Growth morphologies and mechanisms of TiC grains during Selective Laser Melting of Ti–Al–C composite powder

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Selective Laser Melting (SLM) was used to consolidate the high-energy ball milled Ti–Al–C composite powder. The morphologies of the in-situ formed TiC grains under different laser processing parameters were investigated. It showed that with increasing the applied laser powers, the TiC grain morphologies experienced successive changes from a laminated shape to an octahedron shape, and then to a truncated near-octahedron shape, and finally to a near-spherical shape. It was believed that the continuously elevated SLM operating temperatures induced by the increasing laser powers played an important role in determining the TiC grain morphologies. Reasonable metallurgical mechanisms for grain growth behind the microstructural developments were proposed.

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1. Introduction

Selective Laser Melting (SLM), as a typical Rapid Manufacturing (RM) technique, enables the quick production of three-dimensional components with complex configurations directly from metals, alloys, or composites powders. SLM creates parts in a layer-by-layer manner by selectively fusing and consolidation of thin layers of loose powder with a scanning laser beam. SLM, due to its flexibility in feedstock and applications. Furthermore, the in-situ presented reinforcements are finer in size and the reinforcement-matrix interfaces are cleaner, yielding stronger interfacial bonding and better mechanical properties [5].

However, SLM involves a transient, dynamic metallurgical process induced by a high-energy, mobile laser beam scanning. Thus, it is rather difficult to control the morphology of the in-situ formed reinforcements in SLM-processed MMCs. As the morphology of the reinforcing grains may significantly affect the final properties of as-processed MMCs, it is highly necessary to be able to understand and control it during SLM. Nevertheless, little previous work has been focused on the relevant issues. In this work, SLM of the high-energy ball milled Ti–Al–C composite powder was performed to prepare in-situ TiC reinforced Ti–Al matrix composites. The microstructural features of the in-situ formed TiC grains under different laser processing parameters were characterized and the reasonable growth mechanisms behind microstructural developments were elucidated.

2. Experimental

The 99.9% purity Ti powder with a polygonal structure and a mean particle size of 30 μm, the 99.5% purity Al powder with an irregular shape and an average particle size of 16 μm, and the pure graphite powder with a mean particle size of 30 μm were used as the raw
An elemental powder mixture consisting of 50 at.% Ti, 25 at.% Al, and 25 at.% graphite was mechanically alloyed in a Pulverisette 6 planetary high-energy ball mill, using the ball-to-powder weight ratio of 10:1, the rotation speed of the main disc of 250 rpm, and the milling time of 32 h. In order to avoid the excessive temperature rise within the grinding bowl, a ball milling duration of 20 min was followed by an interval time of 10 min. The as-prepared Ti–Al–C composite powder had a uniform near-spherical shape and a significantly refined particle size of ∼0.7 μm in average.

3. Results and discussion

Fig. 1 depicts the typical XRD pattern of SLM-processed composites. The strong diffraction peaks corresponding to TiC and TiAl3 were clearly identified. The diffraction peaks for Ti3AlC2, although the intensity was comparatively weak, were also well detected. Therefore, it was reasonable to conclude that SLM of as-milled Ti–Al–C composite powder yielded the TiC reinforced (TiAl3 + Ti3AlC2) matrix MMCs. Within the matrix, the TiAl3 acted as a major phase and the Ti3AlC2 was a minor phase. A detailed metallurgical explanation concerning the formation mechanisms of these two matrix compounds during SLM has been proposed in our previous work [6].

In the present work, we laid a strong emphasis on microstructures and growth mechanisms of the in-situ formed TiC grains during SLM. Fig. 2 shows the characteristic morphologies of the TiC grains under different laser processing parameters. In general, EDX scan results revealed that only two elements Ti and C with a near equal atomic proportion were detected within these grains. Thus, it was reasonable to consider that the TiC grains were completely extracted via the deep etching and dissolution of the metallic matrix. Also, it was noticeable that the TiC grain morphologies were significantly influenced by the applied laser powers. At a relatively low laser power of 700 W, the laminated TiC grains were observed (Fig. 2a). With increasing the laser power to 725 W, although a majority of TiC grains still possessed a laminated structure, the laminated grains became thicker and, meanwhile, the size of each layered grain was decreased (Fig. 2b). Differently, SLM at a higher laser power of 800 W produced the granulated TiC grains with a refined size less than 1 μm (Fig. 2c). High-magnification SEM micrograph (Fig. 2d) revealed that the synthesized TiC grains were typically in an octahedron shape. (We have selectively indicated an exposed half-octahedron in Fig. 2d.) At an even higher laser power of 875 W, the TiC grains had a truncated near-octahedron shape and the grains were slightly coarsened to ∼2 μm (Fig. 2e). (Here we have also indicated an exposed one-half structure.)
power reached 900 W, near-spherical shaped TiC grains with an average grain size larger than 2 μm were formed in SLM-processed MMCs (Fig. 2f).

The reasonable TiC crystal growth mechanisms behind the microstructural developments at different laser processing parameters are provided in Fig. 3. During SLM, the absorbed energy heats up the powder particles speedily, leading to the liquid formation via the complete melting of the Ti–Al–C composite system. The energy gain of the powder is related to the applied laser power, which essentially influences the SLM operating temperature [7]. Generally, the TiC carbides are formed through a dissolution–precipitation mechanism by means of the heterogeneous nucleation of TiC nuclei and the subsequent grain growth [8]. Nevertheless, the morphologies of the TiC grains developed from the liquid are determined by the working temperature. For a low laser power, the obtainable SLM temperature is limited, hence significantly lowering the diffusion velocity of the Ti and C atoms within the melt. In this situation, the present TiC nuclei prefer a two-dimensional layered growth (Fig. 2a and b). Each layer undergoes a preferential growth along the radial direction via the gathering of the Ti and C atoms in this direction, but grows slowly in the normal direction within a three-dimensional space due to the insufficient diffusion activity of the atoms (Fig. 3a).

As the SLM temperature increases at a higher laser power, the TiC grains are developed in an octahedral growth mode (Fig. 2c and d). According to Yang et al. [9] and Jin et al.’s [10] work, TiC is a typically faceted crystal with a NaCl-type structure, in which {111} planes share the highest surface atomic density and the lowest surface energy. The octahedron may act as the growth unit of TiC; in other words, the octahedral TiC grains developed are enclosed by eight {111} planes (Fig. 3b). With increasing the laser power, the octahedral TiC grains change their morphology to truncated near-octahedron (Fig. 2e). In this instance, a higher atomic diffusion rate is realized as the SLM temperature increases, leading to a higher density of crystal defects (e.g., impurities and dislocations) on the {111} planes of TiC. This causes the destabilization of the octahedral grains [11] and thus accelerates the growth of TiC grains in a truncated near-octahedron manner (Fig. 3c). At an even higher laser power, a near-spherical growth mechanism prevails (Fig. 3d). In such a way, the TiC grains with a close-to-orbicular morphology are finally developed. Nevertheless, a slight grain coarsening occurs in this case due to an elevated SLM temperature obtained (Fig. 2f).

4. Conclusions

Selective Laser Melting (SLM) of the high-energy ball milled Ti–Al–C composite powder yielded the in-situ TiC reinforced (TiAl3 + Ti3AlC2) matrix composites. As the applied laser powers increased, the morphologies of the in-situ formed TiC grains experienced successive changes as follows: a laminated shape–an octahedron shape–a truncated near-octahedron shape–a near-spherical shape. The continuously elevated SLM operating temperatures induced by the increasing laser powers determined the growth mechanisms and the resultant morphologies of the in-situ TiC grains.

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