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Eutectic MC carbide growth morphologies of a laser clad TiC/FeAl composite coating

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Abstract

In this paper, eutectic MC carbide growth morphology and its evolution with laser scanning speed were studied comprehensively of a laser clad MC carbide reinforced FeAl intermetallic matrix composite coating. As the laser scanning speed increased, the growth morphology of eutectic MC carbide was found to be needle-aligned annulation, butterfly-like and well-developed dendrite.

Keywords: Carbide; Crystal growth; Laser processing

1. Introduction

FeAl intermetallic alloy is of interest for potential structural material in industrial applications because of its excellent resistance to oxidation and high-temperature sulfidation, low density and high melting melt (1250 – 1400 °C) [1,2]. However, the industrial application is mainly limited by the low fracture toughness and mediocre mechanical properties above 600 °C. With the intention to utilize FeAl intermetallic alloy for high-temperature structural applications, composites with FeAl as the matrix have been the focus of many investigations [3 – 6], in which TiC type MC carbide is found to be a suitable reinforcement for improving the mechanical properties of FeAl alloy due to the combination of excellent high temperature stability, high hardness and low density. However, only few investigations have, so far, been devoted to fabrication TiC reinforced FeAl composite as the coating materials. From the tribological point of view, TiC reinforced FeAl matrix composites is expected to possess excellent abrasive resistance due to high hardness of TiC. Additionally, the strong atomic bonds and relatively high hardness of FeAl alloy make it difficult to be deformed during contacting with metallic mating materials. Our previous research [7,8] reported that TiC reinforced FeAl intermetallic matrix composite coating has been successfully fabricated using laser cladding technique, and such coating has excellent wear resistance under both room- and high-temperature dry sliding wear conditions.

It is well known that the growth morphology of the reinforcement has strong effect on the mechanical properties of these composites, and therefore it is necessary to study the growth morphology of TiC type MC carbide in laser clad TiC/FeAl composite coating. Previously, considerable research has been carried out on TiC type MC carbide in different solidification conditions and different alloy system. The near-equilibrium growth morphology of MC carbide in nickel-base superalloys are octahedral blocks and these would transform gradually to Chinese-script morphology, flower-like and radially branched colonies with increasing cooling rate [9 – 12]. Meanwhile, the growth morphologies of MC carbide of a laser surface alloyed γ-TiAl alloy with carbon is found to have a faceted dendritic morphology

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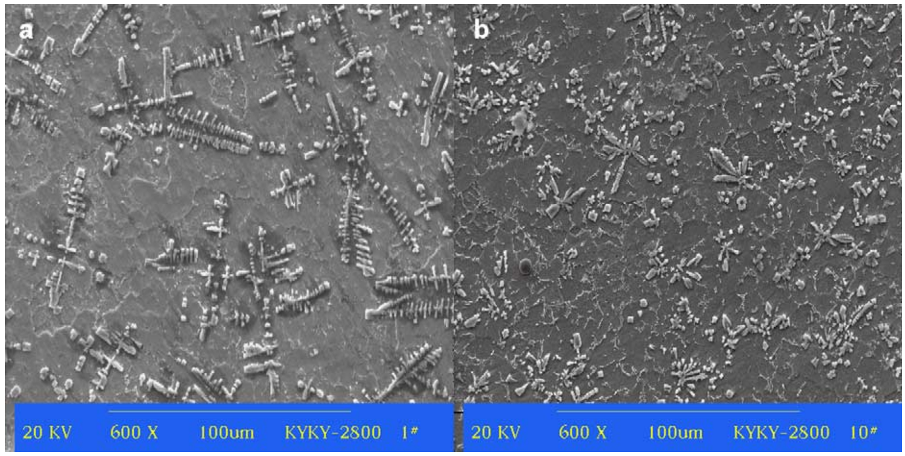

Fig. 1. Typical microstructure of laser clad TiC/FeAl composite coating with a laser scanning speed of 5 mm/s (a) and 10 mm/s (b).

having zig-zag platelet or three-dimensional faceted-platelet networks on the growth surface of dendritic arms [13], cross-petal-like with symmetrical arms and irregular block or undeveloped dendrite [14]. Also, a unique radial-branching dendritic primary MC carbide, nucleates heterogeneously on the surface of oxide particles, was found in laser clad TiC/FeAl composite coatings in our previous research. In this paper, the rapidly solidified growth morphologies of eutectic TiC type MC carbide in laser clad TiC/FeAl composite coatings were investigated.

2. Experimental procedures

The stainless steel of 1Cr18Ni9Ti, $15 \times 10 \times 8$ mm in size, was selected as substrate for laser cladding treatment, and the

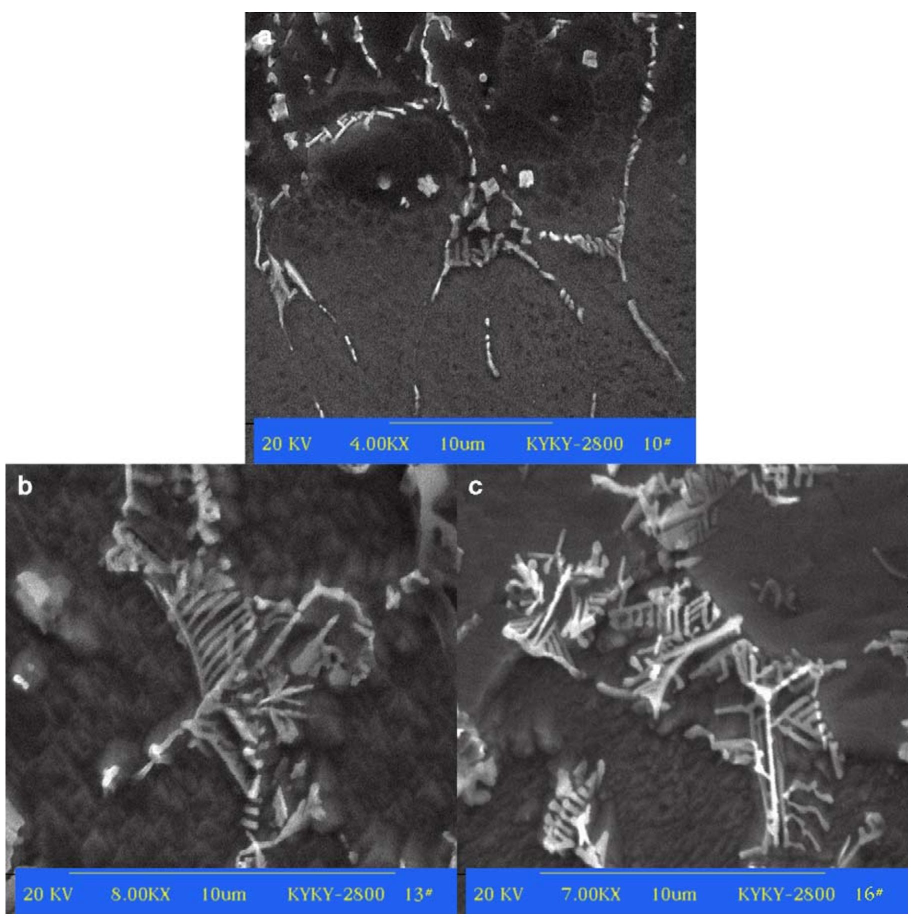

Fig. 2. SEM micrographs showing the typical growth morphologies of eutectic MC carbide in laser clad TiC/FeAl composite coating with a laser scanning speed of 5 mm/s (a), 8 mm/s (b) and 10 mm/s (c).

surface of samples were cleaned and coated with black paint in order to increase the laser absorption coefficient of the material. The starting precursor materials were prepared from Fe–28Al–4Ti–4C (at.%), then pre-placed on the substrate surface, approximately 1.5 mm in thickness. A 5 kW CO_2 continuous wave laser was adopted for laser cladding. The laser processing parameters are: laser power 2.8 kW, beam diameter 3.0 mm, laser scanning speed 5~10 mm/s.

The transverse and longitudinal sections of laser clad coating were mechanically polished and etched by HCl+H_2O (1:1) solution at room temperature. Microstructure and the growth morphologies of eutectic TiC carbide in laser clad TiC/FeAl coating were examined by Nephot-II optical microscope (OM) and KYKY-2800 scanning electron microscope (SEM) with EDX attachment. The phase constitution of laser clad composite coating was identified by Rigaku D/max 2200 type X-ray diffractometer (XRD), using CuK_α radiation operated at a voltage of 40 kV, a current of 40 mA, and scanning rate of 5°/min.

3. Results and discussion

As shown in Fig. 1, the typical microstructure of the middle part in the laser clad TiC reinforced FeAl intermetallic matrix composite coating with two different laser scanning speed illustrates that these composite coatings are all composed of primary MC carbide and MC carbide/FeAl eutectic. Meanwhile, combined with the XRD and EDX analysis results [7], it is clearly shown that the MC carbide reinforced FeAl intermetallic composite coating is successfully fabricated using laser cladding technique.

Fig. 2 shows the rapidly solidified eutectic MC carbide growth morphologies at three laser scanning speed. Clearly, the growth morphologies of eutectic MC carbide are all totally different from both the blocky or Chinese-script conventionally solidified ones and the primary ones reported previously [9,10]. Furthermore, the growth morphologies of eutectic MC carbide vary considerably as a function of laser scanning speed. As shown in Fig. 2a, the eutectic MC carbide morphology in the laser clad coating with a laser scanning speed of 5 mm/s is needle-aligned annulations. As the laser scanning speed increases to 8 mm/s, the growth morphology of eutectic MC carbide is indicated in Fig. 2b, and is butterfly-like with a characteristic of regular branching. As the laser scanning speed increases further, the growth morphology of MC carbide in laser clad coating with a laser scanning speed of 10 mm/s is characteristic of well-developed dendrtites. It is worthy noting that the degree of branching increases with increasing laser scanning speed. Also, it is clearly seen the branching angles are nearly same, which implies eutectic MC carbide grows with a crystallographic branching mechanism.

From the above-observed microstructure of laser clad composite coating, MC carbide/FeAl eutectic growth is might followed

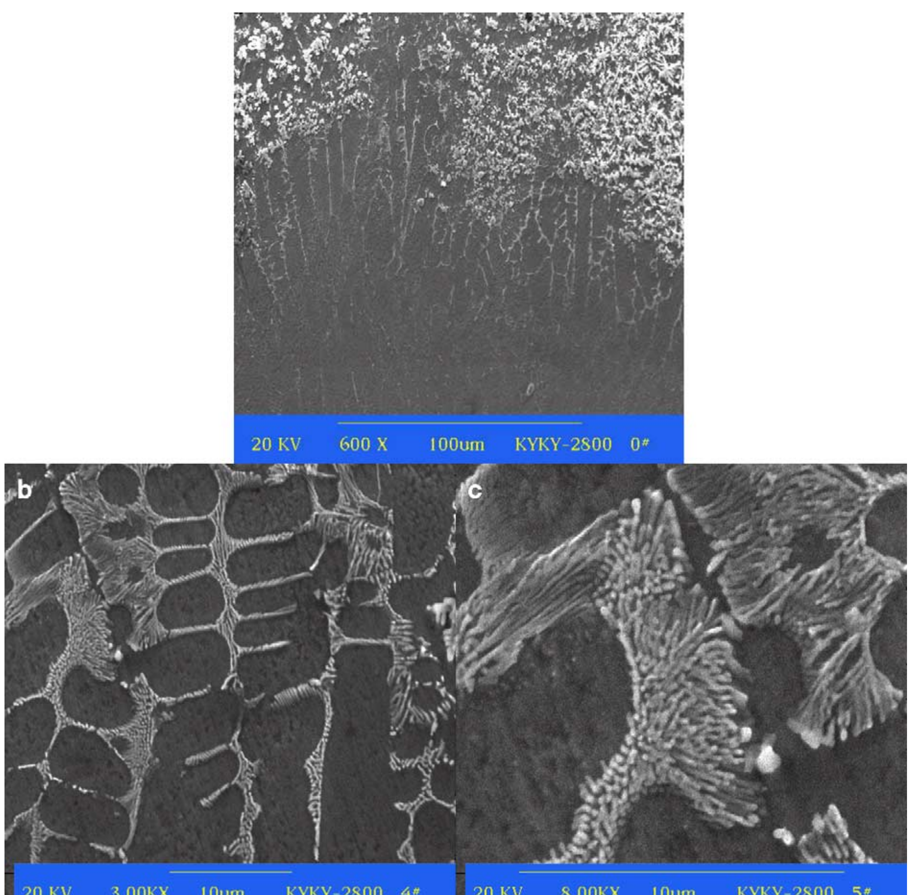

Fig. 3. SEM images showing microstructure of bottom of laser clad TiC/FeAl composite coating (a) and the flower-cluster-like MC carbide (b), (c).

by the precipitation of primary MC carbide in the process of the solidification of laser-generated melt pool. It is well known that the eutectic growth is a diffusion-controlled process, and therefore the eutectic MC carbide growth morphology is strongly affected by the cooling rate. Generally, the cooling rate increases with increasing laser scanning speed in the process of laser material processing if other conditions are given. The higher the laser scanning speed, the higher the solidification cooling rate, leading to the smaller the diffusion ability of MC carbide forming elements in the process of MC carbide/FeAl eutectic growth. As a result, eutectic MC carbide can only coordinate the diffusion of MC carbide forming elements by more frequent bifurcating, leading to the degree of branching increases with the increasing of laser scanning speed. Additionally, MC carbide is regards as a typical faceted crystal due to its strong atomic bonding and higher entropy of melting [15], and it therefore grows laterally through these crystal defects such as screw dislocation and/or twins [16]. It is well understood that the density of crystal defects increases drastically with increasing cooling rate [17]. Therefore, the number of the ledges or steps, originated from crystal defects increases with increasing laser scanning speed, and eutectic MC carbide may bifurcating easily depending upon these much more ledges or steps, resulting in increase in the degree of branching. The intrinsic lateral growth mechanism and the diffusion-controlled eutectic growth process are the essential factors giving rise to the diversification of eutectic MC carbide morphologies.

It is interesting that no primary MC carbide is found at the bottom of the laser clad coatings (Fig. 3a), and the growth morphology of these eutectic MC carbide surrounding the FeAl intermetallic alloy takes up to be a flower-cluster-like, as shown in Fig. 3b and c, illustrating that the MC carbide/FeAl eutectic is divorced one. A thin substrate, 1Cr18Ni9Ti stainless steel, is melted with Fe–Al–Ti–C starting precursor materials placed on its surface during laser cladding, the composition of the laser generated melt pool is inhomogeneous due to alloy elements in melt pool cannot diffuse sufficiently. Therefore, composition of alloy elements at the bottom of melt pool might lie in the scope of the MC carbide/FeAl eutectic reaction, avoiding the precipitation of the primary MC carbide. Due to the stronger self-cooling effect originated from substrate, the higher cooling rate at he bottom of melt pool can be obtained, leading to the increase in the degree of branching of MC carbide.

4. Conclusions

Eutectic MC carbide growth morphology and its evolution with laser scanning speed were studied comprehensively of a laser clad MC carbide reinforced FeAl intermetallic matrix composite coating. As the laser scanning speed increased, the growth morphology of eutectic MC carbide was found to be needle-aligned annulation, butterfly-like and well-developed dendrite. Meanwhile, the eutectic MC carbide at the bottom of the laser clad coating was characteristic of flower-cluster-like due to the strongest self-cooling effect from substrate. The intrinsic lateral growth mechanism and the diffusion-controlled eutectic growth process are the essential factors giving rise to the diversification of eutectic MC carbide morphologies.

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