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Enhanced micro-hardness and wear resistance of Al-15Si/TiC fabricated by selective laser melting

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ABSTRACT

High relative density (> 98%) Al-15Si alloy samples were fabricated by selective laser melting (SLM) with laser re-melting process. The micro-hardness and wear resistance of Al-15Si alloy samples were investigated in this study. The addition of 5 wt% TiC improved the micro-hardness of SLM-produced Al-15Si alloy, which had a remarkable micro-hardness of 172.8 Hv. After the heat treatment (annealing or quenching), the hardness of all tested samples decreased significantly, while the Al-15Si/TiC composites with the laser re-melting kept the higher hardness values (145 Hv). This sample presented the lower coefficient of friction (0.42) and wear rate (2.75×10^{-5} mm^3 N^{-1} m^{-1}) than other conditions. Based on the results, the addition of 5 wt% TiC with laser re-melting in SLM process, together with annealing treatment afterwards, was a feasible approach to obtain a high micro-hardness and good wear resistance of Al-15Si alloys.

1. Introduction

Selective laser melting (SLM) is a promising additive manufacturing techniques owing to its flexibility in producing complex shaped parts directly from metal powders [1]. A wide scale of alloys, including titanium alloy [2], nickel alloy [3], steel [4], and aluminum alloy [5] has been fabricated by SLM. Within these alloys, Aluminum (Al) alloy features lightweight and plays a significant role for structure materials. Attempts on Al alloys fabricated by SLM have been carrying out for pure Al [6], Al-7Si-0.3Mg [7], AlSi10Mg [8], Al-12Si [9] and Al-20Si [10] focused on the microstructure and tensile property. A few preliminarily studied the hardness(the maximum micro-hardness, 140 Hv) or wear resistance (the maximum wear rates, 2.94×10^{-5} mm^3 N^{-1} m^{-1}). However, by far the hardness and wear resistance not high enough to satisfy the requirements, requires further investigations.

As a potential reinforcement for Al alloys, TiC exhibits a number of favorable characteristics including high elastic modulus, high hardness and good wettability within the molten Al [11]. Some studies on the SLM of Al alloys with TiC addition were reported. However, they mainly focused on the mechanical properties in terms of processing parameter, microstructure evolution and particle distribution [5,12], rather than the effect of doping TiC on the hardness and wear resistance which had significant contribution to the service performance of Al alloys.

In this work, Al-15Si alloys with high Si content which have excellent wear and hardness performance have been produced by SLM. It aims at investigating the effect of TiC reinforcement, laser re-melting and heat treatment on the micro-hardness and wear property. An optimized condition is chosen to obtain a high micro-hardness and good wear resistance of Al-15Si alloy. This offers the possibility to tune micro-hardness and wear resistance property of Al-15Si alloys to meet specific requirements.

2. Experimental details

The 99.5% purity Al-15Si powder with a spherical shape (D50 = 25 μm) and the 99.7% purity TiC powder with a near spherical shape (D50 = 6 μm) were used in this study. Firstly, the powders were mixed by high energy ball milling method, using a ball-to-powder weight ratio of 1:1, a rotation speed of 200 rpm and a mix duration of 4 h. Then, the mixture were feed to SLM with the HRPM-II SLM machine (Huazhong University of Science and Technology, Wuhan, China). The working chamber was filled with argon gas to avoid the oxidation. The processing parameters were optimized as follow: the laser power of 360 W, scanning speed of 650 mm/s, hatch space of 0.06 mm and the layer thickness of 0.02 mm. In order to improve the surface quality of the sample, the laser re-melting method was used in this study, in which the top/final surface of the part was re-melted after

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Table 1
The relative densities of different samples.

Sample	Al-15Si	Al-15Si(re-melting)	Al-15Si/TiC	Al-15Si/TiC(re-melting)
Rel. density (%)	96.92	98.05	96.25	97.13

the actual laser scanning which melted and fused the materials. To investigate the effect of post heat treatment, half of the samples were heated 6 h at 623 K followed by furnace cooling (annealing) and half of them by water cooling (quenching).

Archimedes method was used to obtain the density of the samples. Vickers indentation tests were conducted to obtain the micro-hardness by Wilson Hardness machine (432SVD) with the loading time of 15 s at 1 kg. Sliding wear tests were performed with the MFT-5000 (Rtec Instrument, USA) under the load of 3 N for 15 min. The counter material was GCr15 bearing steel ball with a diameter of 6.3 mm, mean hardness of 60 HRC. The friction frequency was 4.5 Hz. The wear volumes V of samples were estimated by the confocal scanning optical microscope (Micromeasure2, France). The wear rate w was then calculated as follows: $w = \frac{V}{FL}$ (mm^3/Nm), where F is the contact load and L is the total sliding distance. The worn surfaces morphologies were observed by SEM (JSM-7600F, Japan).

3. Results and discussion

Table 1 shows the relative density of Al-15Si and Al-15Si/TiC samples produced by SLM. It indicates that the laser re-melting process increases the density by about 1%. The result can be contributed to the re-melting effects of removing surface contaminates, breaking down oxide films and providing a clean solid-liquid interface at the atomic level [13]. Besides, it also can be seen that the samples with TiC addition have the lower relative density than those without TiC. During the SLM process, the TiC particles can increase the viscosity of Al alloy melts, which handicaps the sufficient flow of the melt and then decreases the overall rheological performance of the composite melt [8].

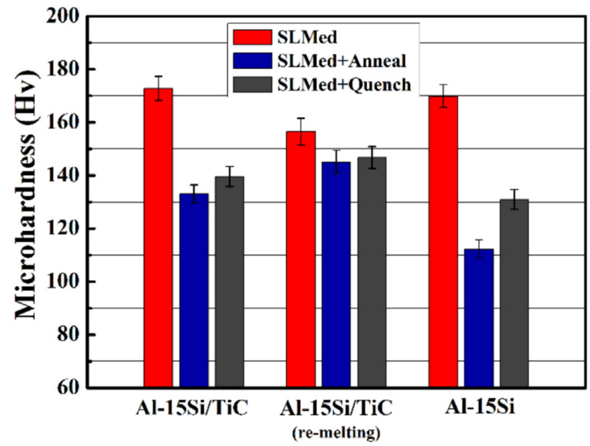

Fig. 2. The effect of TiC and heat treatment on the micro-hardness of Al samples.

Fig. 1 shows the microstructure of Al-15Si/TiC samples with different processing conditions. It can be seen the TiC particles are dispersed uniformly in Al matrix through SLM process with and without laser re-melting strategy as shown in Fig. 1a and d. Further, the elements distributed in the Al matrix are analyzed by EDX as shown in Fig. 1c and f. It also could be seen that Si, Ti and C were more evenly distributed in the Al matrix for the sample with laser re-melting strategy than that sample without laser re-melting strategy. Therefore, it can be speculated that the laser re-melting strategy can promote the uniformity of element distribution. It is easy to understand that the solidified surfaces are carried out a heat treatment through the laser re-melting. In this case, the microstructure and element distribution has been changed.

Fig. 2 depicts the micro-hardness on the top view of Al-15Si and Al-

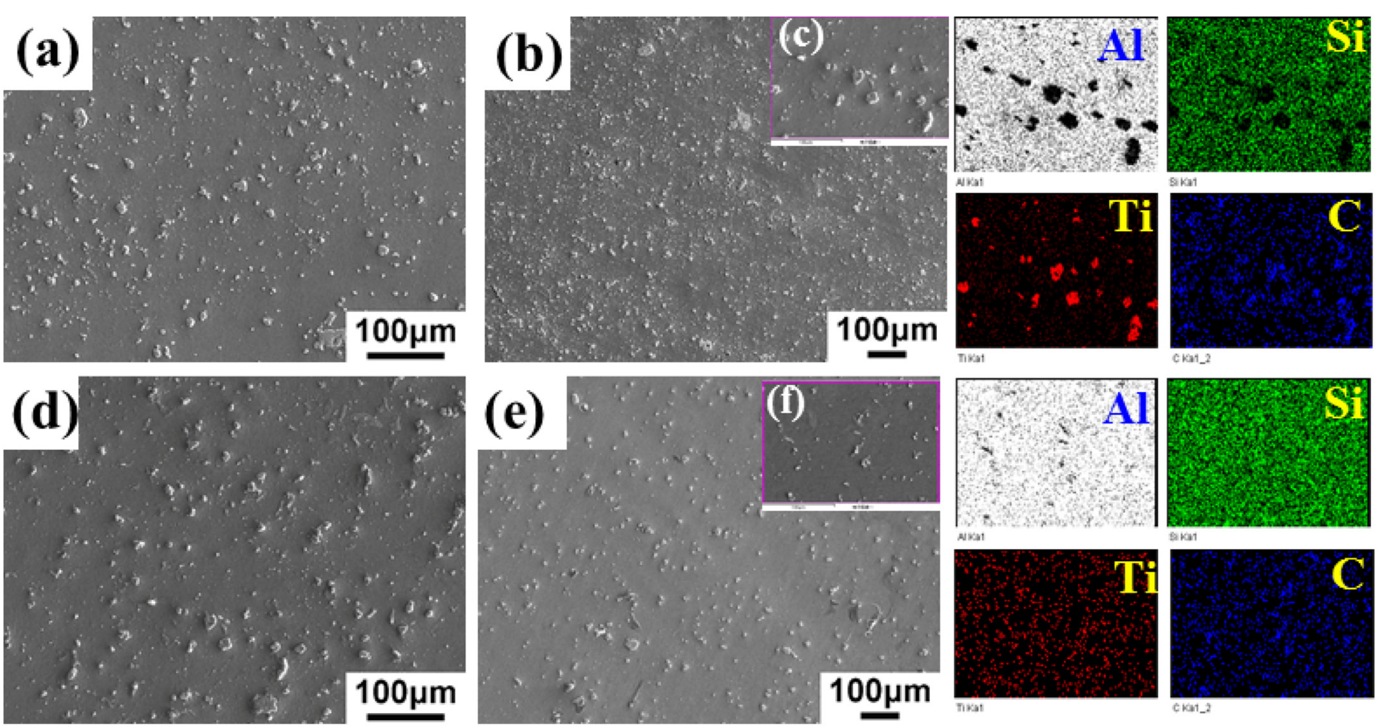

Fig. 1. SEM of the samples (a) SLM-processed Al-15Si/TiC, (b) SLM-processed Al-15Si/TiC with annealed treatment and corresponding EDX maps of Al, Si, Ti and C; SEM of the samples with laser re-melting (d) SLM-processed Al-15Si/TiC, (b) SLM-processed Al-15Si/TiC with annealed treatment and corresponding EDX maps of Al, Si, Ti and C.