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Featured Letter

Reconstruction and refinement of TiB whiskers in titanium matrix composite after electron beam remelting

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ABSTRACT

The size and distribution of TiB whiskers (TiBw) in TiB reinforced titanium matrix composite (TiB-TMCs) were tailored by the electron beam remelting. A significant refinement of TiBw has been achieved in the remelted region, as well as the grain. Interestingly, the refined TiBw were reconstructed via electron beam remelting, forming the quasi-continuous network (QCN) structure and dispersive structure along the depth direction of the remelted region. A gradient hardness is obtain in the remelted TMCs, and the wear resistance is greatly improved after remelting. This study provides a promising method to tailor the architecture of TiBw in the TiB-TMCs for enhancing the surface performance.

1. Introduction

Titanium matrix composites have received more attentions from the aerospace and automobile industries in the past decades, owing to high specific strength, good wear resistance and excellent high temperature durability [1–4]. Among the investigated reinforcements, the TiB has been identified as the most promising reinforcement for TMCs, due to its good compatibility with Ti matrix and high thermodynamic stability [2–4].

However, the stiffer reinforcements, especially the TiBw, are prone to stress concentration and fracture, triggering the failure of the composites [3,5]. Moreover, the coarser TiBw are more easily and frequently cracked, resulting in the further degradation of performance [6]. Undesirably, the large TiBw are easily visible in the TMCs fabricated by the powder metallurgy (PM) [7]. In dry friction conditions of sliding or rolling contact motion, extensive fracture and galling easily generate at the surface layer of such composite [8], which must be suppressed.

In this work, the TiBw in PM-fabricated TiB-TMCs were reconstructed via electron beam remelting, forming the QCN and dispersive distribution regions along the heat field direction. The refinement of TiBw during electron beam remelting was investigated, and the mechanical and tribological properties of remelted TMCs was also evaluated.

2. Experimental

The TiB reinforced TMCs were in-situ synthesized with the pure Ti powders (average diameter ~50 μm) and B_4C powders (average diameter ~5 μm). The mixtures of Ti and 0.5 wt% B_4C powders were milled at rotational speed of 100 rpm for 2 h, with fixed balls to powder mass ratio of 5:1. The blended powders were sintered and fully reacted by the spark plasma sintering (SPS) processing at 1200 °C for 15 min. Afterward, the specimens with a dimension of Φ20 mm × 4 mm were cut from the sintered products and then treated by electron beam remelting technique under a vacuum of 10^{-3} Pa at a scanning velocity of 10 mm/s. The accelerated voltage and beam current were 60 kV and 6 mA, respectively. The microstructure and composite of specimens were characterized by the scanning electron microscope (SEM, ΣIGMA) and electron probe micro analyzer (EPMA, 8050G), respectively. The mechanical and tribological properties of TMCs were evaluated using the nanoindentation (Agilent G200) and sliding reciprocating tribotester (MFT-3000), respectively. The testing conditions and the calculation of wear rate were mentioned in details in the Ref. [9]. The worn track was observed by SEM.

3. Results and discussion

3.1. Microstructural characterizations

The microstructure of TiB-TMCs before and after electron beam remelting are presented in Fig. 1. In the SPS-fabricated TMCs, the

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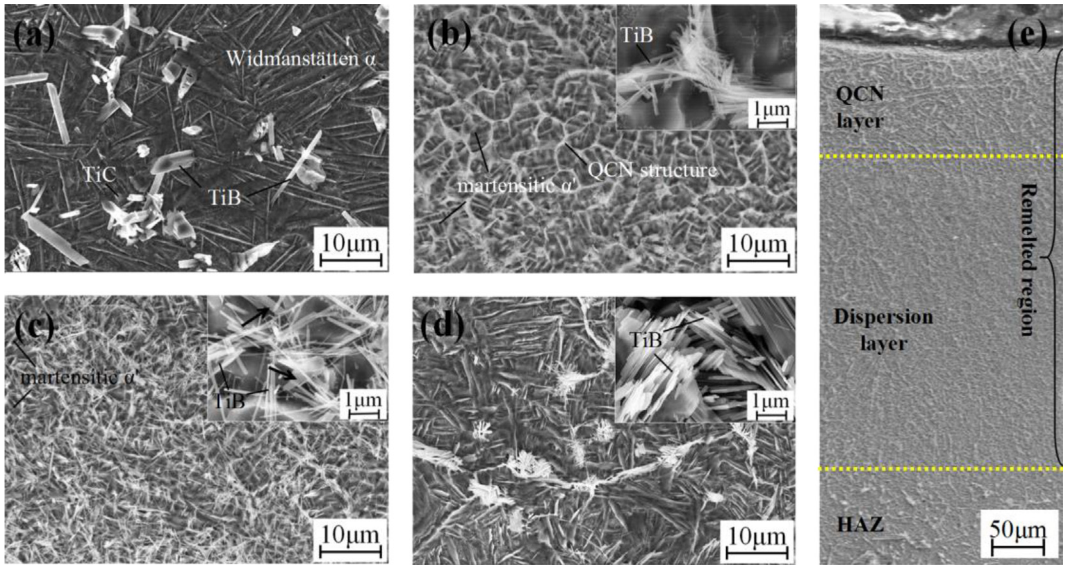

Fig. 1. Microstructure of TiB-TMCs before and after electron beam remelting: (a) un-remelted sample (b) QCN layer (c) dispersion layer (d) HAZ (e) cross section.

micron-scale TiBw are formed and homogeneously distributed in the α-Ti matrix with Widmanstätten structure (Fig. 1a). The refinement of grain size and the formation of α′ matensite are observed for the remelting regions (Fig. 1b and c). The refined TiBw identified by EMPA (Ti 51.77 at.%, B 48.23 at.%) are reconstructed to network structure along the grain boundaries (the QCN structure in Fig. 1b) and the uniformly dispersed fine whiskers structure (dispersive structure in Fig. 1c) along the electron beam remelted region from top to bottom at the depth of ~420 μm (Fig. 1e). In addition, as shown in the high magnification figure inserted in Fig. 1b, the size of the TiBw is obviously reduced in the QCN region, and the ultrafine TiBw aggregate along the grain boundaries, developing into a QCN structure. Such structure was also observed in the welded joints of TMCs [10–12]. A similar refinement of the TiBw is observed for the dispersed structure region (as shown in Fig. 1c). However, there still exist a small amount of comparatively coarse TiB flakes as indicated by the arrows in the enlargement figure inserted in Fig. 1c. From Fig. 1d, the TiBw in the heat affected zone (HAZ) are divided into some slender flakes (Fig. 1d), ascribed to the intensified diffusion of boron under thermal cycle [10,11]. The decomposed flakes are similar with the coarse TiB flakes in the dispersion layer (as indicated by arrows in the inserted figure in Fig. 1c). Therefore, these TiB flakes observed in the dispersion layer seem to be the residual decomposed TiB. It is possible that the carbon is dissolved into the Ti matrix because the TMCs has a lower carbon content (0.109 wt%) than the equilibrium carbon solubility in Ti solid (0.28 wt%) [2]. Furthermore, the rapid solidification favored the expansion of the carbon solubility thresholds [5,9].

3.2. Formation mechanisms

The formation process of remelted layer has been summarized, as illustrated in Fig. 2. Firstly, a molten pool is formed on the surface of TiB-TMCs substrate during the electron beam remelting. In general, a high temperature region directly radiated by the electron beam locates in the front part of molten pool, while the low temperature region locates in the beneath part [13]. In the high temperature region (Fig. 2a), the TiB are thoroughly melted in the molten pool owing to its low melting point (2473 K) [10,11]. In the following rapid solidification, the β nuclei firstly emerge from the liquid due to the hypoeutectic concentration of boron (0.391 wt%). Owing to the limited solid solubility of boron in Ti matrix, the boron solutes will be rejected from β nuclei creating the solute segregation around the β phase boundary. The boron enrichments retard the β grain growth, leading to the refinement of the grains [12,14], as shown in Fig. 1b. Afterward, the refined

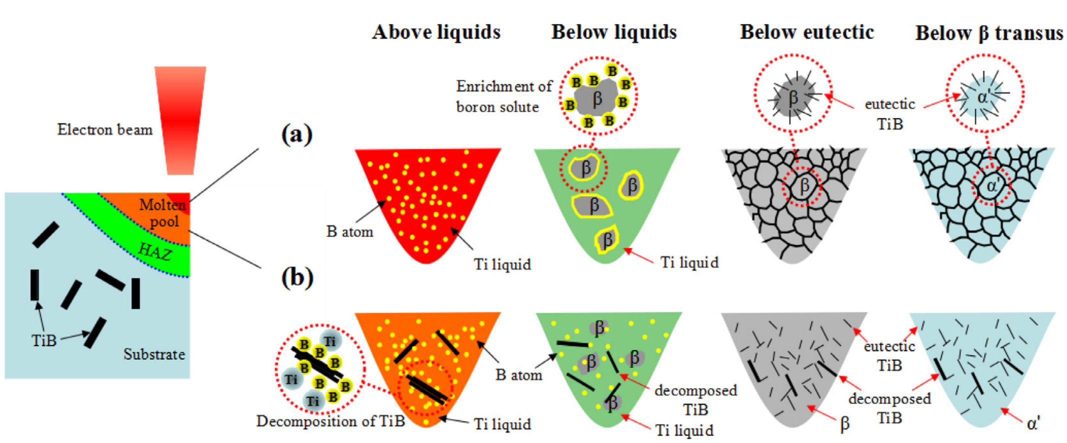

Fig. 2. Schematics illustrating formation of the remelted layer: (a) high temperature region (b) low temperature region.