics with long-range order but no translational periodicity, quasicrystals have aroused more and more interests in the intense theoretical and experimental studies, since firstly discovered by Schatman et al. in the case of rapid solidified Al-Mn alloy in 1984 [1]. Over one hundred kinds of quasicrystals were developed up to date, they all are generally known for their high strength, high corrosion and wear resistance, such as quasicrystalline (QC) alloys based on aluminum [2], copper [3], magnesium [4], nickel [5], titanium [6] and zinc [7]. Among metallic glasses, Al-Cu-Fe system QC alloys are known to present a very low cost and high forming ability [8]. The QC phases can be obtained using conventional solidification, which allows us to produce large single-grain samples with a relatively low cooling rate [9]. However, due to their high room-temperature brittleness, the applications of QC alloys are confined to the coating area [10] or metal-matrix/polymer-matrix composite materials as reinforcement particles [11,12]. Thermal spraying technologies were considered as an effective way to produce the QC coatings [13] and quasicrystal-reinforced composites [14], the high ductility of substrate/matrix material could compensate for the fragile mechanical properties. Recently, spray forming technology was used to produce the bulk Al-Cu-Fe based quasicrystals and composites [15,16]. They indicated that the spray formed sample presents a high hardness and low ductility, leading to low workability.

Selective Laser Melting (SLM), a novel high accuracy powder-bed fusion additive manufacturing process, has been more and more used in the past decades [17]. And it is particularly attractive to produce near net-shaped components with customized geometries and properties, without resorting to moulds, tools or dies. The 3D parts are constructed layer by layer, using a laser that melts selectively the material particles at the surface of a powder bed to construct the part cross-sections. Moreover, the high cooling rate (10^3–10^8 K/s) could result in an ultrafine microstructure or even metastable phases [18,19]. Attar et al. produced a dense composite part with a nanostructure and high mechanical properties using SLM [20]. Dubois et al. confirmed that using Al-based QC particles

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allows extending the selective laser sintering technology to produce Al-based parts of any complex shape [21]. Therefore, developing Al-based QC or quasicrystal-reinforced composite materials via SLM may be interesting and valuable, for the production of lightweight metallic components, especially in the automotive and aviation industry.

The objective of this work is concentrated on the effects of SLM process parameters, such as laser power and laser scanning speed etc., on the melting of QC material, during which the QC parts present numerous cracks and low formability, as layer number increases. Thus “from single layer to multilayers” method was employed. In this work, $Al_{65}Cu_{20}Fe_{10}Cr_5$ (all compositions are in atom percent unless otherwise stated) QC alloy was melted on a pure Al substrate using SLM under argon atmosphere. The influences of laser power and scanning speed on the microstructure and phase composition were investigated. Additionally, the entire building process from 1 layer (50 μm) to 20 layers (1 mm) was also studied.

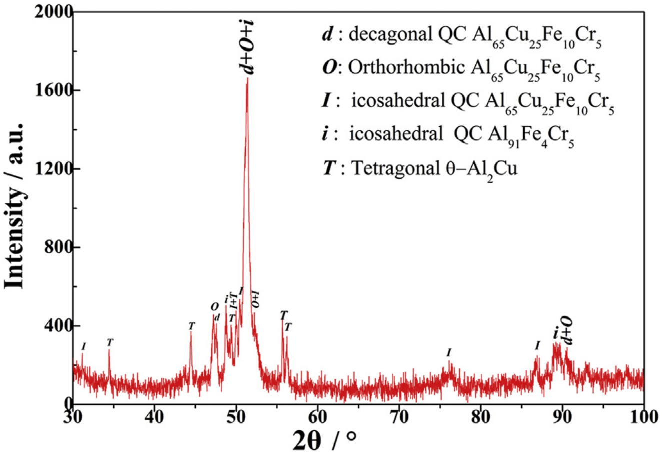

Fig. 2. XRD patterns of gas-atomized powders.

2. Experimental

An $Al_{65}Cu_{20}Fe_{10}Cr_5$ powder produced in the laboratory by gas atomization in argon atmosphere (Nanoval process) was used in this study. The surface morphology and cross-section of the QC powders were shown in Fig. 1(a) and (b). Particles size distribution was determined by laser light scattering (Malvern Masterizer 2000). The raw atomized metal glass powder exhibited an average value of 45 μm (d (50)). The size distribution of the QC powders was shown in Fig. 1(c). QC particles appear free of porosity as shown in Fig. 1(b). The small grains could be observed in both the surface morphology and cross-section of the gas-atomized powders.

X-ray diffraction (XRD) pattern of the gas-atomized $Al_{65}Cu_{20}Fe_{10}Cr_5$ powders is shown in Fig. 2, which indicates that a decagonal QC $Al_{65}Cu_{20}Fe_{10}Cr_5$ (i.e. d-phase) is the major phase; and an orthorhombic $Al_{65}Cu_{20}Fe_{10}Cr_5$ (i.e. O-phase) as an approximant of the d-phase whose XRD patterns are quite similar to those of the d-phase, also exists in the powders. The peaks of d-phase and O-phase can be well indexed according to the scheme proposed by Dong et al. [22]. Additionally, the other three minor phases detected include two icosahedral QC phases, I-$Al_{65}Cu_{20}Fe_{10}Cr_5$ (i.e. I-phase)

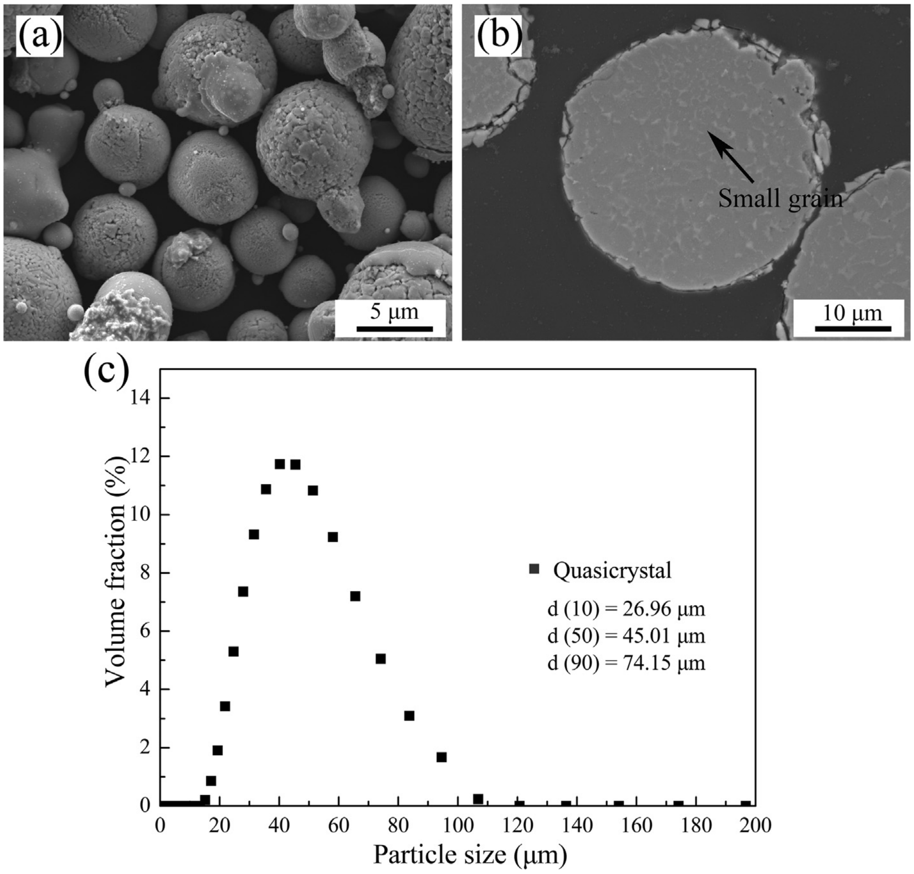

Fig. 1. (a) Morphology and (b) cross-section of the $Al_{65}Cu_{20}Fe_{10}Cr_5$ QC powders.