COMPRESSIVE FAILURE OF ALUMINUM MATRIX COMPOSITE REINFORCED WITH GRAPHITE FIBERS

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Abstract

The Al-Mg-Si matrix composites reinforced by M40J graphite fibers were fabricated using pressure permeation casting method. The compressive properties of the composite were measured, the micro morphologies of failure surfaces were observed and the form of compression damage and the mechanism of fracture were discussed.

1 Introduction

Aluminum matrix composites reinforced by carbon fibers (C_f/Al) have superior specific strength, high specific stiffness, low thermal expansion coefficient and better thermal conductivity and other properties, and they are available to be widely used in the field of manufacturing high-performance lightweight aviation or aerospace structures[1]. The compressive strength is one of the most important properties of fiber reinforced composite materials. Many of long fiber reinforced composite applications require high compression strength, such as long fiber-reinforced wings, fuselage, tail and other structural parts, and the axial compression design target strength is critical. The research about the compressive strength of metal matrix composite reinforced with fiber is not sufficient [2~4].The anisotropy of unidirectional ply fiber reinforced composite is evident. It has good mechanical properties in the fiber direction, but the poor performance in the vertical fiber direction. The property of the composite depends on the combination of matrix and interface conditions. Orthogonal ply composite board weakens the anisotropy of the property, therefore, it adapts to the application requirements in the complex stress conditions and prevents the degradation of the compressive performance of the composite caused by the fibers bending. In this paper, the 6061 Al matrix composites reinforced by M40J graphite fibers which are put along the 0° or 0°/90°directions alternately were fabricated using pressure permeation casting method. The compressive properties were measured, the micro morphologies of failure surfaces were observed and the form of compression damage and the mechanisms of fracture were discussed.

2 Experimental

6061 Al matrix composites reinforced by M40J graphite fibers were fabricated by pressure permeation casting method. The fibers were put along the 0° direction only or 0° and 90° two directions alternately. In this study, 0° direction means that the fibers are parallel to the loading direction and 90° direction means that the fibers are perpendicular to the loading direction. Two composites were made by different fibers laying way and they are named as single 0° laminated composite and 0°/90° laminated composite, separately. The density and fiber volume fraction of two composites are 2.1g/cm^3 and 63%, respectively. Fibers have high strength and high modulus, and play the main bearing role in the composite components; Aluminum matrix with good toughness can fix fiber and maintain the laying form of fibers, therefore, it can effectively distribute and transfer the loads and reinforce the carrying capacity of fibers [5]. Microstructure of two composites is shown in Figure 1. Uniform fiber arrangement and better orientation consistency can be observed. The compressive test was carried out according to ASTM fiber reinforced polymer composites compression performance test criteria and the sample size is 50 × 10 × 2 mm.

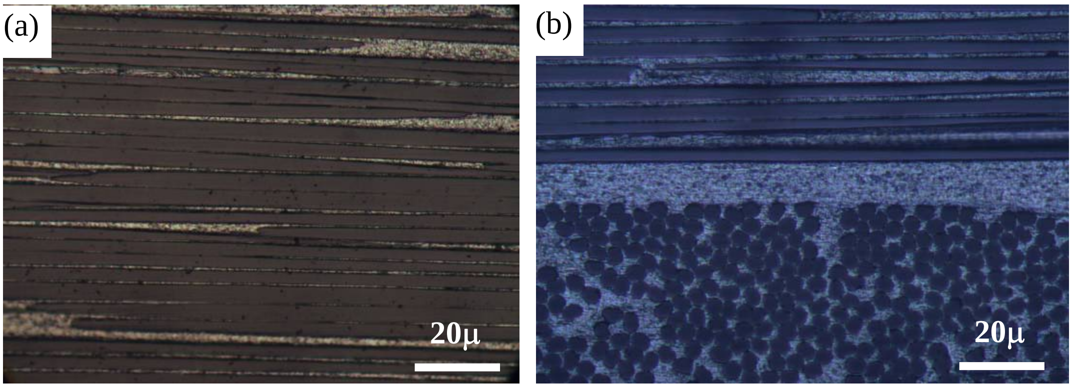


Figure 1. Metallographs of C_f/Al composites
(a) single 0° laminated composite;(b) 0°/90° laminated composite

Compressive properties were measured on INSTRON5569 electron tension tester with 1mm/min loading rate and the compressive sample was fasted using a test fixture developed by ourselves. The macro and micro morphologies of failure surfaces were observed by Olimpas microscope and S570 scanning electron microscope.

3 Results and Discussion

The compressive stress-strain curves of two composites are shown in Figure 2, and the compressive strength and elastic modulus can be achieved from the curves in the figure. It can be seen in Figure 2(a) that the compressive stress-strain curve of single 0° laminated composite is linear elastic basically, and it has not plastic deformation stage before destruction. It is difficult to determine the start of the microyield [4]. In the continuous fiber reinforced aluminum matrix composites, the fibers bear the main loading and the aluminum matrix transfers the effective load to the fiber when the composites are loaded. The study by some researchers in Harbin Institute of Technology [6] shows tha t the high density local stress in the composites results in the local yielding and plastic deformation in some area of matrix, and consequently, the stress and plastic deformation are heterogeneous. The stress-strain curves of fibers reinforced metal matrix composite is generally divided into four stages. The first one is the elastic deformation of fibers and matrix, the second is the elastic deformation of fibers and the plastic deformation of matrix, the third is the plastic deformation of the fibers and matrix and the last is the fracture of fibers. In the compression process of the high modulus graphite fibers reinforced aluminum composite, the modulus of stage I and stage II are very close, the plastic deformation of brittle fiber is little, and can be neglected. The specimen breaks immediately after the elastic deformation, so stage III and stage IV are combined to form a nearly straight line, as shown in Figure 2.

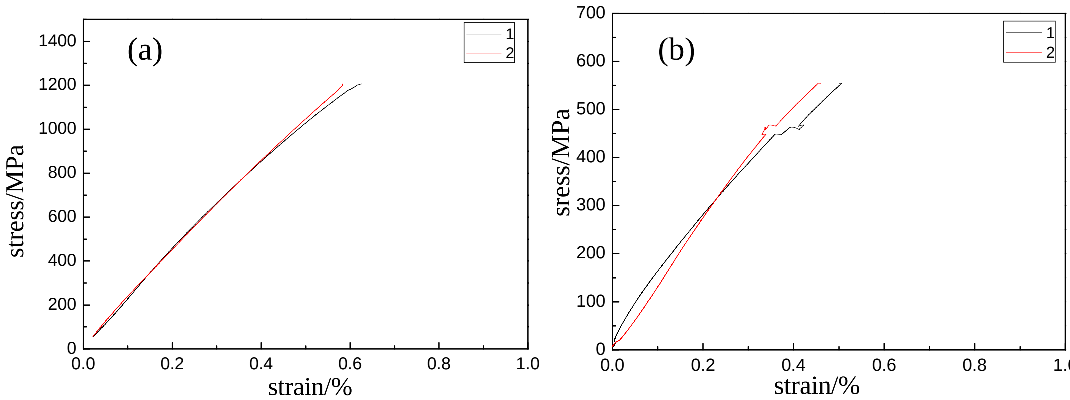
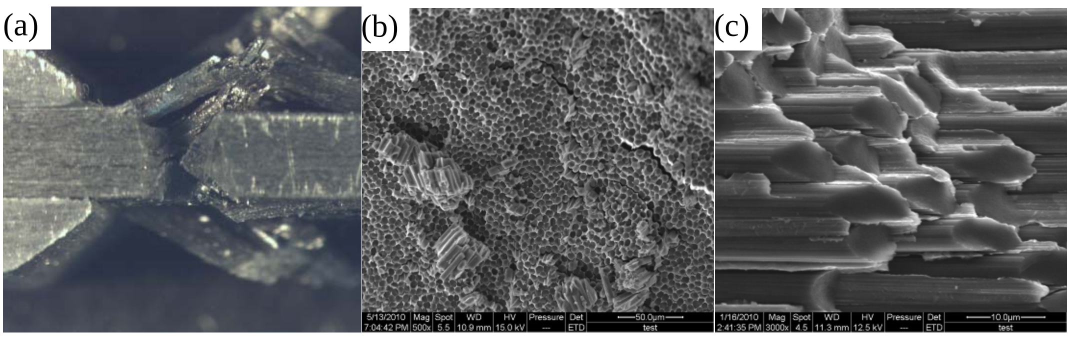


Figure 2. Stress–strain curves of C_f/Al composites
(a) single 0° laminated composite;(b) 0°/90° laminated composite

Figure 2(b) shows that fibers perpendicular to loading direction have no help to the bearing capacity of fibers parallel to the loading direction, and the compressive strength depends on the matrix strength and interfacial bond strength for the 0°/90° laminated composite. When compressed, the strength of transverse ply is much lower than that of the longitudinal ply, and the damage of transverse ply take place at low stress levels. With the increase of strain, the longitudinal fibers parallel to the loading direction yield micro-flection deformation. When the stress reaches the failure stress of fibers, the brittle fracture of longitudinal fibers happens. Because of the residual stress in the sample and the yielding of the matrix, the stress-strain curve of the composite has no yield platform. The inflection point on the stress-strain curve is due to the instantaneous bending failure caused by the deformation of one side of the transverse ply, and it is recovered when the other side of the transverse ply failures. The 0°/90° two-ply laminated composite can be equivalent to the parallel connection with a half of the single 0° laminated composite and a half of the single 90 ° laminated composite. Theoretical compressive strength should be a half of that of the single 0° laminated board, that is 676MPa, however, the actual compressive strength is only 584MPa. It is resulted from that the deformation of the transverse fiber ply brings to the transverse stress on the longitudinal fibers and makes the fiber deflection and kinking.
The compression modulus of the single 0° laminated composite and the 0°/90° laminated composite are 245GPa and 120GPa, respectively, from their stress-strain curves, and the calculated compression modulus of two composites are 270GPa and 135GPa, respectively, according to law of the composite mixture. The compression modulus tested by the stress-strain curves are in good agreement with those calculated by the law of the composite mixture.



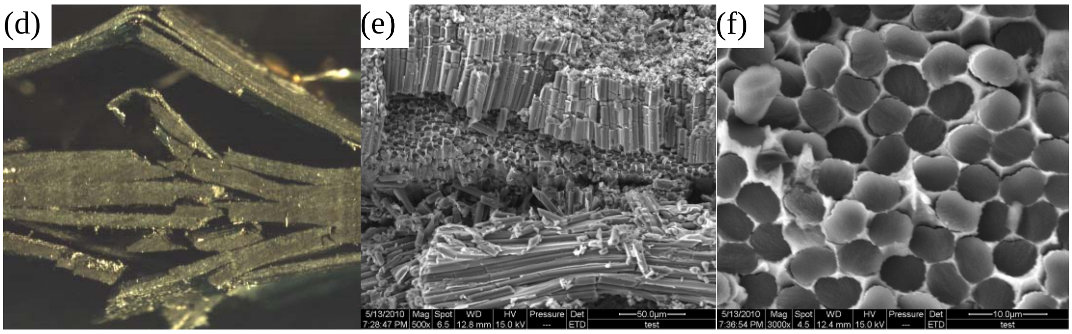


Figure 3. Failure surfaces of C_f/Al composites
(a)(b)(c) macro and micro morphologies of the single 0° laminated composite;
(d)(e)(f) macro and micro morphologies of the 0°/90° laminated composite.

The photographs of the fracture surface of the compression failure samples are shown in Figure 3. The fragmentation of the single 0° laminated composite is mainly pure compression fracture as well as a few longitudinal cleavages. The fracture macroscopic morphology of pure compression fracture is shown in Figure 3(a), one end of the sample cracks in a fasciculated way, while another end forms a horn of 90°. From the observation by scanning electron microscopy it can be discovered that the fracture surface is smooth and there are some stairs with different heights on it, as shown in Figure 3(b). With the support of the aluminum matrix, the fibers in the composite could keep parallel to the loading direction effectively, and it can bear a very large load without a decrease of bearing capacity due to bending. From Figure 3(c), it can be seen that the fibers fracture is shear fracture. It can be found from the stereoscan photograph that in the fracture section, the fibers and the matrix separate, the neighboring fibers are terraced and are arranged as the macroscopic fracture, see Figure 3(a). It is inferred that in the compression fracture process, the interface cracks first and then the dehiscence of interface consumes a part of energy, as a result, the compression strength of the composite is increased. The fact that the composite failures in the way of shear fracture during compression proves that the bonding strength of composite interface is moderate and the bearing capacity of fibers can be exerted effectively without decreasing properties of material because of over intense interfaces. This is in accord with the research results of Sivashanker et al about SiC_f/Ti composite[7].

From Figure 3(d), the laminating composite fractures in a fasciculated way owing to the weaker bonding strength between different layer spread fibers. The fibers of 0°/90° two-ply bring about the anisotropy of composite and the intense shear stress exists between the layers which would lead to a shear fracture between those layers. Figure 3(e) shows that longitudinal loading bearing fibers form a twist fracture zone as a result of compression deformation, while the failure of transverse fibers comes from the stripping of interfaces produced by shear deformation. The fibers keep intact basically, and the matrix and the fibers separate. It can be seen from Figure 3(f) that the compression fracture morphology of fibers in the laminated composite is different from that in the single laminated composite, as presented in Figure 3(c). This is because for laminated composite at a compression loading, interlamination cracking occurs firstly and the transverse layers which are vertical to the loading direction can be destroyed under a low stress level, while lengthwise layers parallel to the loading direction have flexural deformation and plump up towards both sides. When the loading exceeds the bending strength of fibers, the sample fractures in a twisting manner.

In summary, for the single 0° laminated composite whose fibers are parallel to the loading direction, the compression fracture is showed as typical morphology of the pure compression fracture, and fracture mode is shear fracture. And for the 0°/90° laminated composite whose fibers are orthogonal, the compression fracture is macro-bundle cracking and peeling layer interface. The fracture mode of the lengthwise fiber whose role is the bearing body is micro-kink fracture.

4 Conclusions

6061 Al matrix composites reinforced by M40J graphite fibers using pressure permeation casting method have better mechanical properties. The compressive strength along fibers 0° and 0°/90° directions of two composites with different arranged fibers are 1352MPa and 584MPa, respectively, and the compression modulus are 245GPa and 120GPa, respectively. Under the compression load, the fibers parallel to the loading direction are the major bearing body. The failure surfaces of the single 0° laminated board and the 0°/90° laminated board are different. The failure of the single 0° laminated board is overall macro-shear fracture, compared with clear laminate layer cracking of the 0°/90° laminated board. The failure models of the single 0° laminated composite and the 0°/90° laminated composite are shear break and bending break, respectively, under compression.

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