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ARTICLE

Effect of La and B Addition on the Microstructure and Mechanical Properties of Titanium Matrix Composite

Han Yuanfei[1], Kuang Wei[1], Yang Xiaofang[2], Li Jiuxiao[1], Huang Guangfa[1], Lv Weijie[1], Zhang Di[1]

[1] State Key Laboratory of Metal Matrix Composite, Shanghai Jiaotong University, Shanghai 200240, China, [2] Northwestern Polytechnical University, Xi'an 710072, China

Abstract: The Ti6Al4V titanium matrix composites added with (0.36 wt%, 0.72 wt%, 1.45 wt%) La and (0.17 wt%, 0.34 wt%, 0.68 wt%) B, were synthesized using common casting and hot forging technology. The microstructural characteristics and tensile properties of the heat-treated materials were investigated, with particular emphasis on the effect of trace reinforcements. The phases were identified by XRD. Optical microscopy (OM) and scanning electron microscopy (SEM) were used to observe the microstructure. Both room temperature and high temperature tensile properties were tested. The results show that the addition of La and B plays an important role in the microstructure and mechanical properties of the titanium matrix composite. Tensile strength can be increased by 148 MPa, which can strengthen the matrix metal markedly.

Key words: titanium matrix composite; mechanical property; microstructure; TiB; La_2O_3

Titanium alloys are considered as one of the competive high temperature structure materials due to their high specific strength, low density, elevated temperature resistance and high corrosion resistance, which are widely used in aerospace, industrial and medical fields[1-7]. Ti6Al4V alloy is one of the important aviation structure materials[8,9]. The incorporation of low density, high modulus and high strength reinforcements into Ti6Al4V alloy could significantly refine the microstructure and improve the mechanical properties[9, 10]. Recently, TiB, TiC and La_2O_3 which are considered as reinforcements with predominant physical properties, were in situ synthesized in titanium matrix composite (TMC) [10-12]. However, little information is available so far on the addition of La and B elements together in titanium matrix composite (TMC). In the present study, the addition of La and B elements was conducted on the titanium matrix composite (TMC) to improve the room tensile strength and high temperature tensile strength.

1 Experiment

The studied materials were fabricated into the ingots with a diameter of Φ120 mm by a consumable vacuum arc remelting furnace. Small amount of La and B element (TMC1: La/0.36 wt% + B/0.17 wt%, TMC2: La/0.72 wt% + B/0.34 wt%, TMC3: La/1.45 wt% + B/0.68 wt%) was added to Ti6Al4V matrix alloy to produce TiB and La_2O_3 (1.2 vol%, 2.4 vol% and 4.8 vol%) during solidification by in situ chemical reaction[13]: $12Ti + 12B + 2La + 3[O] \rightarrow 12TiB + La_2O_3$.

After casting, the ingots were hot forged between 1100 and 1150 ℃, followed by heat treatment at 700 ℃ for 1 h to release the residual stress. Phase identifications were carried out via X-ray diffraction using a Rogaku D/max

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Corresponding author: Han Yuanfei, Ph. D., Assistant Research Follow, State Key Laboratory of Metal Matrix Composite, Shanghai Jiaotong University, Shanghai 200240, P. R. China, Tel: 0086-21-34202641, E-mail: hyuf1@hotmail.com

2550V X-ray diffraction under the condition of Cu Kα, 35 kV, and 200 mA. Microstructure observations were carried out by optical microscopy (OM) and FEI Quanta FEG 250 scanning electron microscopy (SEM). Specimens with a gauge section of 4 mm×18 mm were tested on a Zwick T1-FR020TN materials testing machine at a strain rate of 1.0×10^{-3} s^{-1} at room temperature. The high temperature tensile specimens were cut from the forged bar by electro-spark wire-electrode cutting, which were carried out on a CSS-3905 materials testing machine. The tensile test temperatures were 400, 450 and 500 ℃. The strain rate were 1.0×10^{-3} s^{-1}.

2 Results and Discussion

2.1 Microstructure and phase transformation

Fig.1 shows the SEM images of the forged ($TiB+La_2O_3$)/Ti6Al4V titanium matrix composite (TMC) with the addition of La and B, and the microstructure is along the forging direction. The matrix alloy exhibits a near fully lamellar structure with an average thickness of 3~5 μm, and some *α* plate colonies could be observed in these images. As shown in Fig.1a~1c, short TiB fiber is about 13.6 μm in length and 7.1 μm in width. La_2O_3 reinforcement is about 1~7 μm in diameter with an irregular shape. The different shapes of reinforcements are related to their crystal structure and solidification paths[14,15]. The quantitative analysis of the reinforcements conducted by commercial software image-pro plus 6.0 reveals that the volume fractions of the reinforcements are increased from 1.2 vol % to 4.8 vol%, and the thickness and length of TiB fibers are also increased correspondingly.

Fig.2 shows the X-ray diffraction patterns of the as-cast titanium matrix composites (TMCs) and matrix Ti6Al4V alloy. It indicates that there are three kinds of phases in the composites: Ti, TiB and La_2O_3, which are synthesized through the reaction between Ti and La, B. There is no diffraction peak of TiB or La_2O_3 observed in Ti6Al4V, and the diffraction intensity is enhanced with the increasing of the La and B addition. Therefore, the addition of La and B element plays a significant role in the phase transformation for the studied composite.

2.2 Mechanical properties

Fig.3 shows the room temperature tensile properties of ($TiB+La_2O_3$)/Ti6Al4V composites and matrix alloy (TC4) with lamellar structure. Compared with matrix composite, the addition of La and B leads to a significant increase in the room temperature yield strength and ultimate strength in the in situ synthesized ($TiB+La_2O_3$)/Ti6Al4V composites. The reason could be the reinforcements generated in the solidification. The addition of La and B can react with Ti to produce TiB fibers and La_2O_3 particles, which could solid-solution in the matrix alloy. Therefore, the dislocation density is much higher around the reinforcements, which

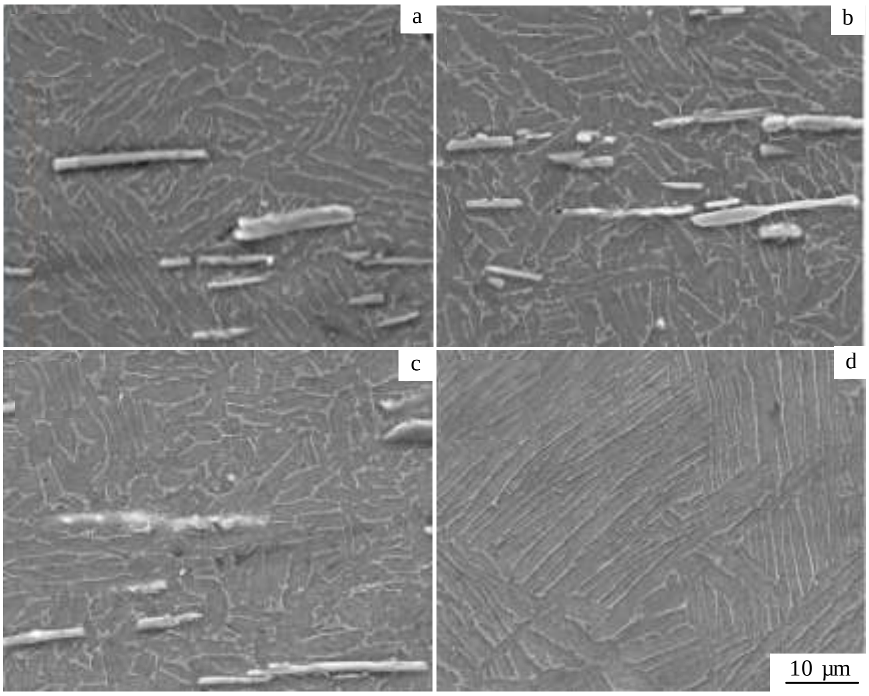

Fig.1 SEM images of the forged ($TiB+La_2O_3$)/Ti6Al4V matrix composite with addition of La and B element: (a) TMC1, (b) TMC2, (c) TMC3, and (d) matrix alloy

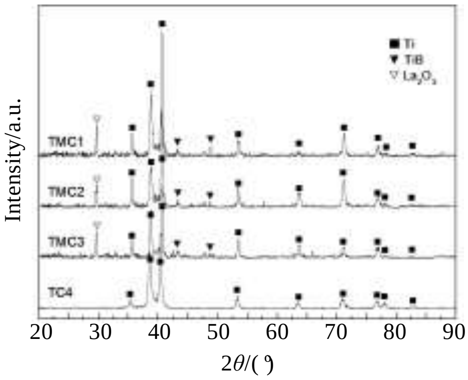

Fig.2 XRD patterns of the prepared specimens

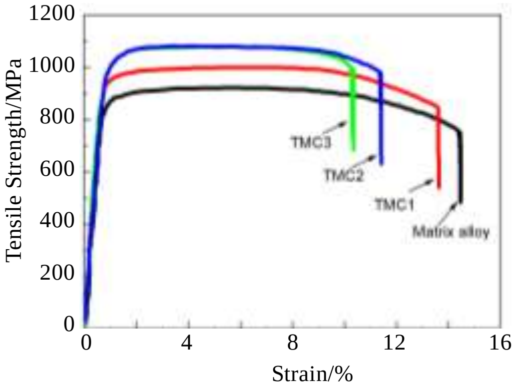

Fig.3 Tensile stress-strain curves of the specimens

could strengthen the matrix alloy and refine the microstructure. In addition, the tensile strength is increased with increasing the La and B addition for the 3 types of composites. TMC3 (1.45 wt% La + 0.68 wt% B) exhibits the highest tensile strength value of 1081 MPa, but its elongation decreases to 9.9%. The main reason should be that the reinforcement volume fraction of TMC3 is much higher than those of TMC1 and TMC2. The TiB and La_2O_3 size increases with the increasing of La and B addition; the strength increases and the ductility decreases as the aspect ratio of the reinforcement becomes smaller, which suggests the dependence of strength and ductility on reinforcement geometry. Therefore, the titanium matrix composite depends largely on the La and B addition.

The high temperature tensile tests of Ti6Al4V titanium alloy with different La、B addition were carried out at 400, 450 and 500 ℃. The strain rate was 1.0×10^{-3} s^{-1}. Fig.4 shows the high temperature tensile strengths of (TiB + La_2O_3)/ Ti6Al4V composites. With the increasing of temperature, the tensile strength decreases. Compared with that of the matrix alloy, the high temperature tensile strength of the titanium matrix composite shows a higher value, which can be considered as an important mechanical property for the application of the titanium alloys in the high temperature

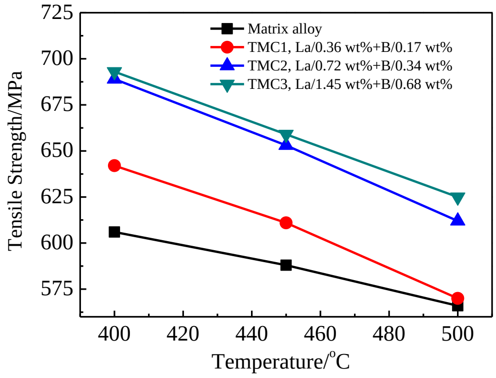

Fig.4 High temperature tensile strengths of (TiB+La_2O_3)/ Ti6Al4V composites

field. In addition, a higher tensile strength is obtained in the specimens with higher La, B content. As mentioned above in the room temperature tensile test in Fig.3, the reinforcements are generated from the reaction between Ti and La, B, which can improve the deformation resistance and strengthen the matrix alloy. The dispersion strengthing effect at high temperature is somewhat similar to that at room temperature, and a higher high-temperature strength is obtained in the specimen with higher content of La and B element.

However, as shown in Fig.4, TMC2 and TMC3 specimens present nearly the highest high temperature tensile strength at the temperature of 400~500 ℃. The main reason may be

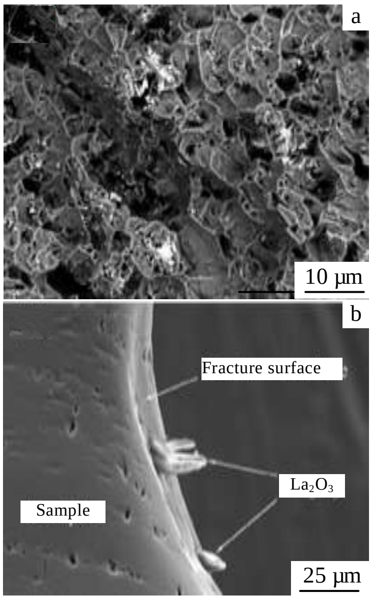

Fig.5 SEM images of high temperature fracture surfaces: (a) TMC3, 400 ℃ and (b) coarse La_2O_3 reinforcement in TMC3, 500 ℃

some coarse La_2O_3 reinforcements generated in the composites. Fig.5 shows the SEM images of the high temperature tensile fracture surfaces of TMC3 specimen, which indicate that the material is dominated by ductile fracture, and also the coexistence of brittle and plastic fracture. When the temperature is 500 ℃, as shown in Fig.5b, some coarse La_2O_3 reinforcements are observed nearby the fracture surface after high temperature fracture at the strain rate of 10^{-3} s^{-1}. It is indicated that the reinforcements are good at resisting the crack growth. Before plastic deformation, the expansion of the crack leads to failure fracture of the specimen, showing a higher high temperature tensile strength due to the coarse La_2O_3.

3 Conclusions

1) The tensile strengths at room temperature of $(TiB+La_2O_3)$/Ti6Al4V titanium matrix composite with lamellar microstructure are higher than that of the matrix alloy, but lower elongation is obtained in all specimens with La and B element addition.

2) A similar phenomenon can be found in high-temperature tensile test for both kinds of specimens with different volume fractions of reinforcements. The addition of La and B enhances the strength of the titanium matrix composite greatly. Higher high-temperature tensile strength is achieved by increasing the La and B addition.

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添加 La、B 对钛基复合材料显微组织和力学性能影响规律

韩远飞[1]，邝 玮[1]，杨小芳[2]，李九霄[1]，黄光法[1]，吕维洁[1]，张 荻[1]

(1. 上海交通大学 金属基复合材料国家重点实验室，上海 200240)

(2. 西北工业大学，陕西 西安 710072)

摘 要：通过添加不同质量分数 (0.36%, 0.72%, 1.45%) 的镧（La）和不同质量分数 (0.17%, 0.34%, 0.68%)的硼（B）到Ti6Al4V基体合金，经过普通的真空自耗电弧熔炼和热锻技术成功制备了$TiB+La_2O_3$颗粒增强钛基复合材料，并对材料热处理后的显微组织和力学性能进行了分析。利用XRD对试样进行了物相分析，应用金相显微镜和扫描电镜对复合材料显微组织进行了观察，特别探讨了增强体的演变特征，测定了材料的室温力学性能和高温力学性能。结果表明，La、B的添加对复合材料的显微组织和力学性能的影响巨大，制备的复合材料表现出优异的力学性能，抗拉强度可提高148 MPa，能显著地强化基体合金。

关键词：钛基复合材料；力学性能；显微组织；TiB；La_2O_3

作者简介：韩远飞，男，1983 年生，博士，助理研究员，上海交通大学金属基复合材料国家重点实验室，上海 200240，电话：021-54742564，E-mail: hyuf1@hotmail.com