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Mechanical properties and microstructure of Fe-Al/Al_2O_3 composite with Cr, Mo and Ti①

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Abstract: When Cr, Mo and Ti were added to Fe-Al/Al_2O_3 composite, the bending strength and fracture toughness of the composite were increased sharply. The highest value of bending strength can exceed 600 MPa and the average value of fracture toughness exceed 12 MPa·$m^{1/2}$. With increasing content of Mo and Ti, the bending strength and fracture toughness both express the trend of increasing first and then decreasing. When the alloying elements were added to the composites the alloying extent is improved. The fracture mode of the composites are mainly transcrystalline.

Key words: Fe-Al intermetallic; Al_2O_3; composite; alloying element

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1 INTRODUCTION

The Fe-Al intermetallic compound has a series of merits[1, 2], such as high strength, low density, good wearablity and low costs, and it has been used in some fields. But its high temperature strength is lower. Al_2O_3 ceramics is one of the structural materials with wide application, but both the higher brittleness and lower toughness limited its application fields. In order to get one material with both high strength and high toughness, one novel Fe-Al/Al_2O_3 composite was fabricated by the authors[3]. It has very wide application prospect for its better properties, but some mechanical properties of the composite should be improved yet[3-5]. In order to improve the mechanical properties of the composite, in this paper, the authors study the properties and microstructure of the composite when Cr, Mo and Ti are added to Fe-Al/Al_2O_3 composite according to theoretical calculation and the researching results in foregoing articles[6].

2 EXPERIMENTAL

The powder of Fe-Al intermetallic compound was prepared with the method introduced in Refs. [7, 8]. The average particle size of Al_2O_3 was 2.3 μm ($w(Al_2O_3)$ > 98%, Zhangjiakou Special Ceramics Materials Co Ltd). The average particle size of Cr was about 74 μm (w(Cr) > 99%). The average particle size of Mo was between 98 μm and 125 μm (w(Mo) > 99.5%). The average particle size of Ti was between 62 μm and 147 μm (w(Ti) > 99.9%, in purity). The three metal powders were all produced by Shanghai Chemicals Co Ltd. According to the proportion, the powders of Fe-Al intermetallic compound, Al_2O_3 and Cr, Mo, Ti were ball-milled with 150 mL alcohol for 6 h in order to fabricate the powder of Fe-Al/Al_2O_3 composite with alloying elements. After milling, the slurries were dried in vacuum dry box and the powder of the composite was acquired. The concrete condition is shown in Table 1.

Sintering was performed by hot-pressing in sintering furnace (High Multi-5000, Japan). Nitrogen was used as protective gas. The velocity to increase temperature was different in different temperature sections. When the temperature reached the highest point an uniaxial pressure of 17.3 MPa was applied. The highest temperature is 1 520 ℃. Both pressure and temperature were held for 30 min. The pressure was then released and the system was cooled to room temperature. The dimensions of the hot-pressed specimen were 60 mm in diameter and 5.5 mm in thickness.

The sintered specimens were machined with a grit resin bonded diamond wheel on a grinder. Then the specimens were cut into rectangular bars about 3 mm × 4 mm × 36 mm with slicer(J5060－1). Three point bending strength was tested by omnipotent experimental machine(WE－50). After Vicker hard-

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ness was tested, the fracture toughness was calculated. The phase identification was performed by X-ray diffractometry (XRD, D/max - rB, Japan). The microstructure of fracture surface were observed with scanning electron microscope (SEM, JXA - 840, Japan).

Table1 Chemical composition of samples (mass fraction, %)

Sample	Fe-Al	Cr	Mo	Ti	Al_2O_3
FC01	20	–	–	–	Bal.
FC02	20	1.5	0.5	3.5	Bal.
FC03	20	1.5	1.5	2.5	Bal.
FC04	20	1.5	2.5	1.5	Bal.
FC05	20	1.5	3.5	0.5	Bal.

3 RESULTS AND DISCUSSION

3.1 Mechanical properties of composites

Fig. 1(a) shows that, when proper quantity of Cr, Mo, Ti were added, the bending strength of Fe-Al/ Al_2O_3 composite was increased at large extent. The biggest value exceeds 600 MPa and the increasing extent exceeds 30% than the values without alloying elements. The strength of the composite increases first and then decreases, which results in a highest point in the curve. This expresses that, when proper quantities of Cr, Mo, Ti were added to the composite, they can influence the strength of the composite to a large extent. If the three alloying elements were optional combined high strength materials could be got. They have a best distributing scope. When the content of Cr is 1.5% and the contents of Mo and Ti are between 1.5% and 2.5%, the average value of bending strength of the composites exceeds 550 MPa. After analyzing, the authors thought that when Cr, Mo, Ti were added to the composite at the same time, partial of them entered the crystal lattice of Fe-Al intermetallic compound and substituted Fe atom. This corresponded with the results of Refs. [9 - 11]. Because they are different atoms, and the bond energy between them is different either, this can change the crystal lattice of Fe-Al intermetallic compound and make the bond stronger, which will result in the increasing of strength. In other words, three elements produce coordinated action and increase the strength of the composite. In addition, the alloying elements at grain boundary can refine the grains and reinforce the grain boundary. This can increase the strength of the composite. Because the contents of Cr, Mo, Ti are different and the coordinated action is different either, the strength of the composite is different accordingly.

Fig. 1(b) shows that, when Cr, Mo, Ti were added at the same time, the average value of fracture toughness of the composite was increased from 8.8 $MPa \cdot m^{1/2}$ to about 12 $MPa \cdot m^{1/2}$. Furthermore, the fracture toughness of the composites all exceeded 14 $MPa \cdot m^{1/2}$ when the contents of Mo and Ti were all between 1.5% and 2.5%. They are all lower than 14 $MPa \cdot m^{1/2}$ when the contents of Mo and Ti are all higher than 2.5% or lower than 1.5%. This expresses that the fracture toughness of Fe-Al/ Al_2O_3 composite can be increased to large extent when proper quantities of Cr, Mo, Ti are added to the composite at the same time. The authors thought when Cr, Mo, Ti were added to the composite at the same time partial alloying elements produced solid action with Fe-Al intermetallic compound and partial alloying elements dispersed uniformly in the matrix and toughened the composite. They all improve the strength and toughness of the composite.

3.2 Phase composition of composite

Fig. 2 shows the XRD pattern of Fe-Al/ Al_2O_3 composites with or without Cr, Mo, Ti alloying elements . There is no alloying element in Fig. 2(a) and there are Cr, Mo and Ti in Fig. 2(b). Fig. 2 shows that Al_2O_3 is the main crystal phase of the two specimens, others are Fe_3Al and α-Fe. But the content of α-Fe is very little. The existence of little α-Fe expresses that the extent of alloying is relatively high. The XRD patterns of Al_5Mo and Al_3Ti are shown in Fig. 2(b), which expresses that the extent of alloying is higher in the composite. This can improve the mechanical properties of the composite. It corresponds with the testing results of mechanical properties. In addition, there are XRD peaks of Cr, Mo, but no Ti. It may be that Ti reacts with Fe-Al intermetallic compound for its higher activities but Cr and Mo are kept in the formation of single element for their lower activities.

3.3 Microstructure of composite

Fig. 3 shows the SEM micrograph of fracture surface of Fe-Al/ Al_2O_3 composite with or without Cr, Mo, Ti alloying elements. From Fig. 3 we can see that some grains have grown up in Fig. 3(a) but the grains of Fig. 3(b) almost do not change, which expresses that alloying elements Cr, Mo and Ti can refine the grains when they are added to the composite. The composite in Fig. 3(a) fractures mainly along the grain boundary but the fracture mode in Fig. 3(b) is mainly transcrystalline and there is apparent tearing phenomenon on the fracture surface of the grains. This expresses that the bonding strength of the grain boundary is lower but the strength of grains is higher in Fig. 3(a) and the condition is inverse in Fig. 3(b). The fracture

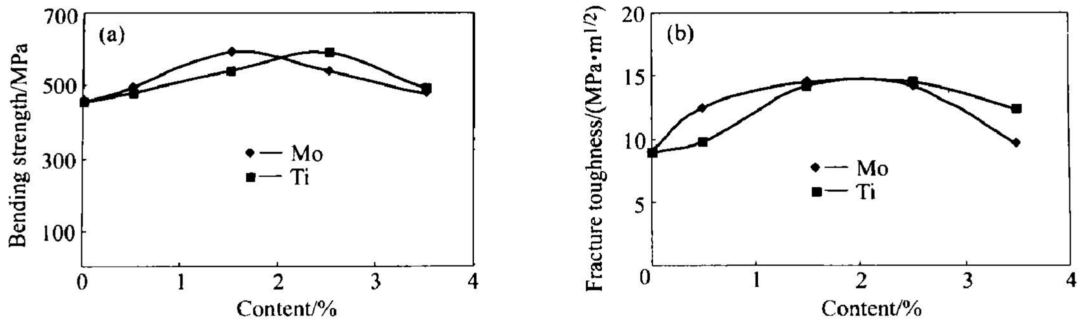

Fig. 1 Curves of mechanical properties and content of Mo and Ti of Fe-Al/Al_2O_3 composite (Total capacity of Mo and Ti is 4.0% in every sample)
(a) —Bending strength curve; (b) —Fracture toughness curve

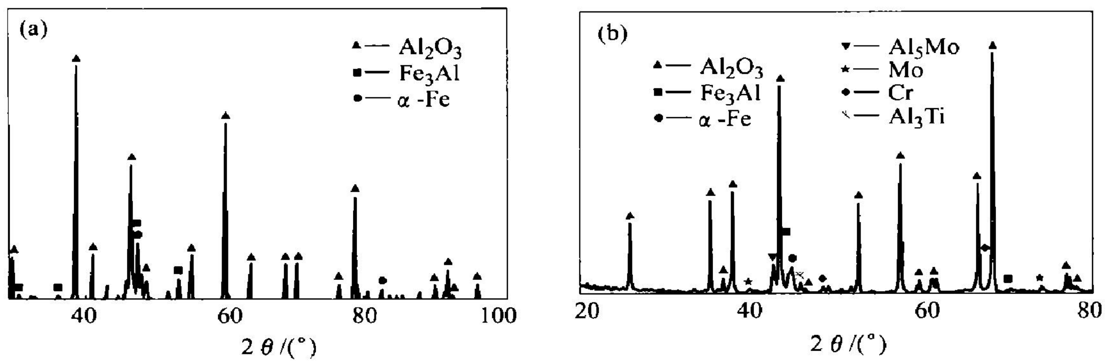

Fig. 2 XRD patterns of Fe-Al/Al_2O_3 composite with or without alloying elements
(a) —FC01; (b) —FC04

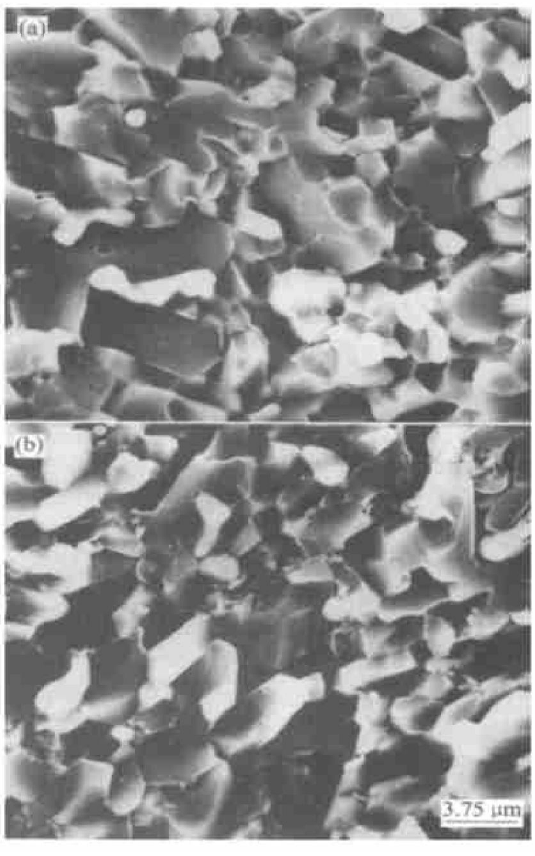

Fig. 3 SEM micrographs revealing fractured Fe-Al/Al_2O_3 composite with or without alloying elements
(a) —FC01; (b) —FC04

surface unfolded ductile attitude in Fig. 3(b). This specimen has higher strength and toughness. This corresponds with the testing results of mechanical properties. When alloying elements are added to the composite some of them go into the crystal and make the crystal produce aberration, which changes the crystal lattice constant and improves the properties of the composites. When only one element is added to the composite its effect is lower. This expresses that they have active coordinated action to improve the properties of the composite when Cr, Mo and Ti are added to the composite at the same time. There are some fine flocules at the grain boundary in Fig. 3(b). It is thought that this maybe the enrichment of alloying elements at grains boundary. This expressed that partial alloying elements produced soliod reaction with Fe-Al intermetallic compound and partial of them accumulated to the grain boundary or dispersed to the composite, which can reinforce the boundary or toughen the composite by plastic formation. This can result in the increasing of toughness and strength. In addition, there are more pores in Fig. 3(a) than in Fig. 3(b), showing that the densification of Fig. 3(b) is higher than that of in Fig. 3(a). This is another reason why the toughness and strength shown in Fig. 3(b) are all higher than that of Fig. 3(a).

Fig. 4 shows the typical transcrystalline micrograph of Fe-Al/Al_2O_3 composite with Cr, Mo and Ti,

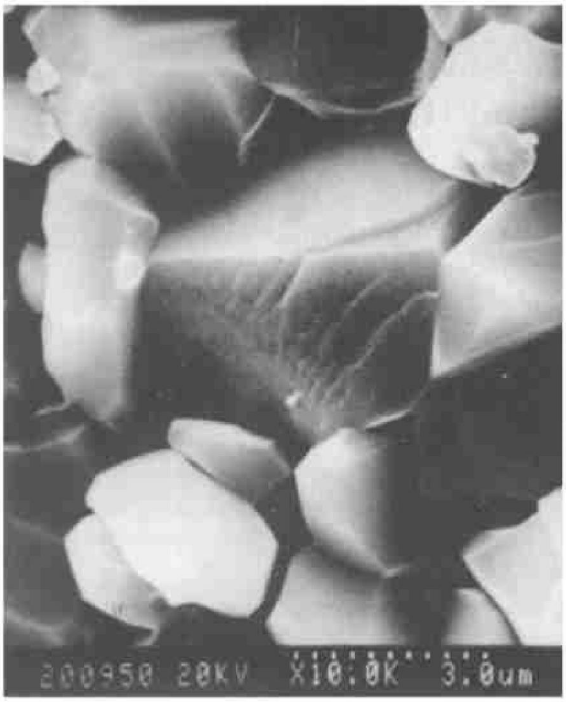

Fig. 4 SEM micrograph of transcrystalline of Fe-Al/Al_2O_3 composite containing Cr, Mo and Ti

which corresponds with FC04. There is apparent rippled or strip structure after the fracture of grains, showing that the phenomenon of transcrystalline is very clear when Cr, Mo and Ti are added to the composite. This verifies the result in Fig. 3.

4 CONCLUSIONS

When proper quantities of Cr, Mo and Ti are added to Fe-Al/Al_2O_3 composite, which produces coordinated action and increases the strength and toughness of the composite at large extent. When the content of Cr is 1.5%, and the contents of Mo and Ti are between 1.5% and 2.5%, but the total capacity of Mo and Ti is 4.0%, the bonding strength of the composite all exceeds 550 MPa and the fracture toughness exceeds 14 $MPa\cdot m^{1/2}$. There exit diffraction peaks of Fe_3Al and very little α-Fe in all XRD patterns, the diffraction peaks of Al_5Mo and Al_3Ti are all found when Cr, Mo and Ti are added. This indicates that the addition of Cr, Mo and Ti to reinforce and toughen the composite promoted the processing of alloying. The composite without alloying elements fractures mainly along grain boundary. When Cr, Mo and Ti are added to the composite at the same time, the fracture mode is main transcrystalline. The grains almost do not grow up and the fracture surface unfolds ductile attitude.

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