

Study on mechanical properties of composite materials by in-situ tensile test

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Abstract: The mechanical properties of the SiC fiber-reinforced Mg-Al metal matrix composite materials have been studied on internal microstructure by SEM in-situ tensile test. The emergence and propagation of the crack, and the fracture behavior in materials have been observed and studied. It is found that in the case of the tensile test, the crack emerged in SiC fiber initially. In the case of the strong cohesion of the fiber-metal interface, the crack propagated in the fiber, meanwhile the fibers in the neighborhood of the cracked fiber began to crack and the Mg-Al metal deformed plastically, and at last the material fractured. Otherwise the toughness of the materials grows in the case of the lower cohesion of the fiber-metal matrix interface.

Key words: Mg-Al matrix; SiC fiber; in-situ tensile test

Composite materials have properties different from conventional engineering materials, specifically present high strength-weight and high stiffness-weight ratios. Considerable work has been done on the fabrication and application of composite materials. During the past years, many engineering applications have increased their search for advanced composite materials. Thus the application of composite materials has significantly increased^[1,2]. Metal matrix composites are becoming attractive materials because their properties can be tailored by adding different reinforcements. Metal matrix fiber composites are mainly applied to such structures requiring combinations of properties as high modulus, strength hardness and wear resistance. These materials have emerged as viable alternatives for use in automotive and aerospace industries.

The use of composite materials calls for studies of mechanical behavior of these materials, so the conditions for qualification of a composite structure are in this case based on results of the mechanical test^[3-8]. In this paper, the mechanical properties of SiC fiber-reinforced Mg-Al metal matrix composite materials have been studied on internal microstructure by the scanning electron microscopy in-situ tensile test.

1 Preparation of Materials and Experimental Process

The composite materials investigated are Mg-Al or Mg-Al-Ca matrix with SiC fiber reinforced. The design chemical compositions are shown in Tab.1.

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Tab.1 Compositions of testing alloy

Sample No.	w(Al)/%	w(Ca)/%	w(SiC)/%	w(Mg)/%
1	8		12	80.0
2	8	0.3	12	79.7

The loading mode of the mechanical test experiment was tensile loading mode. The tensile experiments were performed inside the X-650 scanning electron microscope with a special tensile test device, which could carry out tensile experiment. The specimens were machined to the shape as shown in Fig. 1 with 2 mm thickness. The specimen was mounted between two guide pins and was directly placed in the specimen chamber of the scanning electron microscope. Load was applied by retracting the movable pulling rod. Therefore, the tensile experimental process could be observed in situ.

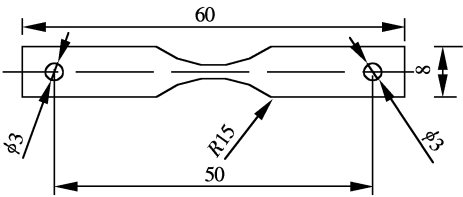


Fig.1 Shape of the specimens (unit: mm)

2 Experimental Results and Discussions

Tab.2 shows the result of the tensile tests on Mg-Al (SiC) and Mg-Al-Ca (SiC) specimens. As seen from Tab.2, the ultimate tensile strength (σ_b) of the Mg-Al (SiC) alloy is similar to that of the Mg-Al-Ca (SiC) alloy, but the yield tensile strength (σ_s) of the Mg-Al (SiC) alloy is higher than that of the Mg-Al-Ca (SiC) alloy and the elongation (σ) of the Mg-Al (SiC) alloy is lower than that of the Mg-Al-Ca (SiC) alloy. So the mechanical properties of Mg-Al (SiC) alloy are

changed by adding Ca into Mg-Al matrix.

Tab.2 Mechanical properties of the Mg-Al (SiC) alloy and the Mg-Al (Ca)(SiC) alloy

Specimen	σ_b /MPa	σ_s /MPa	σ /%
Mg-Al (SiC)	262	154	6
Mg-Al-Ca (SiC)	260	138	15

It is well known that the mechanical properties of metal matrix composites are influenced by their microstructure parameters, such as the size, the volume fraction and the distribution of SiC fiber. Fig.2 shows the microstructure of Mg-Al (SiC) alloy. It could be seen from Fig.2 that the SiC fibers in Mg-Al matrix were well distributed, the size of SiC fiber was about 25 μm and the volume fracture of SiC fiber was about 10%. Fig.3 shows the microstructure of Mg-Al-Ca (SiC) alloy. It could be seen from Fig.3 that the SiC fibers in Mg-Al-Ca matrix were well distributed, the size of SiC fiber was about 25 μm and the volume fracture of SiC fiber was about 10%. The microstructural investigation could not explain the results of the tensile tests on Mg-Al (SiC) specimens and Mg-Al-Ca (SiC) specimens, which showed the difference of mechanical properties between Mg-Al (SiC) alloy and Mg-Al-Ca (SiC) alloy.

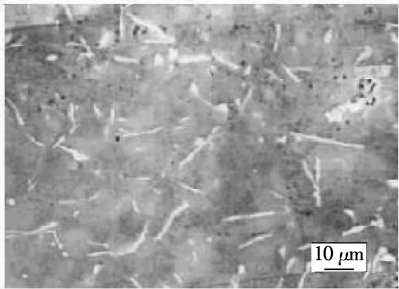


Fig.2 Microstructure of Mg-Al (SiC) alloy

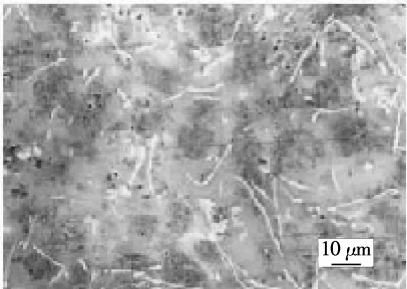


Fig.3 Microstructure of Mg-Al (Ca)(SiC) alloy

The mechanical properties of SiC fiber reinforced Mg-Al metal matrix and Mg-Al (Ca) metal matrix composite materials were studied on internal microstructure by the scanning electron microscopy with in-situ tensile test. Fig. 4 shows the secondary electron images of Mg-Al (SiC) tensile specimen under the test loading. The emergence and the propagation of the crack and the fracture behavior in

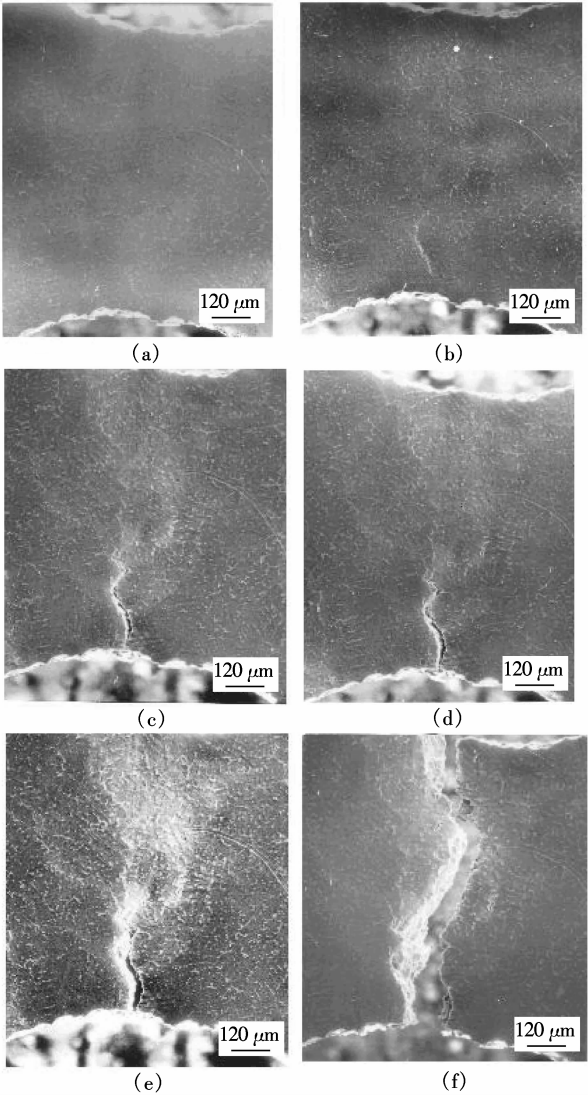


Fig.4 Scanning electron microphotographs showing the emergence and the propagation of the crack and the fracture behavior in Mg-Al (SiC) tensile specimen under the test loading

Mg-Al (SiC) tensile specimen under the test loading can be observed. In Mg-Al (SiC) tensile specimen, the crack emerged at the lower part of the specimen (Fig.4 (b)). As the load increased, the crack propagated along the line perpendicular to the load direction (Fig.4(c)). At the load of 154 MPa, the specimen began to deform (Figs. 4 (d) and (e)). At last, as the load increased to 262 MPa, the specimen fractured (Fig.4 (f)). In order to observe the emergence of the initiated crack and the path of the crack propagating, the representative high-magnification structures of the specimen were taken. Fig.5 is the local magnifying images of Al-Mg (SiC) tensile specimen under the test loading. It could be seen that the crack initiated in a SiC fiber (Fig.5(a)). As the load increased, the crack propagated in the fiber, meanwhile, some other fibers nearby began to crack and the Mg-Al matrix nearby

began to deform plastically (Fig. 5 (b)). As the additional load was applied, the crack grew wider and the plastic deformation in the matrix increased. At last, under larger loading, the local stress concentrated in the matrix was so large that the crack propagated into the matrix (Fig. 5 (c)), and the specimen fractured suddenly.

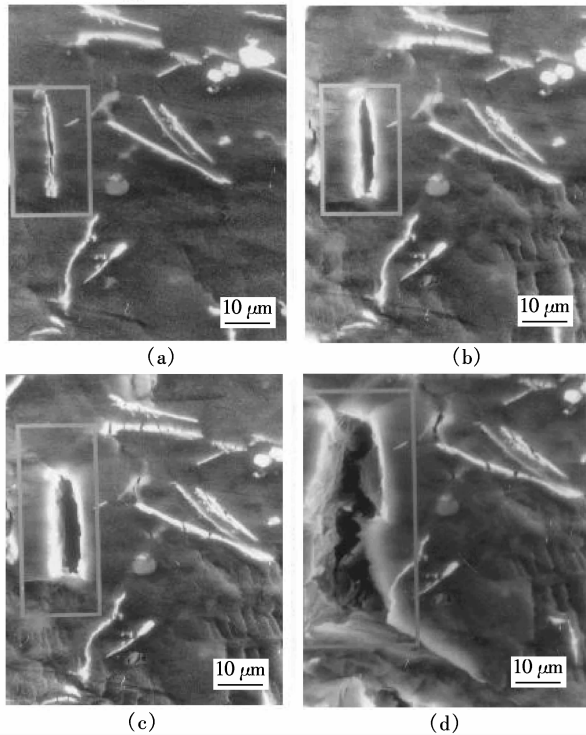


Fig.5 The high magnifying images of the emergence and the propagation of the crack in Mg-Al (SiC) tensile specimen under the test loading

Fig.6 shows the secondary electron images of Mg-Al-Ca (SiC) tensile specimen under the test loading. The emergence and the propagation of a crack and the fracture behavior in Mg-Al-Ca (SiC) tensile specimen under the test loading can be observed. The fracture surface of the Mg-Al-Ca (SiC) tensile specimen is dimply rather than flat and it can be observed that there are some debond fibers on the fractured surface of the Mg-Al-Ca (SiC) tensile specimen. On the contrary, the bonding of the matrix-fiber interface is weaker in the Mg-Al-Ca (SiC) material than in the Mg-Al (SiC) material.

The results presented above indicate that under loading the crack nucleates in brittle fibers in Mg-Al (SiC) material. The path through which the crack propagates depends on the bonding of the matrix-fiber interface. In the case of Mg-Al (SiC) material, the bonding of the matrix-fiber interface is stronger, so the crack propagates in the fiber and under larger loading it propagates into the matrix, then the fracture occurs suddenly. Therefore, in the case of Mg-Al-Ca (SiC)

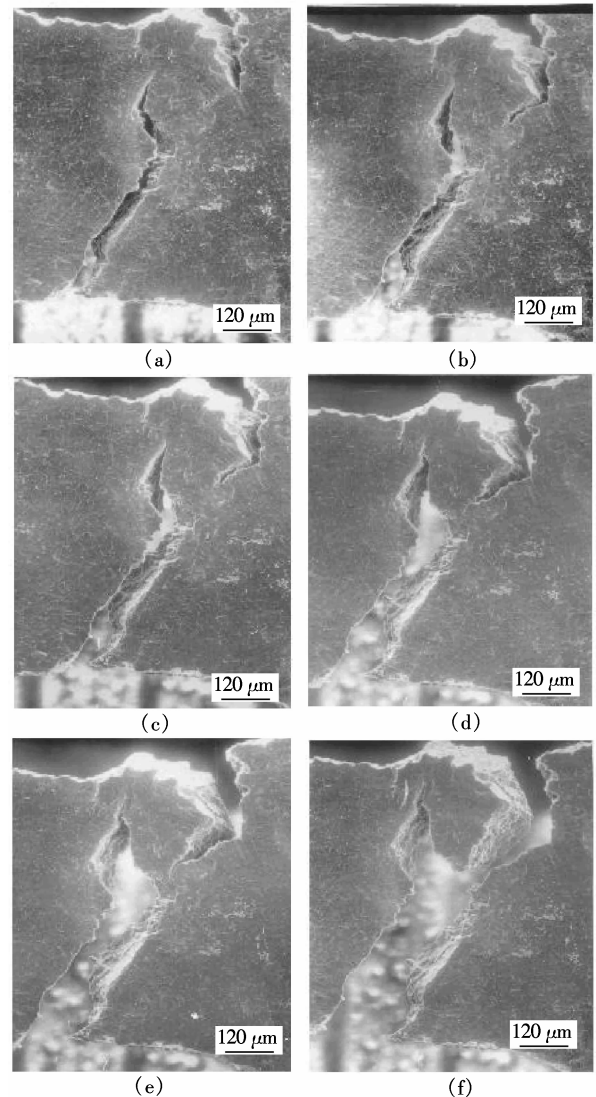


Fig.6 Scanning electron microphotographs showing the propagation of the crack and the fracture behavior in Mg-Al-Ca (SiC) tensile testing sample under the tensile loading

material, the bonding of the matrix-fiber interface is weaker. When the propagating crack contacts the ductile matrix, the cohesion of the matrix-fiber interface is not strong enough to withstand the high stress concentration at the interface, and cannot transfer the stress from fiber to matrix, so the crack is obstructed and propagates along the matrix-fiber interface. The external load must increase to deform the matrix and absorb fracture energy until the fracture occurs. Debonding of the matrix-fiber interface and the ductile matrix toughen the Mg-Al-Ca (SiC) composite cooperatively.

Summarizing the above-mentioned, the mechanical properties of composite materials are affected by the size, the volume fraction, the distribution and the properties of the reinforced fibers and the matrix material, and especially the bonding of the matrix-fiber interface. The weakly bounded matrix-fiber

interface increases crack-propagating resistance; therefore, the optimization of the overall mechanical behavior requires a suitable matrix-fiber interfacial bound strength.

3 Conclusion

In this paper, two procedures of crack propagation in metal matrix with fiber reinforced composite materials are studied on internal microstructure. The matrix-fiber interface plays a special role in these procedures. It is found that in the case of the tensile test, the crack emerged in SiC fiber firstly and in the case of the strong cohesion of the fiber-metal matrix interface the crack propagated in the fiber, meanwhile the fibers in the neighborhood of the cracked fiber began to crack and the Mg-Al metal matrix deformed plastically, and at last the material fractured. The toughness of the materials will grow in the case of the lower cohesion of the fiber-metal matrix interface. This kind of structure not only improves the fracture toughness of composite materials, but also can protect the composite materials from catastrophic failure under maximum load.

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用原位拉伸研究复合材料的机械性能

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摘要: 用扫描电镜原位拉伸的方法研究了碳化硅纤维增强镁铝复合材料的机械性能.通过对材料中裂纹的起源、扩展、断裂过程的观察研究,发现在拉伸状态下,裂纹最初起源于碳化硅纤维;在碳化硅纤维与基体结合较强时,裂纹首先在碳化硅纤维中扩展,同时裂纹附近的碳化硅纤维亦开始产生微观裂纹、镁铝金属基体发生塑性变形,最终断裂;而在碳化硅纤维与基体结合较弱的状态下,材料的韧性较高.

关键词: 镁铝基体; 碳化硅纤维; 原位拉伸试验

中图分类号: TG115.21+5.2; TG111.91