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Microstructure and tensile properties of TiB_{2p}/6061Al composites

JIANG Long-tao(姜龙涛)[1], CHEN Guo-qin(陈国钦)[1], HE Xiao-dong(赫晓东)[2],
ZHAO Min(赵 敏)[1, 3], XIU Zi-yang(修子扬)[1], FAN Rui-jun(范瑞君)[1], WU Gao-hui(武高辉)[1]

1. School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, China;
2. School of Astronautics, Harbin Institute of Technology, Harbin 150001, China;
3. Research Institute, PetroChina Dushanzi Petrochemical Company, Kelamayi 833600, China

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Abstract: 14% and 20% (volume fraction) TiB_{2p}/6061Al composites were fabricated by pressure infiltration method, and then were extruded. The microstructure and properties of TiB_{2p}/Al composites before and after extrusion were studied by TEM, SEM and tensile method. The results show that TiB_2 particles employed are equiaxed polyhedrals and are well wetted with the aluminum alloy. Hot extruding is effective in eliminating defects such as pores, which are induced in the fabrication process. After T6 treatment and extrusion treatment, elastic modulus, tensile strength and elongation of 14%TiB_{2p}/6061Al composites are 107 GPa, 364.1 MPa and 9.25%, respectively. While those of 20%TiB_{2p}/6061Al composites are 120 GPa, 472.6 MPa and 9.79%, respectively, which show high strength and plasticity. A lot of dimples and a few cracked particles are observed on the fracture surfaces of the composites, which indicates good plasticity of the composites. The high strength and plasticity of TiB_{2p}/6061Al composites are attributed to good bonding between TiB_2 particles and aluminum alloy.

Key words: TiB_{2p}/Al composites; microstructure; tensile behavior; high plasticity

1 Introduction

Metal matrix composites exhibit outstanding physical property and mechanical performances such as low density, high strength, and high elastic modulus, which help them to become promising candidates for application in the aviation and aeronautics industry[1−2]. However, the addition of particle reinforcement deteriorates the material plasticity. It is reported that the addition of particle reinforcement may reduce the plasticity of the base alloy by one order of magnitude. Hence, fabrication of aluminum matrix composites with high plasticity is one of the most important research aspects in this field[3−5].

It is reported that the size, shape and distribution of the particle reinforcement, the interface bonding, as well as the nature and stress condition of the base alloy will greatly influence the strength and ductility of the composites[6−9]. The application of reinforcements possessing good wettability with aluminum alloy, small particle size, and near equiaxed shape will be beneficial to the strength and ductility of the composites. Compared with the widely used reinforcements of SiC and Al_2O_3 particles, TiB_2 possesses high melting point, high hardness, high elastic modulus and super heat resistance, super wear resistance[10−12], and good wettability with aluminum alloys[13] which contributes to the interface bonding strength between the particles and the aluminum alloys. At present, TiB_2 reinforced aluminum matrix composites are mainly fabricated by the in situ synthesis techniques. During these processes of fabrication, many intermediate products were produced, which is harmful to the properties of the composites[14−16]. Therefore, pressure infiltration method was adopted in this study to fabricate low volume fraction TiB_{2p}/6061Al composite. And the microstructure and properties of the composites before and after extrusion treatment were studied by transmission electron microscope (TEM), scanning electron microscope (SEM) and tensile method.

2 Experimental

TiB_2 with 1.5 μm nominal grain size was chosen as

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Corresponding author: JIANG Long-tao; Tel: +86-451-86402373-5055; E-mail: jlongtao@263.net

reinforcement and was proportionally mixed with aluminum powder with average grain size of 7 μm to form precast block. 6061 aluminum was chosen as matrix alloy. 14% and 20%TiB_{2p}/6061Al composites were fabricated by pressure infiltration method, and then were extruded with extrusion ratio of 10:1 and extrusion temperature of 550 ℃. All composite specimens before and after excursion were solution treated at 530 ℃ in KNO_3 salt-bath furnace for 1 h and water quenched at room temperature. After solution treatment, specimens were aged at 160 ℃ for 10 h and cooled in air.

Composites extruded and un-extruded were prepared into tensile sample and dimensions are shown in Fig.1. Room-temperature tensile test was conducted by Instron 5569 universal electrical tensile testing machine, and the microstructure was observed by Hitachi S−4700 and Philips CM12 transmission electron microscope (TEM).

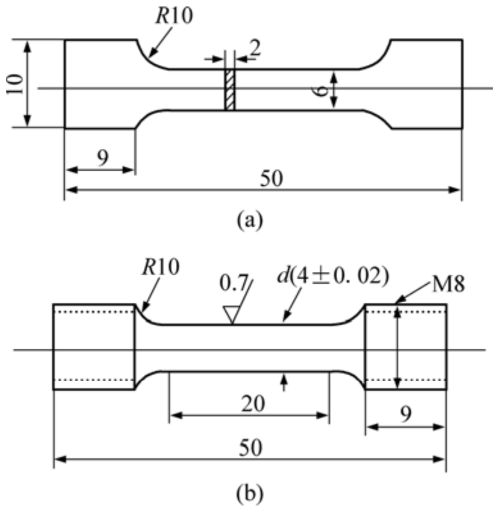

Fig.1 Dimensions of tensile sample (mm)

3 Results and discussion

3.1 Microstructure

Fig.2 shows the SEM micrographs of TiB_{2p}/6061Al composite before and after hot extrusion. From Fig.2, it can be seen that TiB_2 particles are equiaxed polyhedral and its grain size is 1−10 μm. With increase of TiB_2 fraction, uniformity of TiB_{2p}/6061Al composite is improved. Hot extrusion can effectively improve compactability and uniformity of the composites, which is favorable to improve the strength, elastic modulus and elongation. After extrusion, TiB_2 reinforcements distribute more homogeneously in 20%TiB_{2p}/Al composites.

The TEM results of extruded 20%TiB_{2p}/6061Al composites are shown in Fig.3. It can be seen that, TiB_2/Al interfaces are clean and smooth without reactants or precipitated phase. In the matrix alloy, there are some dislocation and precipitates, which is benefit to strengthen composites. In addition, crystal grains are refined in the matrix of extruded composite, which shows obvious improvement of strength and elongation.

3.2 Mechanical properties

3.2.1 Tensile curve

Fig.4 shows tensile stress—strain curves of two with different volume fractions of TiB_{2p}/6061Al composites before and after extrusion. From Fig.4(a), it can be seen that the volume fraction has great effect on tensile curve of un-extruded composite. Elastic modulus and tensile strength of 14%TiB_{2p}/6061Al is lower, while its elongation is higher than that of 20%TiB_{2p}/6061Al composites. Tensile curve of extruded composites differs from that of un-extruded composites, as shown in Fig.4(b). After extrusion, the strength of the composites increases by different degrees. The 20%TiB_{2p}/6061Al composites exhibit the most obvious improvement in terms of the ultimate tensile strength and also a good elongation of 6%−10%.

3.2.2 Elastic modulus

Fig.5 shows comparison of elastic modulus of TiB_{2p}/6061Al composite with different volume fractions

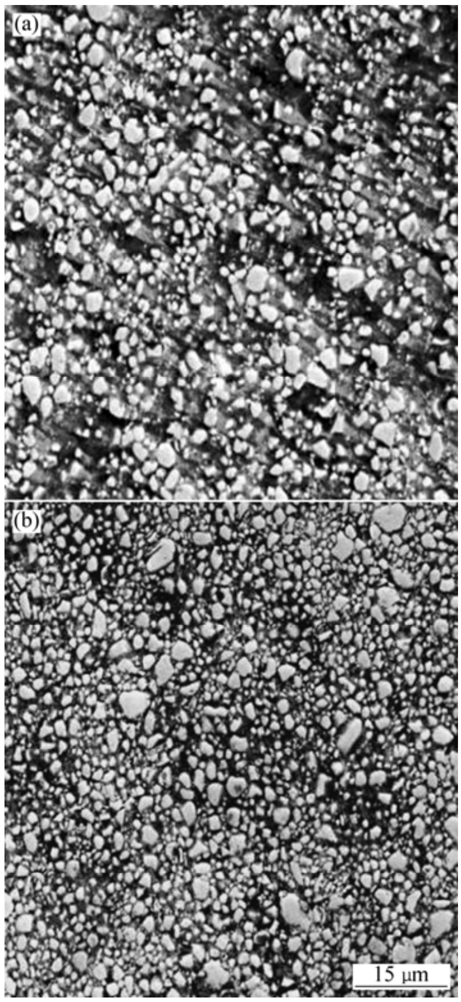

Fig.2 SEM images of TiB_{2p}/6061Al composite: (a) 20%TiB_{2p}/6011Al before extrusion; (b) 20% TiB_{2p}/6011Al after extrusion

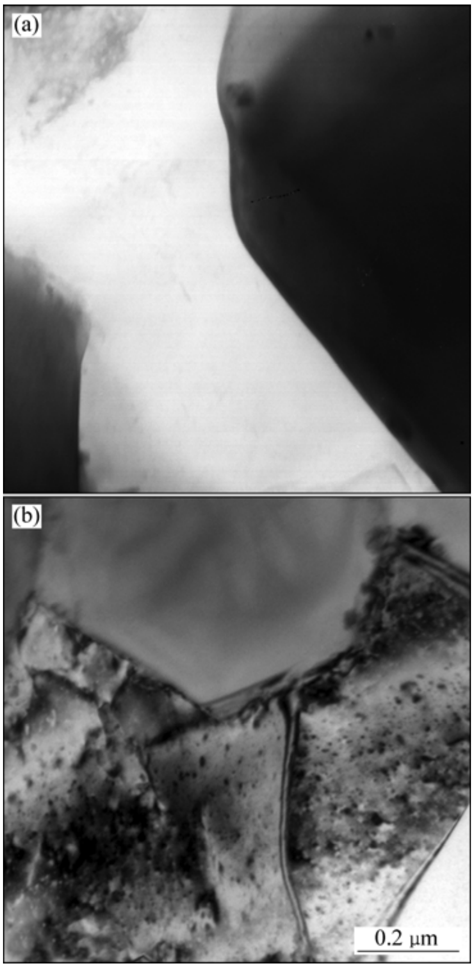

Fig.3 TEM images of extruded 20%TiB_{2p}/6061Al composites: (a) Interfaces; (b) Ageing precipitate in matrix alloy

of TiB_2 before and after extrusion. It can be seen that, the elastic modulus of 14%TiB_{2p}/6061Al composite before extrusion is nearly 76.2 GPa, and after T6 heat treatment its elastic modulus is nearly 61.1 GPa. While compared with that of the composite before extrusion, there is an increasing tendency in elastic modulus after extrusion treatments. After extrusion, elastic modulus of 14%TiB_{2p}/6061Al composite before and after T6 heat treatment are 97.6 GPa and 107.1 GPa, respectively. Generally, elastic modulus is considered as physical characteristic of material and do not change with treatment conditions. Further, extrusion treatment can make composite pyknosis, which can improve the elastic modulus of composite. The change of elastic modulus of 20%TiB_{2p}/6061Al before and after extrusion can verify this point. From Fig.5, elastic modulus of 14% and 20%TiB_{2p}/6061Al composites before extrusion are 94.8 GPa and 96.9 GPa，while after extrusion elastic modulus are improved to 115.6 GPa and 120 GPa, respectively. By calculation, when the volume fraction increases by 6%, the elastic modulus of the composites can be improved by about 12%.

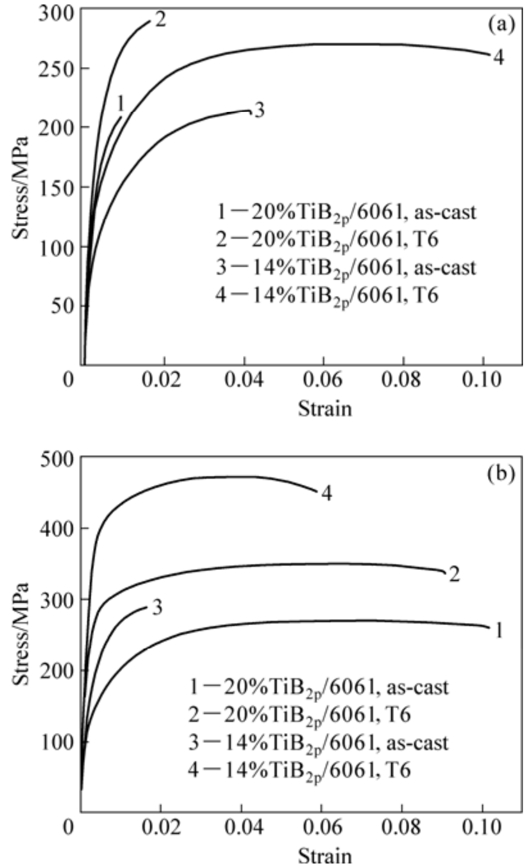

Fig.4 Tensile stress—strain curves of TiB_{2p}/6061Al composite before and after extrusion: (a) Before extrusion; (b) After extrusion

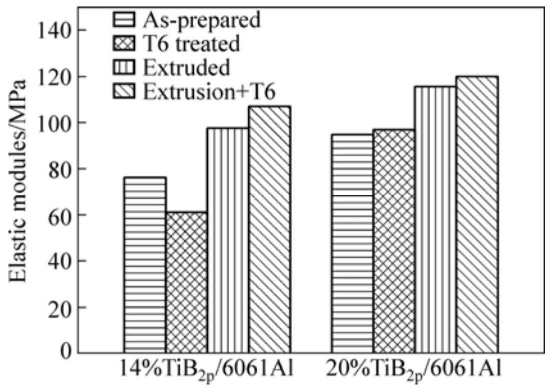

Fig.5 Comparisons of elastic modulus for TiB_{2p}/6061Al composites

3.2.3 Tensile strength

Comparisons of tensile strength of TiB_{2p}/6061Al composites with different volume fractions of TiB_2 before and after extrusion treatments are shown in Fig.6. It can be seen that extrusion treatment is beneficial to enhancing tensile strength of the composites. By extrusion treatment, tensile strength of 14%TiB_{2p}/6061Al increases from 223.95 MPa to 241.3 MPa. Heat treatment has effect on tensile strength of the composites. For 6061Al alloy, precipitation strengthening is one of main strengthening mechanisms. Especially for low volume fraction composites, ageing strengthening of matrix alloy can effectively improve strength of the composite. Researches show that, after extrusion and heat treatment, tensile strength of 14%TiB_{2p}/6061Al composite is improved from 241.1 MPa to 364.1 MPa and that of 20% TiB_{2p}/6061Al composite is improved from 228.9 MPa to 472.6 MPa，which is improved by 50.9% and 106.5%, respectively. All of these can reveal that ageing strengthening is the main strengthening mechanism for low volume fraction TiB_2/6061Al composites.

3.2.4 Elongation

Elongation is an important property index for aviation structural materials, which can ensure structure safety. Fig.7 shows the elongations of TiB_{2p}/6061Al composites with different volume fractions of TiB_2 before and after extrusion. It can be seen that hot extrusion can obviously improve elongation of the composites. For example, after extrusion, elongation of 20%TiB_{2p}/6061Al increases from 0.69% to 11.65%. This is due to the fact that in extrusion treatment, tightness of the composites can be obviously improved, which has a beneficial effect on load transfer and stress distribution between matrix and particles to avoid brittle fracture under low stress. Heat treatment has no obvious effect on elongation and even lower elongation of composite with high volume fraction of TiB_2 is observed.

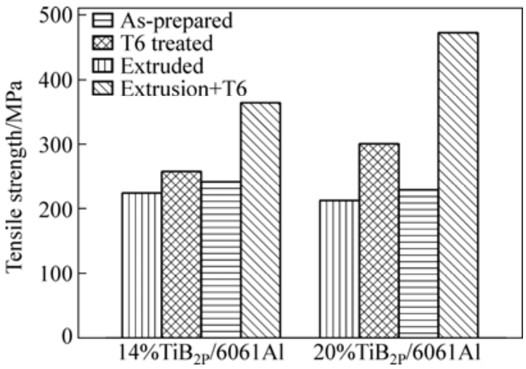

Fig.6 Comparisons of tensile strength for TiB_{2p}/6061Al composites

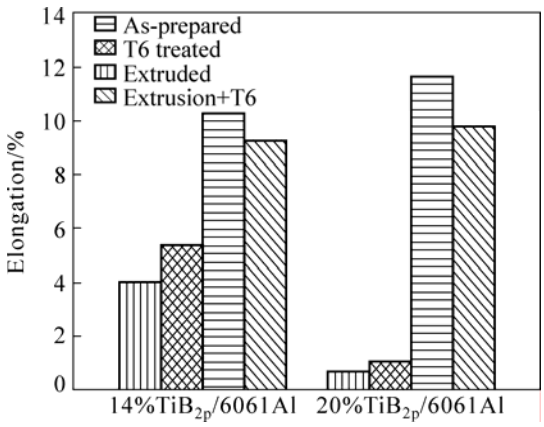

Fig.7 Comparisons of elongation for TiB_{2p}/6061Al composites

For the composites, the ductility of the base alloy, the interface bonding between the base alloy and the reinforcements, and the volume fraction of the reinforcements are important factors influencing the elongation of the composites. Obviously, hot extrusion greatly improves the elongation of the composites. The extrusion processing improves the plasticity of the base alloys via improving the interface bonding and refining the grain size. From the microstructure of the composites after extrusion (as shown in Fig.3), it is observed that the composites after extrusion have good interface bonding and fine subgrains in the size of 0.2−0.5 μm. The refinement of gains greatly improves the strength of the composites, and at the same time promotes the plasticity. The tensile tests show that the elongation of the composites after ageing treatment lowers within a narrow range, which is related to the large amount of precipitates after ageing treatment. As the precipitates aggregate and grow up, the movement of dislocations needs to cross the precipitation, which increases the resisting force of dislocation movement, and also increases the difficulty of grain boundary sliding. Thus, the strength of the composites is enhanced, while the elongation is reduced. Moreover, the precipitation of phases at the grain boundaries breaks down the continuity of the base alloy, which also leads to the decrease of the plasticity of the composites.

3.2.5 SEM analyses

Fig.8 shows tensile fracture surfaces of TiB_{2p}/

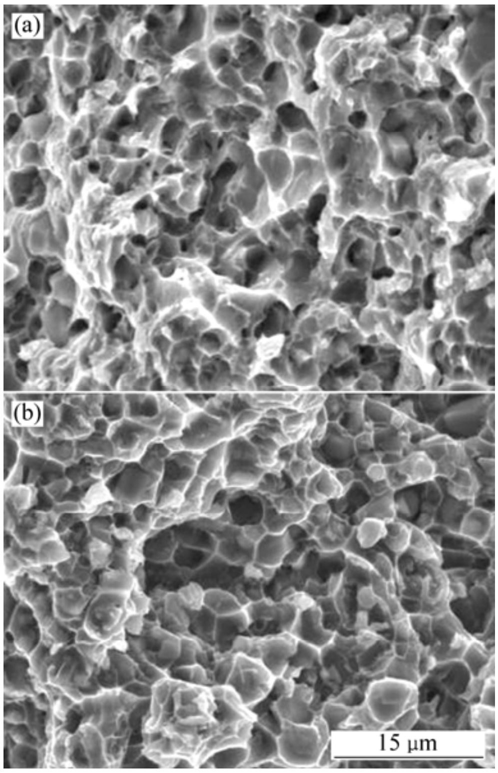

Fig.8 Tensile fractographs of TiB_{2p}/6061Al composites before and after extrusion: (a) 14%TiB_{2p}/6061Al; (b) 20% TiB_{2p}/6061Al

6061Al composites with different volume fractions of TiB_2 after T6 treatment. The fractographs show good plastic deformation characteristic. There are a lot of dimple and tearing edge on tensile fracture surfaces. Some TiB_2 particles distribute homogeneously in the matrix alloy. And also some flush TiB_2 particles are found, which shows that some crack may origin from TiB_2 particles. It can be seen that bonding condition between TiB_2 particles and 6061Al alloy is good.

4 Conclusions

1) TiB_2 particles employed in the present study are equiaxed polyhedrals and distribute homogeneously in aluminum alloy without obvious glomeration. Composite is dense and macroscopically homogeneous, free from porosity, shrinking cavities and bright aluminum ribbon.

2) After T6 treatment and extrusion treatment, elastic modulus, tensile strength and elongation of 14%TiB_{2p}/6061Al composites are 107 GPa, 364.1 MPa and 9.25%, respectively. While those of 20% TiB_{2p}/6061Al composites are 120 GPa, 472.6 MPa and 9.79%, respectively, which shows high strength and plasticity.

3) The characteristics of good plastic failure are found on fracture surfaces of the composites, such as a lot of dimples and cracked big particles. The high strength and plasticity of TiB_{2p}/6061Al composites are attributed to good bonding between TiB_2 particles and aluminum alloy.

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