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Directional growth whisker reinforced Ti-base composites fabricated by laser cladding

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ABSTRACT

New type Ti-base composite coatings with in-situ synthesized directional growth whiskers were successfully fabricated from a precursor mixture of titanium alloy and B_4C powder by laser cladding. The typical microstructures, formation mechanism and properties of the reinforced composite coatings were experimentally studied for the purpose of developing novel hard facing coatings of titanium alloy. The results show that, there are two typical microstructures obtained in the composite coatings, i.e. the equiaxial composite structures and the columnar composite structures. The novel and interesting TiB whiskers, namely the directional growth TiB whiskers, are founded in the columnar composite structure zones. These TiB whiskers show uniform growth directions and display the characteristics of large slenderness ratio. The lengths of the whiskers are in the range of 10–30 μm, but the diameters are of extremely fine size in the nanometer range. The microhardness of the coating is in the range of 430–520 HV and is about 150 HV higher than that of the substrate, which implies that these composite coatings are effectively reinforced by in situ synthesized TiB phases. The analysis shows that, solidification velocity *R*, temperature gradient *G* and direction of heat flow were the key factors to determine what kind of whiskers can be obtained.

1. Introduction

Recently, titanium matrix composites (TMCs) reinforced with in-situ synthesized ceramic phases have attracted much researchers' attention because of their favorite properties [1–5], e.g. easier fabrication, stable interfaces between reinforcements and matrix, uniform distribution of reinforcements and high specific strength. Typically, the reinforcing phases of in-situ TMCs contain TiC [6,7], TiN [8,9], TiB_2 [10] and Al_2O_3 [11]. These reinforcing phases prevalently display the granular morphologies. However, in some specialized applications, we demand the properties beyond these traditionally particulate reinforced composite coatings. This continues to drive the attempts to explore new material concepts such as in-situ fiber-reinforced composites. TiB is considered as one of the best reinforcing phases for TMCs because of such attractive properties as good thermal stability at high temperature, high elastic modulus, and the density similar to that of titanium [12–15]. Besides, it is interesting to note that TiB can form long and pristine single-crystal whiskers/short fibers in the titanium matrix [16–18]. This means that, on the basis of the theories of stiffening and strengthening by whisker reinforcement, large increases in composite modulus and strength can be obtained with a relatively smaller amount of reinforcing phases. These type composites will offer dramatic improvements on performance in the regions where previously only continuous-fiber-reinforced titanium metal-matrix composites were used.

In recent years, a variety of manufacturing processes that have been used for the synthesis of TiB whiskers reinforced titanium matrix composites, e.g. common casting technique [12,13], powder metallurgy technique [15] and plasma surface modification [19]. Compared with the technologies above, laser cladding is a rapid solidification processing technology. The concurrent large undercooling and high cooling rates in laser cladding were found to be very effective for the production of in-situ titanium matrix composites which contain large volume fractions of the reinforcing phases [16–18]. Furthermore, the feature of rapid solidification is beneficial to obtain novel phenomenon and results.

This paper presents a novel microstructural characteristic of Ti–TiB composites with directional growth TiB whiskers. The mechanical properties and the growth mechanism of Ti–TiB composites are also investigated. The objective of this paper is to provide the references for the further theoretical researches and industrial applications in this area.

2. Experiment and material

The substrate was Ti–8Al–1Mo–1V alloy, which was cut in to plates with diameters of 30 mm and thickness of 5 mm. The chemical

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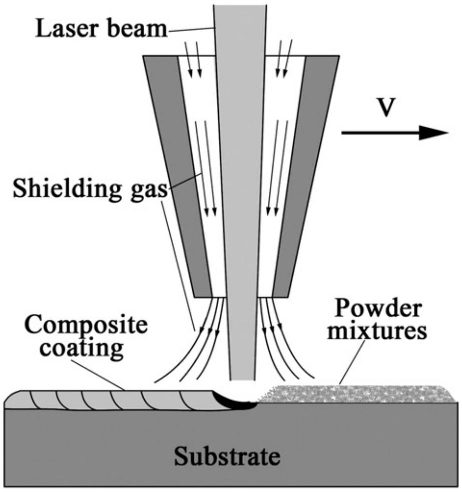

Fig. 1. Schematic diagram of laser cladding process.

composition (in wt.%) was: 7.8% Al, 0.9% Mo, 1.1 V, 0.3 Fe, 0.05 N, 0.015 H, 0.12 O, and the rest Ti. B_4C (particle size 10–30 μm, 95% purity) and Ti–8Al–1Mo–1V powders (particle size ~100 μm) were used as the precursor for laser cladding with a mass ratio of 1:39, i.e. 2.5 wt.% B_4C. The powders were mixed homogeneously using ball mill for 1 h and then dried at 200 °C for 1 h. Before cladding, the powder mixtures were preplaced on substrate surface with a thickness of ~0.8 mm.

The cladding process was conducted by using a 5 kW high power CO_2 laser with a shielding gas system, which has been schematically described in Fig. 1. The cladding experiments were carried out at the following parameters: laser power 1.5–2 kW, spot diameter 4 mm, scanning speed 120–240 mm/min, and overlapping ratio 60%. Argon gas was used for protecting the molten pool from oxidation with a flow rate of 15 L/min.

After laser cladding treatment, metallographic cross-sections of clad samples were selected perpendicular to the scan direction. Samples were polished and etched in 5% HF solution to reveal the microstructures. The phase composition was identified by X-ray diffraction (XRD) with Cu Kα radiation at 18 kV. The morphologies and microstructures of the coatings were characterized by scanning electron microscope (SEM). The Micro-Vickers hardness along the depth direction was tested by using a load of 50 g and dwell time of 15 s. The hardness of each point resulted from averaging three values obtained at that depth and the error was represented by the standard deviation.

3. Results and discussion

3.1. General view of the composite coatings

Fig. 2(a) shows the cross-sectional morphology of the clad coating obtained by laser cladding with optimized parameters of power 1.8 kW and velocity 180 mm/min. The thickness of the composite coating is in the range of 320–400 μm, and no obvious defects are detected. The typical microstructures are displayed in Fig. 2(b) which reveal that there are two typical microstructures, i.e. the equiaxial structure which is a thin layer at the surface and the columnar structure which is the main part of the composite coating under the equiaxial structure layer. The composite coating is fully dense with uniform distribution of reinforcing phases throughout the matrix.

As marked in the cross-sectional morphology shown in Fig. 2(a), there are many block particles can be observed in the coating. These block particles with irregular sizes (the level from several μm to ~50 μm) disperse randomly in the coating. Micrograph Fig. 2(c) is the magnification of a single block particle which is marked with black arrows in Fig. 2(a). With a visible and clear interface, as shown in Fig. 2(a) and (d), the composite coatings are metallurgically bonded to the substrate.

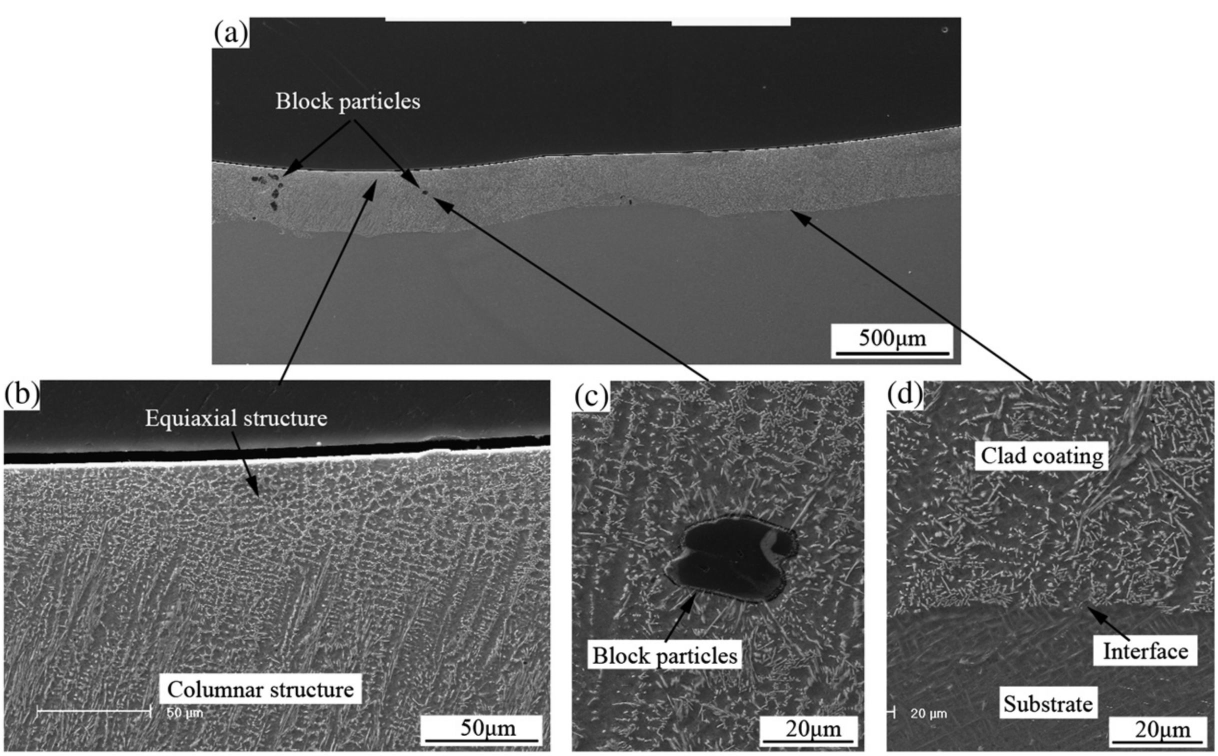

Fig. 2. The composite coating formed by CO_2 laser cladding: (a) general view of the coating; (b) typical microstructures; (c) magnification of block particles and (d) clad coating-substrate interface.