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Crack initiation and propagation behavior of WC particles reinforced Fe-based metal matrix composite produced by laser melting deposition

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ABSTRACT

It is generally believed that cracks in metal matrix composites (MMC) parts manufacturing are crucial to the reliable material properties, especially for the reinforcement particles with high volume fraction. In this paper, WC particles (WC_p) reinforced Fe-based metal matrix composites (WC_p/Fe) were manufactured by laser melting deposition (LMD) technology to investigate the characteristics of cracks formation. The section morphology of composites were analyzed by optical microscope (OM), and microstructure of WC_p, matrix and interface were analyzed by X-ray diffraction (XRD) and scanning electron microscopy (SEM), in order to study the crack initiation and propagation behavior under different laser process conditions. The temperature of materials during the laser melting deposition was detected by the infrared thermometer. The results showed that the cracks often appeared after five layers laser deposition in this experiment. The cracks crossed through WC particles rather than the interface, so the strength of interface obtained by the LMD was relatively large. When the thermal stress induced by high temperature gradient during LMD and the coefficient of thermal expansion mismatch between WC and matrix was larger than yield strength of WC, the cracks would initiate inside WC particle. Cracks mostly propagated along the eutectic phases whose brittleness was very large. The obtained thin interface was beneficial to transmitting the stress from particle to matrix. The influence of volume fraction of particles, laser power and scanning speed on cracks were investigated. This paper investigated the influence of WC particles size on cracks systematically, and the smallest size of cracked WC in different laser processing parameters was also researched.

1. Introduction

In recent years, metal matrix composites (MMC) have been widely investigated by researchers due to their excellent mechanical and thermal properties [1]. To increase the wear resistance and corrosion of materials at room or high temperature, WC particles with favorable properties such as high melting point, high hardness and a good wettability with molten bonding metals, which are widely used as the reinforcement of Fe-based alloy to form the ceramic reinforced Fe-based metal matrix composites during laser melting deposition (LMD) [2,3]. With the rapid development of laser additive manufacturing technology, the fabrication of MMC parts by LMD has been becoming possible in industrial revolution today. The processes of LMD are based on layer-by-layer materials melting and deposition process to build complete parts. LMD provides a new technology to fabricate complex components of difficult-to-process metal matrix composites [4]. An apparent advantage of manufacturing MMC by LMD is that it can realize the free design of reinforcement volume fractions and manufacture gradient MMC [5].

It is generally believed that cracks in MMC parts manufacturing are crucial to the reliable material properties, especially for the reinforcement particles with high volume fraction. Some works about the crack characteristics have been done during the past several years. P.B. Kadolkar [6] stated that the formation of cracks during laser cladding was related to the thermophysical properties of depositing materials and substrate, such as melting point, coefficient of thermal expansion and Young's modulus. Shengfeng Zhou [7] demonstrated that cracks depended on the microstructure of Ni-based WC composites and laser processing parameters such as laser power and scan speed. In Changmin Lee's work [8], the residual stress distributions of the Co-based WC+NiCr composites were measured, and he believed that residual stress could be potential driving force to provide an easy crack path ways for large brittle fractures combined with the crack initiation sites such as the fractured WC particles, pores and solidification cracks. He also found that brittle eutectic phases

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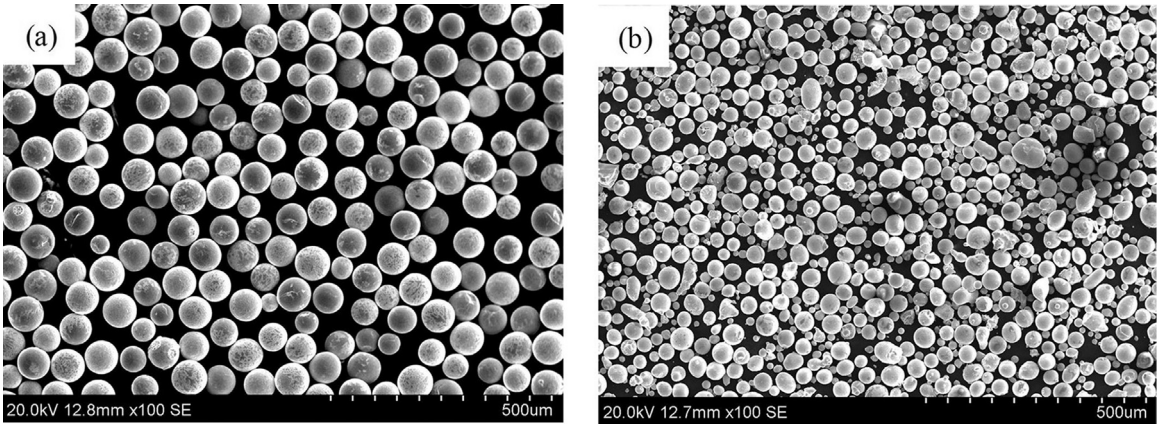

Fig. 1. SEM micrographs of the powders (a) WC powders, (b) 316 L stainless steel powders.

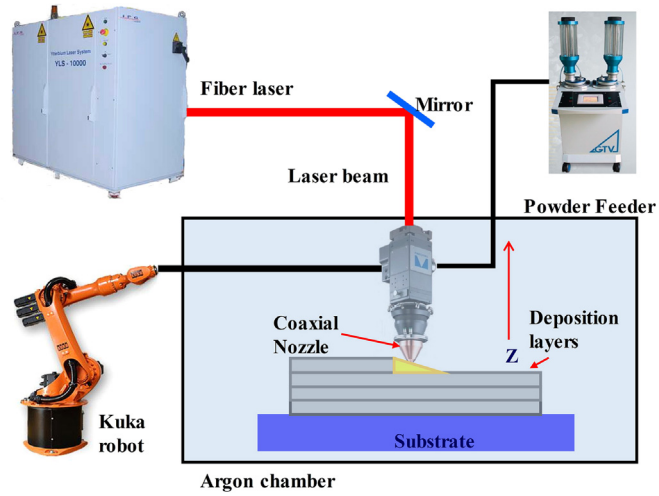

Fig. 2. Schematic diagram of laser melting deposition process.

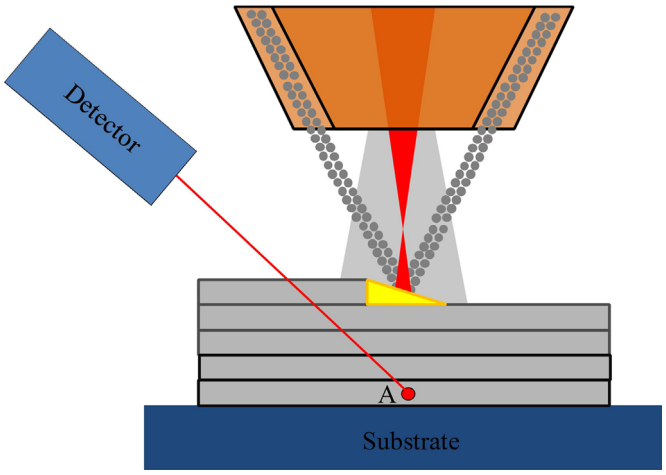

Fig. 3. Schematic diagram of measuring the temperature of materials.

Table 1
Laser melting deposition parameters.

Specimen no.	WC volume fractions (%)	Laser power (W)	Laser scanning speed (m/min)
1	9.1	300	0.3
2	16.7	300	0.3
3	16.7	300	0.6
4	16.7	500	0.3
5	28.6	300	0.3
6	16.7	800	0.3

composed of $\gamma+Cr_7C_3$ played an easy path way for crack propagation in the coating layer. Babout [9] studied that the internal stress of WC particles was proportional to the WC volume fractions. Subrata Kumar Ghosh [10] researched crack density and wear performance of SiC particulate (SiC_p) reinforced Al-based metal matrix composite (*Al*-MMC) fabricated by direct metal laser sintering (DMLS) process, he found that crack density increased significantly after 15 vol percentage (vol%) of SiC_p, because with the amount of reinforcement increasing, the chances of the clustering effect that resisted the flow of molten material increased, which led to the formation of pores in the specimens. He also clarified that the relationship between the size of reinforcement and wear resistance of the composite, but he did not illuminated the influence of reinforced particles size on cracks. Liu [11] studied the fracture behavior of metal matrix composites reinforced with monocrystalline WC particles. He found that there were two crack nucleation mechanisms in the WC particles. These previous researches are very useful for the better understanding of the cracks formation.

As is known to all, the materials are easy to suffer from high residual stress during the process of LMD, which will lead to the formation of cracks in the materials. The cracks generation during the LMD remains an unsolved problem [8]. Under the action of applied load, the cracks will result in premature failure and consequently rather low performance in the metal matrix composites manufactured by LMD. So it is necessary to investigate the crack characteristics in the MMC produced by LMD.

In this paper, WC particles (WC_p) reinforced Fe-based metal matrix composites (WC_p/Fe) are manufactured by LMD technology. The cracks formation, which include crack initiation and propagation, and the influences of WC size and volume fraction and laser processing parameters on the cracks have been systematically investigated.

2. Experiments

The materials used in this work were WC powders and 316 L stainless steel powders. As we know, the particles with irregular shape were easy to generate stress concentration in the sharp corners [12], so the spherical powders were selected. Both diameter sizes of the two kinds of powders were in the range of 15–100 μm. The SEM micrographs of the two powders are shown in Fig. 1. The substrate material used was 8-mm thick 304 stainless steel plate. The laser melting deposition system (Fig. 2.)