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Selective Laser Melting of Novel SiC and TiC Strengthen 7075 Aluminum Powders for Anti-Cracks Application

Yingjie Li, Hanlin Liao

Department of Materials Science and Engineering, UTBM, Belfort, France
Email: yingjieli618@163.com,Hanlin.liao@utbm.fr

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Abstract

The aerospace and military sectors have widely used AA7075, a type of 7075 aluminum alloy, due to its exceptional mechanical performance. Selective laser melting (SLM) is a highly effective method for producing intricate metallic components, particularly in the case of aluminum alloys like Al-Si-Mg. Nevertheless, the production of high-strength AA7075 by SLM is challenging because of its susceptibility to heat cracking and elemental vaporization. In this study, AA7075 powders were mechanically mixed with SiC and TiC particles. Subsequently, this new type of AA7075 powder was effectively utilized in green laser printing to create solid components with fine-grain strengthening microstructures consisting of equiaxial grains. These as-printed parts exhibit a tensile strength of up to 350 MPa and a ductility exceeding 2.1%. Hardness also increases with the increasing content of mixed powder, highlighting the essential role of SiC and TiC in SLM for improved hardness and tensile strength performance.

Keywords

Selective Laser Melting (SLM), AA 7075, Fine Grain Strengthen, TiC, SiC, Green Laser

1. Introduction

Selective laser melting (SLM) offers several benefits compared to traditional production methods in metal fabrication [1]. Typically, constructing components layer by layer allows for the creation of intricate shapes on a large scale, expanding their use in industries like aerospace and biomedical [2]. Currently, only a restricted range of materials, such as titanium alloy and certain steels, may be easily produced using SLM with sufficient density and mechanical qualities that meet industrial standards [3]. Consequently, there is a high need for the growth of material options in this technology.

Al-Zn-Mg-Cu alloys of the 7 series aluminum alloy family are widely used due to their low weight and high specific strengths [4]. However, hot cracking makes AA7075 unsuitable for SLM processing. Hot cracks in AA7075 start in the semi-solid stage and expand during solidification, which pose long-term difficulties for broad applications [5]. Due to SLM's inherent properties, including a significant temperature gradient (~106 K/m) and thermal pressures, massive, directed dendritic grains may develop during solidification, causing crack propagation along grain boundaries [6]. Hot cracks are difficult to eradicate in materials with a wide freezing range, such as AA7075. The aerospace sector relies on costly machining and riveting to obtain complicated geometries due to the limited printing and welding capabilities of AA7075.

Recently, powder mixing has gained importance in metallurgy by mixing ceramic particles with the metal matrix to improve alloy characteristics. Recent research reports limited effectiveness in eliminating cracks in aluminum alloys using mixed powders in various production processes. Traditional techniques may be used to cast crack-free Al-Zn-Mg-Cu with TiC or TiB_2 particles [4], and nano-treated welding rods can connect high-strength AA7075 without cracking [7]. Adding particles may improve the tribological [8] and thermal performance of 7-series aluminum alloys, making them more desirable for various applications. This study will introduce one novel and successful strengthening method for enhancing the anti-crack properties of AA7075 by mixing SiC and TiC integrated particles manufactured by SLM. Crack-free features with high hardness and tensile strength will be obtained by mixing 2% TiC and 2% SiC. This research offers valuable insights for developing powder-mixing aluminum alloy powders for SLM.

2. Experimental Procedures

The AA7075 powder, which had been mixed with SiC and TiC micro-scale particles from Sichuan Huomosi Industrial Technology Co., Ltd., was used as the raw material for printing components utilizing the TruPrint 1000 additive manufacturing system. Particle size was measured by a laser diffraction powder sizer (Mastersizer 2000, Malvern Instruments Ltd., UK), revealing sizes of 15 - 60 μm, 1 - 5 μm, and 1 - 10 μm for AA7075, SiC, and TiC, respectively. A novel green laser configuration was employed in this study. The wavelengths of green laser and fiber laser (normally used) are different, and the corresponding absorption rates are also different. The absorption rate of green light is better. Aluminum alloy can be printed with lower energy and reduce the evaporation of Mg and Zn elements in AA7075 (see **Figure 1**). Optimized processing parameters are laser power 300 W, scanning speed 800 mm/s, and energy density 78.1 J/mm^3.

To characterize and analyze the properties, the samples were ground using SiC papers up to a 1200 grit size. Subsequently, they were polished using 200-proof

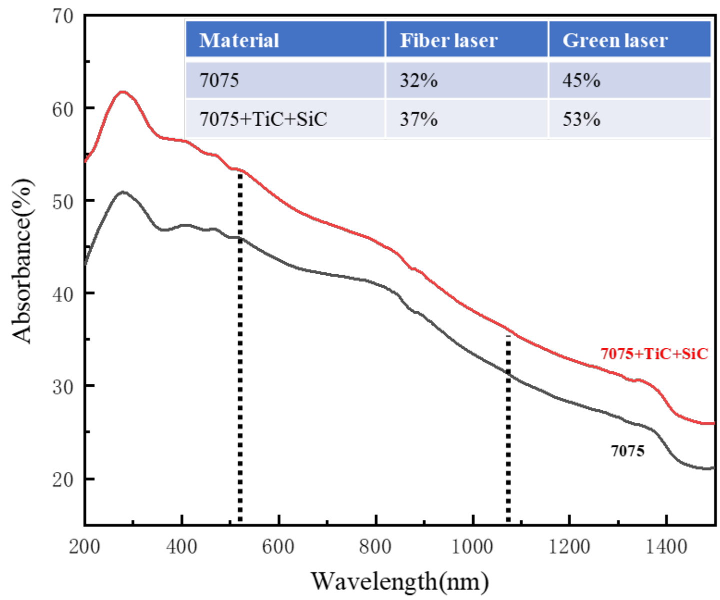

Figure 1. Green laser generation for AA7075 and mixed powder.

anhydrous ethanol and a 0.05 μm alumina polishing slurry. Tensile testing was performed using an INSTRON 5967 Electronic universal testing machine, with a nominal strain rate of 0.001 mm/mm per second. Following the tensile testing, the fracture surfaces were analyzed using scanning electron microscopy (SEM) with a German ZEISS Sigma 300 instrument. Gold spray was used as the target for electron conductivity enhancement. The gun used is a Schottky field emission electron gun, with a resolution of 1.0 nm @ 15 k. The SEM was equipped with energy dispersive spectroscopy (EDS, Smartedx), as well as Electron backscatter diffraction (EBSD, Oxford Nordlys max3). Gold coating was applied using the Quorum SC7620 for 45 seconds before SEM observation. Vickers hardness measurements were carried out using a microhardness tester (Leiz-Wetzlar, Germany) at various locations on the XY and XZ planes, respectively. This was performed under conditions of a load of 100 g and an indentation time of 25 s, repeated 10 times for accuracy. The mechanical test was conducted using an Electronic universal testing machine (American INSTRON 5967).

3. Results and Discussion

3.1. Mixed Powder

As shown in **Figure 2**, the powder morphology of AA7075 mixed SiC + TiC powder can be seen, TiC and SiC micro-scale powder was attached to AA 7075 powder surface and distributed evenly.

3.2. Microstructure Characterization

As seen in **Figure 1**, compared to AA7075 in fiber laser (32%), the mixed powder absorbs light better in green laser (53%), which facilitates the evaporation of elements like Mn and Zn for improved mechanical performance. In **Figure 3(a)-(c)**,

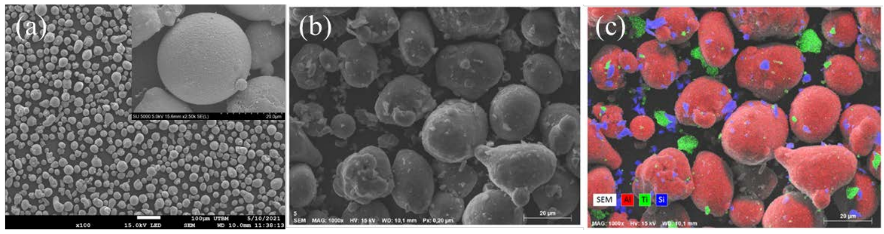

Figure 2. (a) Mixed powder morphology and distribution; (b) Detailed powder morphology; (c) Element distribution and mixed pattern.

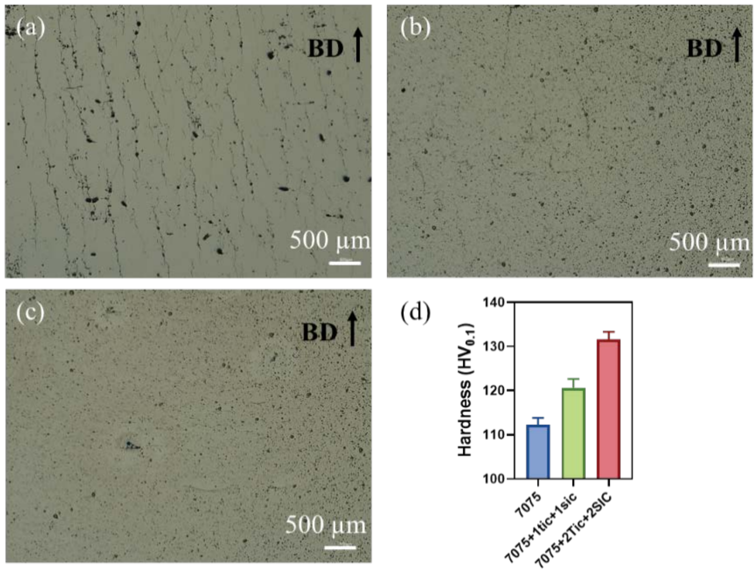

Figure 3. (a) AA 7075; (b) AA7075 + 1% TiC + 1% SiC; (c) AA7075 + 2% TiC + 2% SiC, (d) Hardness comparison.

with TiC and SiC strengthening benefits, Additive Manufactured (AMed) samples exhibit fewer holes and cracks along the build direction (BD), explaining the hardness enhancement in **Figure 3(d)**. Micro-scale TiC and SiC particles melt and then bond with unmelted, melting, and melted aluminum alloy particles, shrinking the cracks and filling the pores generated during solidification by the flow of molten metal driven by Marangoni forces [9]. The significant reduction in crack and pore defects indicates a sharp enhancement in hardness. As seen in **Figure 3(d)**, with the increase in mixing content (0 to 2%), hardness increases.

3.3. Mechanical Properties

The mechanical properties of SLMed AA7075 were further characterized by tensile testing, with representative curves shown in **Figure 4**. The as-built parts offered an ultimate tensile strength (UTS) of 208.4 MPa and a ductility of 0.6%. The SLMed parts of AA7075 + 2% TiC + 2% SiC achieved a UTS of 350.2 MPa and a ductility of 2.01%. With the strengthening effect of particle mixing, the as-built samples exhibited outstanding tensile strengths (a 75% improvement), and the ductility was also enhanced, indicating the anti-crack strengthening behavior of SiC and TiC particles.

3.4. Strengthen Mechanism

Figure 5 demonstrates the element distribution, and their corresponding element content by EDX characterization is listed in **Table 1**. The AA7075 as-built or novel mixed powder as-built parts contain higher Zn and Mg contents to account for vaporization during SLM, which verifies our expectations of lower element loss. Additionally, the TiC and SiC strengthening phases were evenly distributed in the as-built samples without gathering defects, indicating that the strengthening behavior generally takes place throughout the entire sample to enhance overall strength. Its excellent dispersivity ensures outstanding strengthening performance [10]. The Inverse Pole Figure (IPF) in **Figure 5(c)**, **Figure 5(d)** suggests the microstructure comparison between AA7075 and AA7075 +

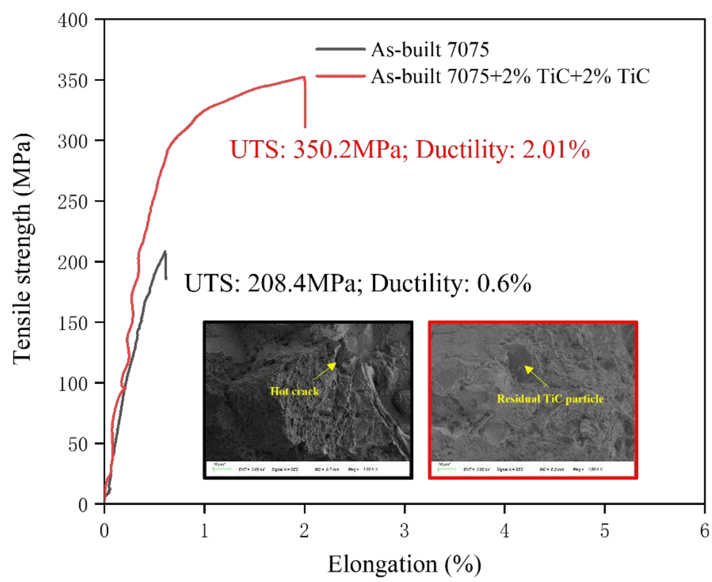

Figure 4. Mechanical properties of as-built AA7075 and AA7075 + 2% TiC + 2% SiC by SLM.

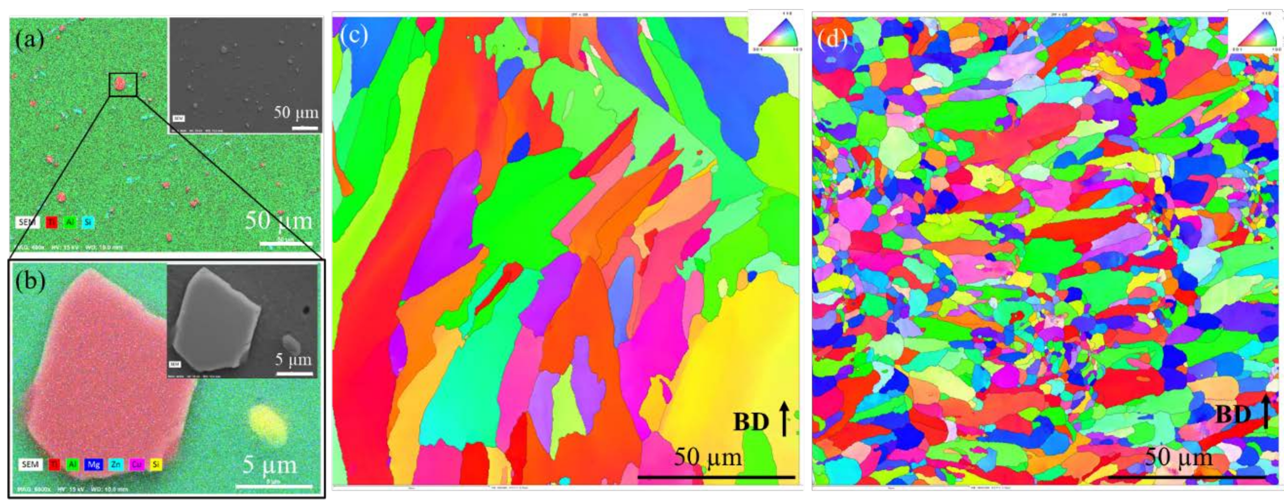

Figure 5. (a) Element distribution of AA7075 + 2% TiC + 2% SiC; (b) Enlarged element distribution of sample a; (c) IPF of AA7075; (d) IPF of AA7075 + 2% TiC + 2% SiC.

Table 1. Compositions of AA7075, as-built AA7075 and mixed powders.

Element (wt%)	Zn	Mg	Cu	Ti	Si	Al
AA7075 powder	5.00 ± 0.07	2.50 ± 0.05	1.70 ± 0.08	-	-	Balance
AA7075 as-built	4.83 ± 0.08	2.26 ± 0.06	1.71 ± 0.05	-	-	Balance
AA7075 + 1% TiC + 1% SiC	4.60 ± 0.11	2.11 ± 0.06	1.59 ± 0.06	0.89 ± 0.12	0.83 ± 0.11	Balance
AA7075 + 2% TiC + 2% SiC	4.61 ± 0.08	2.12 ± 0.56	1.60 ± 0.10	1.73 ± 0.09	1.69 ± 0.08	Balance

2% TiC + 2% SiC. Their mean grain sizes are 12.1 μm and 3.7 μm for AA7075 and mixed powder, respectively. AA7075 exhibits a coarse columnar crystal structure, while fine columnar and equiaxed crystals can be observed in the mixed powder. Mixing TiC and SiC particles contributes to fine grain strength performance, further benefiting hardness and tensile strength. Finer metal grains result in a larger total area of grain boundaries, more dislocation obstacles, the need for coordination among grains with different orientations, and higher resistance to metal plastic deformation. Moreover, the grain direction perpendicular to the BD and mixed powder shows more directional grain orientation. The essence of dispersion strengthening is to use dispersed ultra-fine particles to hinder the movement of dislocations and improve the mechanical properties of materials [11] [12].

4. Conclusion

In this study, a novel approach utilizing green laser equipment was employed to strengthen traditionally unprintable AA7075. By mixing TiC and SiC micro-scale particles in AA7075 powders, the alloy's susceptibility to hot cracking and pore formation during the SLM process was effectively eliminated. Additionally, the hardness and tensile strength of AA7075 + 2% TiC + 2% SiC as-built samples demonstrated significant improvement. The excellent dispersivity of mixed TiC and SiC in AA7075 + 2% TiC + 2% SiC samples contributed to fine grain strengthening. These novel, nano-treated powders hold great potential for widespread applications in the SLM of high-performance alloys.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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