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Superior tensile strength and microstructure evolution of TiB whisker reinforced Ti60 composites with network architecture after β extrusion

B. Wang, L.J. Huang *, H.T. Hu, B.X. Liu, L. Geng

School of Materials Science and Engineering, Harbin Institute of Technology, P.O. Box433, Harbin 150001, China

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The tensile properties (at room and high temperatures) and microstructure evolution after extrusion (1200 °C) have been systematically investigated in TiBw/Ti60 composites with network architecture. The microstructure of matrix of composites shows that grain size was significantly refined and sufficient substructure was introduced after β extrusion. DRX occurred prior near TiBw region due to providing the nucleation site and having high driving force. Moreover, ordered α_2 phase which is formed in sintering process was re-dissolved after extrusion. The as-extruded composite exhibits strong $<0001>_{\alpha}$//ED fiber texture which is transformed from $<110>_{\beta}$//ED fiber texture based on Burgers' relationship, which are beneficial to tensile properties of the composites. The highest tensile strength (1454 MPa) of the as-extruded 5.1 vol.% TiBw/Ti60 composites and the well combination of tensile strength (1364 MPa) and elongation (6%) of the as-extruded 3.4 vol.% TiBw/Ti60 composites have been obtained at room temperature. In particular, the as-extruded composites also exhibited super-high tensile strength at elevated temperatures (close to 1000 MPa at 600 °C and 800 MPa at 700 °C) compared with matrix alloy. Combining analysis of fracture surfaces and microstructure evolution, the better properties can be attributed to the alignment distribution of TiBw along the extrusion direction and the matrix strengthening effects including refinement of grain, the substructure and texture strengthening.

1. Introduction

During the past decades, a series of near α high-temperature titanium alloy have been developed by many countries to meet the requirements of aerospace lightweight structural materials, such as IMI834 (UK), Ti-1100 (USA), Ti-60 (China) and BT36 (Russia) alloys [1–3]. However, the service temperature of these titanium alloys is no more than 600 °C. One of the major problems hindering their application is insufficient strength at more than 600 °C. The solution and precipitation strengthening effects of these titanium alloys have reached the limit at 600 °C [4–7]. Comparing with conventional titanium alloys, titanium matrix composites (TMCs) exhibit higher specific strength, higher specific modulus and excellent high temperature durability [8–10]. The strength of composites is determined by the matrix strength and the strengthening effect of reinforcements which is mainly associated with the type, size, distribution of reinforcements and the interface between matrix and reinforcement [11]. The previous studies indicated that the novel network structured TMCs offer high combination of strength and ductility at room and high temperatures in pure Ti matrix [12] and Ti6Al4V matrix [13] composites. In this work, in order to further improve high temperature mechanical properties of titanium matrix composites (TMCs), spherical Ti60 alloy powders are selected as matrix which possesses the highest service temperature of 600 °C [14], while in situ TiBw as reinforcement to fabricate TiBw/Ti60 composites with network structure by powder metallurgy (PM) technique.

The microstructure and properties of TiBw reinforced Ti or Ti6Al4V matrix composites have been extensively investigated in recent years, the results demonstrated that TiBw are effective for the strength improvement of the composites [7,9,10,12,13,15]. However, there are few researches on the TiBw reinforced near α Ti alloy matrix composites, especially fabricated by PM technique. Different from pure Ti or α + β Ti alloy, near α Ti alloys always exhibit excellent strength at high temperature and low toughness and ductility at room temperature due to the solution of mass α stabilizing elements. A study on B-modified Ti metal 685 alloy as cast condition showed significant reduction of elongation with increasing boron content at room temperature. It is reported that the cracking of TiBw is the leading role of decreasing ductility during the tension test [16]. Actually, no matter what kind of the fabrication techniques, subsequent thermo-mechanical processing is always involved to optimize the microstructure of matrix and improve the mechanical properties. In Chandravanshi's work [17], in the thermo-mechanically processed condition, the tensile strength of B-modified Ti-1100 alloy increased significantly without drop in elongation compared with matrix alloy. Lu et al. also concluded the yield strength and elongation of the (TiBw + La_2O_3) reinforced IMI834 composites increase with increasing the degree of deformation [8]. Previously, Hu et al. have investigated the effects of extrusion on the

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* Corresponding author.
E-mail address: huanglujun@hit.edu.cn (L.J. Huang).

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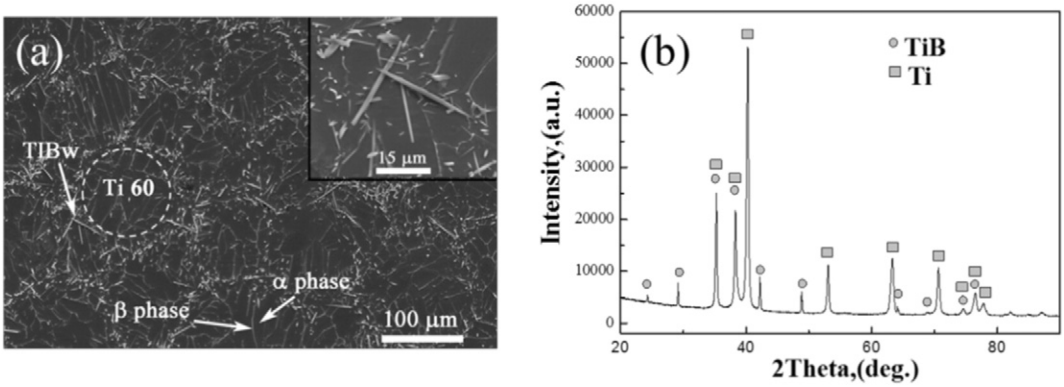

Fig. 1. SEM micrograph (a) and XRD result (b) of the as-sintered 3.4 vol.% TiBw/Ti60 composites.

microstructure and tensile properties of TiBw/Ti60 composites [18]. However, they just simply presented the change of TiBw during the extrusion and not considered microstructure characteristic of the matrix of composites including the effect of precipitates, grain size, texture and substructure, which are very important factors for tensile properties. On the other hand, in the present work small raw Ti60 powders are selected to fabricate the composite, which can result in small size of network microstructure in the composites. As reported in Huang's work [19,20], at the condition of same volume fraction of TiBw reinforced Ti6Al4V composites, the smaller network microstructure size led to the better strengthening effect of TiBw and an improved combination of tensile properties can be obtained.

In this work, hot extrusion in β phase region has been performed to develop the potential properties of the TiBw/Ti60 composites. The systematic tensile properties of the as extruded composites have been tested at room and elevated temperatures. The microstructure evolution

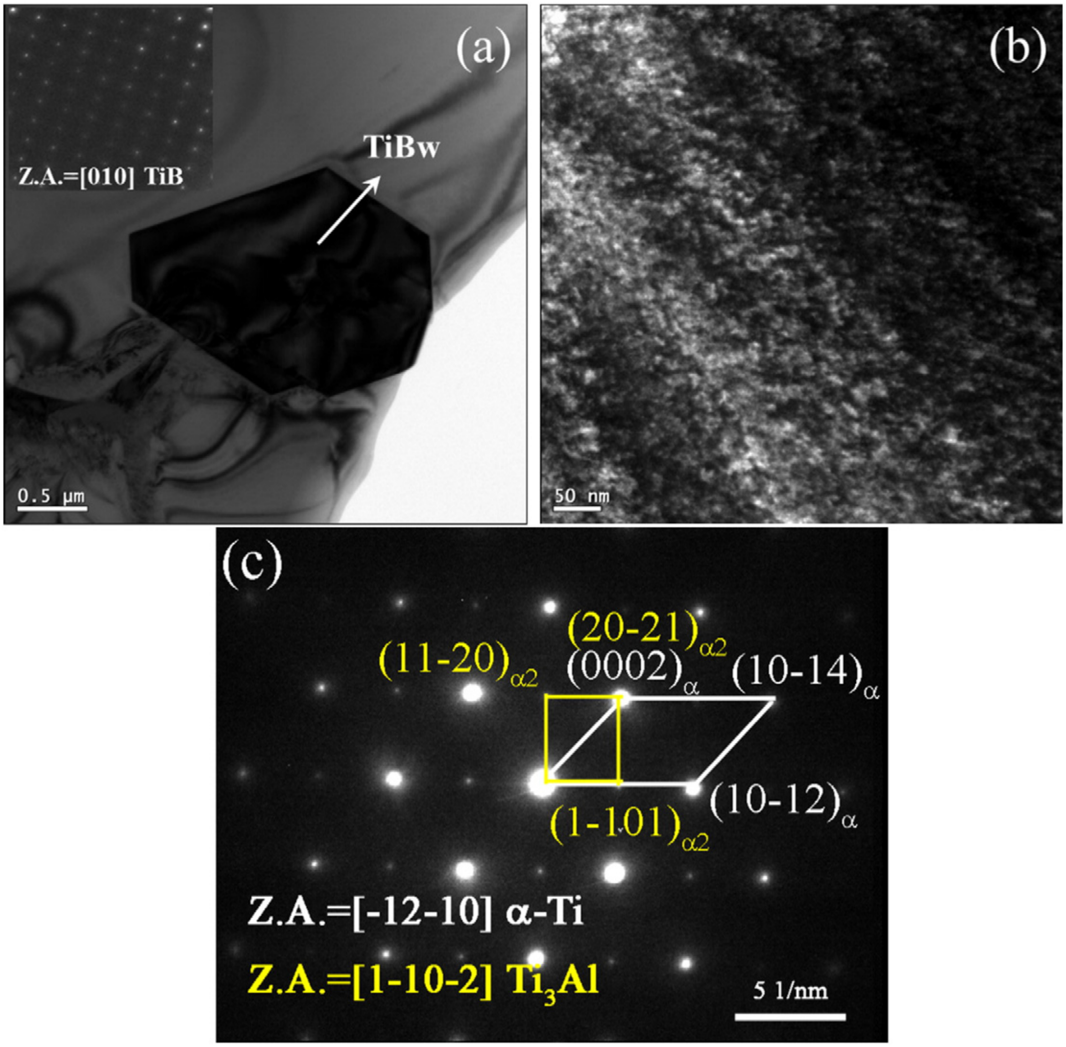

Fig. 2. The TEM micrographs of the as-sintered 3.4 vol.% TiBw/Ti60 composites. (a) the bright-filed TEM micrograph of TiB; (b) the dark-field micrograph of α_2 phase; (c) diffraction patterns of α_2 matrix.