Final Draft
of the original manuscript

Sun, Z.; Hu, X.; Wang, X.; Wu, K.; Gan, W.:

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In: Composites Communications. Vol. 24 (2021) 100640.

First published online by Elsevier: 13.01.2021

https://dx.doi.org/10.1016/j.coco.2021.100640

Microstructure and Mechanical Properties of M40/AZ91 Composites Fabricated by Pressure Infiltration Method

Zhenming Sun[1], Xiaoshi Hu[2]*, Xiaojun Wang[2]*, Kun. Wu[2],Weimin Gan[3]

1-State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology.

2-School of Materials Science and Engineering, Harbin Institute of Technology

3-GEMS at Heinz Maier-Leibnitz Zentrum (MLZ), Helmholtz-Zentrum Geesthacht GmbH, Lichtenbergstr. 1, 85748 Garching, Germany

Corresponding author: X.J. Wang (xjwang@hit.edu.cn); Xiaoshi Hu(huxiaoshi@hit.edu.cn)

Abstract

The M40 carbon fibers reinforced magnesium matrix composites were fabricated by pressure infiltration method. The preheating temperatures of preform and casting temperatures of AZ91D melting during pressure infiltration significantly affected the interfacial reactions and mechanical properties of the composites. The lower preheating temperatures of preform resulted in casting defects at the interface between carbon fibers and magnesium matrix and making composites rapidly to be failed in a brittle fracture mode. In addition, the higher casting temperatures of melting would result in excessive interfacial reactions at the interface. However, the serious reactions would damage the carbon fibers, which would weaken the reinforcement effect of the carbon fibers. When the preheating temperature of the preform was 550 ℃ and the casting temperature of melting was 760℃, the moderate interfacial reactions occurred at the interface and the composites failed in a cumulative mode. At this preparation temperature, the bending strength of the composites reached its maximum value of

1793MPa.

Keywords: Magnesium matrix composites; Pressure infiltration; Bending strength; Interface

1.Introduction

Magnesium alloy is the lightest structural metal, which has been considered to be used in aerospace and automotive to reduce the weight of vehicles[1]. However, the utilization of magnesium alloy is often restricted since its high thermal expansion coefficient, low strength and stiffness[2]. Continuous carbon fibers reinforced magnesium matrix composites (Cf/Mg) exhibitlow thermal expansion coefficient and density, higher specific strength and stiffness. Moreover, it also holds higher electrical, thermal conductivity, and better thermal stability[3]. Thus, Cf/Mg composites have attracted much attention in recent years, and they have been identified as a great potential replacement of traditional structural materials for wide application in aerospace and automotive fields[4].

At present, the main preparation methods of Cf/Mg composites are liquid phase methods[5].Among them, the pressureless infiltration method is not suitable for the poor wettability between carbon fibers and magnesium matrix[6]. For the gas infiltration process is prone to form porosity and require high security of equipment[7]. On the contrary, the pressure infiltration method shortens the preparation cycles and costs. Furthermore, the major advantages of this process are the elimination of the gas cavity and shrinkage porosity at liquid-solid state, which can produce excellent castings[8].

The optimized properties of composites come from appropriate interface reactions. And the interfacial reactions of Cf/Mg composites depend on the alloy composition, graphitization degree of carbon fibers and the preparation temperatures. Feldhoff et al.[9]indicated that the Al elements in the magnesium alloy were prone to react with C and produce Al_4C_3. Thus the wettability of the interface of Cf/Mg composites was obviously improved by adding Al elements into magnesium alloy. Moreover, Rawal et al. [10]found the $Mg_{17}Al_{12}$ particles at the interface, they indicated that $Mg_{17}Al_{12}$ intermetallics can be an obstacle to dislocation and strengthen the interfacial bonding. Hence, adding Al elements into magnesium alloy is also favorable for effective load transfer. Song et al.[3]reported that, compared with T700/AZ91D, the size and amount of Al_4C_3 were significantly reduced at the interface of M40/AZ91D. It is related to the higher degree of graphitization of M40 than T700 fibers, which reduces surface free energy and increases chemical stability[11] [3].Thus M40 fibers would prevent serious interfacial reactions between fibers and alloy elements. As stated above, most of the attention on interface reactions of Cf/Mg composites was focused on the alloy composition and carbon fibers category. However, for a given fiber and alloy composition, it is worth noting that the preparation temperatures of Cf/Mg composites are a crucial factor for the degree of interfacial reactions. Unfortunately, the effect of preheating temperatures of the preform and casting temperatures of the magnesium melting on the interfacial reactions and mechanical properties of Cf/Mg composites have not been well studied.

In this work, AZ91D alloy was selected as the matrix to provide Al elements, and the M40/AZ91 composites were prepared by using the pressure infiltration method. The effects of preheating temperatures of the preform and casting temperatures of the AZ91D melting on interfacial reactions and mechanical properties of Cf/Mg composites were investigated.

2.Experimental

2.1 Materials

M40 carbon fibers were selected as the reinforcement due to its higher degree of graphitization, elasticity modulus, better chemical stability and lower coefficient of thermal expansion. AZ91D magnesium alloy was employed as the matrix alloy. The chemical compositions of the AZ91D alloy is shown in Table S1. The specification of AZ91D alloy and M40 carbon fibers are listed in Table S2.

2.2 Fabrication process of M40/Mg composites

In this work, the M40 carbon fiber bundles were unidirectionally winded to a graphite block (150×75×50mm) by Three-Dimensional Winding Machine to prepare the M40 preform. M40/Mg composites were fabricated by pressure infiltration, as shown in Fig. S1.

2.3 Microstructure characterization

Scanning electron microscope(SEM) (SUPRA55, Zeiss, Germany) was used to analyze the microstructure of the Cf/Mg composites. Element distribution in composites was observed by the energy disperse spectroscopy (EDS). The interface between carbon fibers and magnesium matrix was investigated by transmission electron microscopy(TEM) (Talos, FEI, America) and selected area electron diffraction (SAED).

2.4 Mechanical properties test

Three-point bending tests of Cf/Mg composites were performed by electronic universal testing machine (Instron-5569).The bending specimens were 40 mm length, 10 mm width and 2 mm thickness, with a constant span length of 30 mm. The tests were carried out at the room temperature with a strain rate of 0.5 mm/s.

3. Results and discussion

3.1 Microstructure of the Cf/Mg composites

Fig.1 shows the microstructures of the M40/AZ91D composites prepared at the different preheating temperatures of the preform (PRT) and casting temperatures of the melting (CAT). When the preheating temperature was 450°C, the carbon fibers were unevenly distributed in the composites (Fig. 1 (a)), and the significant casting defects and cracks at the interface were also observed under OM (Fig. 1 (b)). As the preheating temperatures of the preform increased, the distribution of carbon fibers in the magnesium matrix got more uniform (Fig. 1 (c) and (e)). However, the significant casting defects were still observed at the preheating temperature of 500°C (Fig. 1 (d)). Through the comparative observation of Fig. 1 (f)、Fig. 1 (g) and (h), it can be found that as the casting temperatures increased, more and more reaction products were observed on the surface of the carbon fibers. It indicated that the different degrees of interfacial reactions have occurred with the increase of casting temperatures. Energy spectrum scanning (EDS) was carried out to further identify the elements of reaction products that on the surface of carbon fibers.

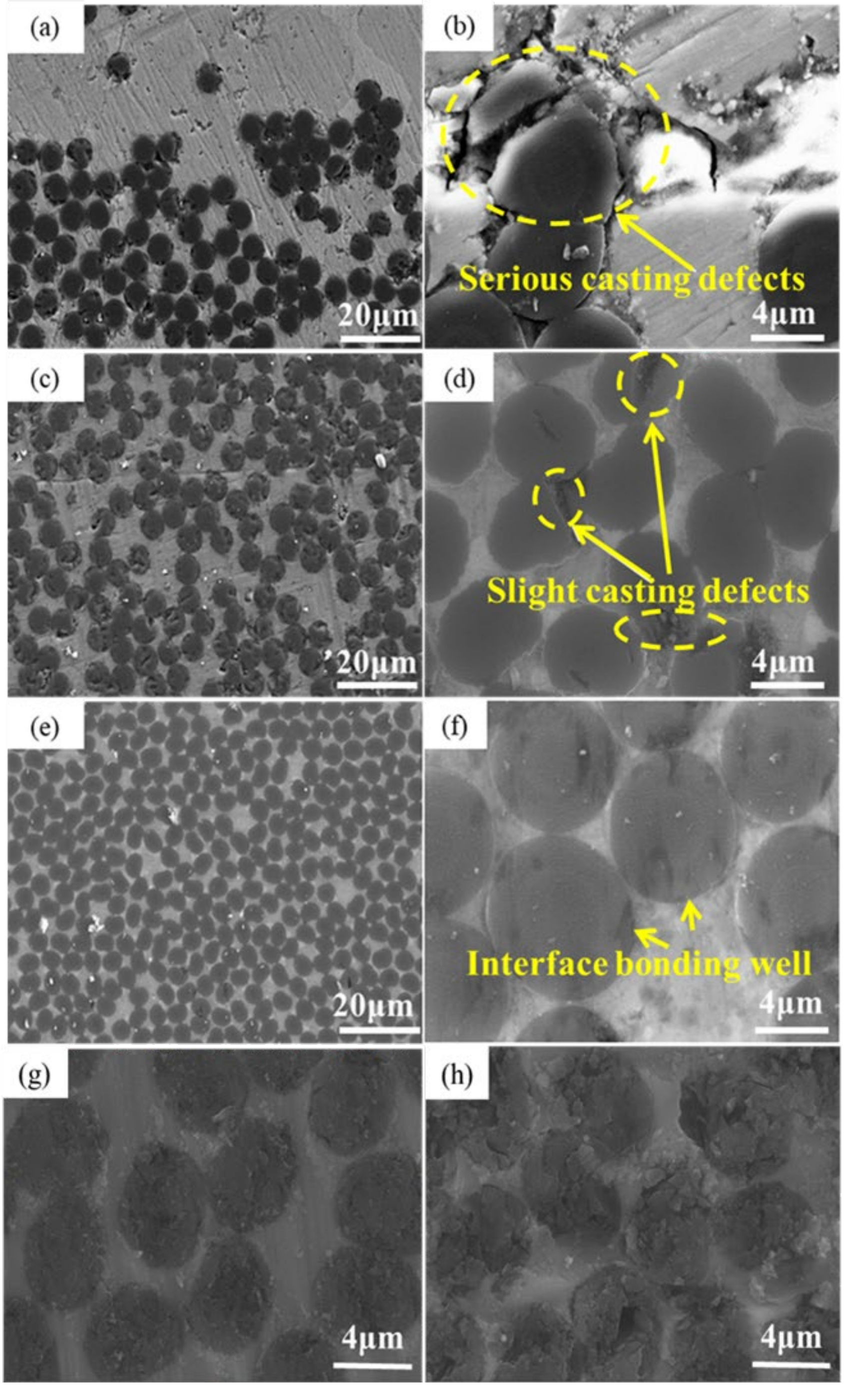

Fig. 1. SEM images for the composites fabricated at different preheating temperatures of the perform and casting temperatures of the melting.
(a) PRT-450 ℃ , CAT-750℃; (c) PRT-500 ℃ , CAT-750℃; (e) PRT-550 ℃ , CAT-750℃; (b)、(d) and (f) are the magnification of (a)、(c) and (e); (g) PRT-550 ℃ , CAT-760℃; (h) PRT-550 ℃ , CAT-780℃.

The EDS results shows that with the increase of casting temperatures of the melting, more and more segregation of Al elements were found at M40/AZ91D interface (Fig.

2 (a)-(c)). Due to the temperature of the fibers was lower than that of the melting, the alloy elements tend to accumulate on the surface of fibers before the solidification of melting. The higher casting temperatures of the melting would provide more abundant time for the accumulation of the Al elements to segregate around the surface of fibers. So the serious segregation of Al elements was observed on the surface of the fibers at a higher casting temperature of 780 °C (Fig. 2 (c)), and consequent excessive interfacial reactions would cause damages to carbon fibers and result in a decrease to the properties of composites. Conversely, when the casting temperature of the melting was 750°C, there was fewer segregation of Al element was found in Fig.2 (a). Compared with Fig. 2 (a) and (c), moderate segregation of Al elements was found at the casting temperature of 760 °C (Fig. 2 (b)), and then moderate interfacial reactions were favorable for the effective load transfer between matrix and reinforcement.

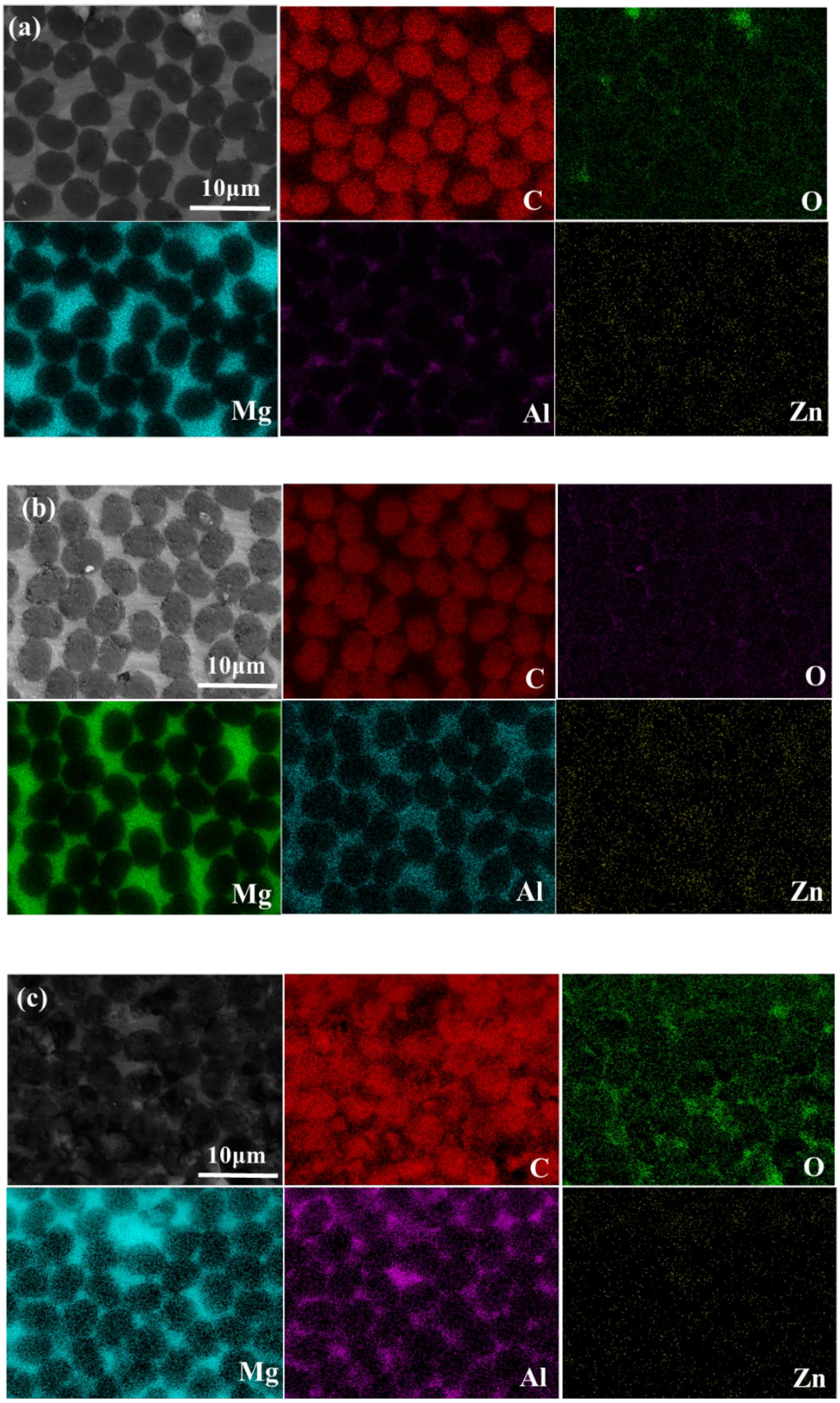

Fig. 2. Element distribution of Cf/Mg composites prepared at different casting temperatures. (a) PRT-550℃, CAT-750℃; (b) PRT-550℃, CAT-760℃; (c) PRT-550℃, CAT-780℃.

The morphology of the M40/Mg interface was analyzed by TEM as shown in Fig. 3. The carbon fibers and the matrix bonded well and an appropriate amount of interfacial reaction products were observed. The needle-like reaction products were confirmed as Al_4C_3 via the SAED (Fig. 3 (c)). It could be seen that these spice-like Al_4C_3 were nonuniformly nucleated from the surface of fibers and grew towards the interior of the AZ91D matrix (Fig. 3 (a)). The formation of Al_4C_3 allowed the load to be effectively transferred between the matrix and the fibers and improved the interface bonding strength. Besides, the block-like precipitates were determined to be $Mg_{17}Al_{12}$ via SAED (Fig.3 (b)), which was a common precipitated phase in AZ91D alloys. It's generally accepted that the moderate degree of interfacial reactions were favorable for load transfer at the interface. In this work, the amount of Al_4C_3 and $Mg_{17}Al_{12}$ precipitates observed was reasonable, which would enhance the interfacial bonding strength.

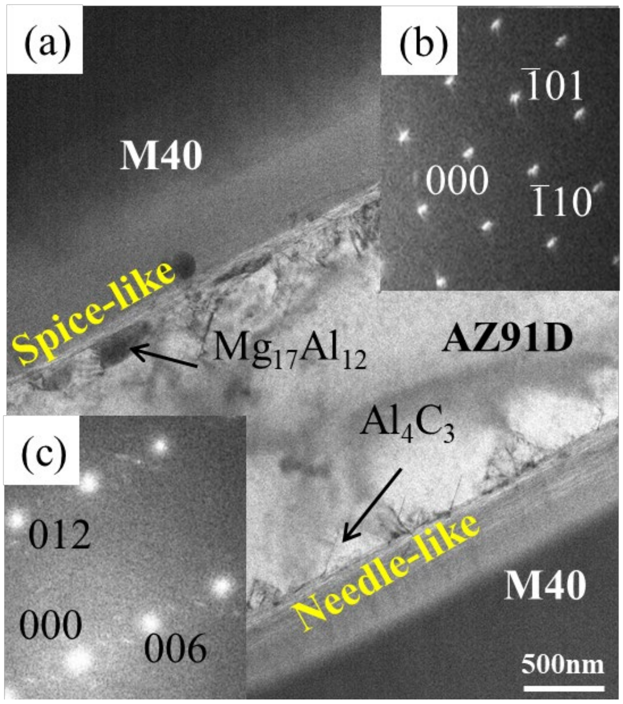

Fig. 3. The TEM observation of Cf/Mg composites prepared at PRT-550°C and CAT-760°C. (a) bright-field TEM observation of composites in the interface region; (b) SAED pattern of $Mg_{17}Al_{12}$; (c) SAED pattern of Al_4C_3.

3.2 The mechanical properties of the M40/Mg composites

The bending strength of Cf/Mg composites is shown in Fig. 4. As the preheating temperatures of the preform increased, the bending strength of the composites was improved from 1007 MPa to 1793 MPa. As the casting temperatures of AZ91 melting increased from 750°C to 780°C, the bending strength decreased to 1042 MPa.

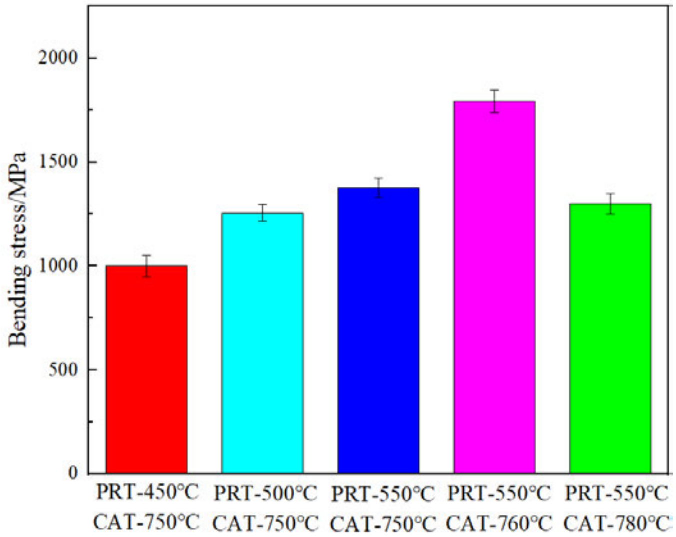

Fig. 4. The bending strength of Cf/Mg composites prepared at different preparation temperatures.

Fig.5 shows the fracture surfaces of Cf/Mg composites at the different preparation temperatures. When the preheating temperature was 450°C, the cracks propagated along the interface between the fibers and matrix. Finally, the composites failed in a typical brittle fracture mode (Fig.5 (a) and (b)). When the preheating temperatures of the preform raised to 550°C and casting temperatures of the melting increased to 760°C, lots of fiber bundles were pulled out (Fig. 5 (c) and (d)). The fracture mode of Fig. 5 (d) is a cumulation type, which is a typical demonstration of moderate interfacial bonding strength. The carbon fibers in composites with moderate interfacial bonding are capable of bearing a considerable number of load during loading. Firstly, some fiber bundles were pulled out with the bending load increasing. Then the stress was transmitted to the other fiber bundles along the interface, and the other fiber bundles continued to bear bending load and be pulled out, the phenomenon kept going on until the composites completely failed. This way of fracture enables maximum use of the reinforcement effects of the fibers. However, as the casting temperatures of melting raised to 780℃, lots of fiber bundles were stripped out on the fracture surface (Fig.5 (e)). It's because of the excessive temperature of melting leading to excessive interface reactions and damage the surface of fibers (Fig.5 (f)). Finally, the mechanical properties of the Cf/Mg composites were reduced.

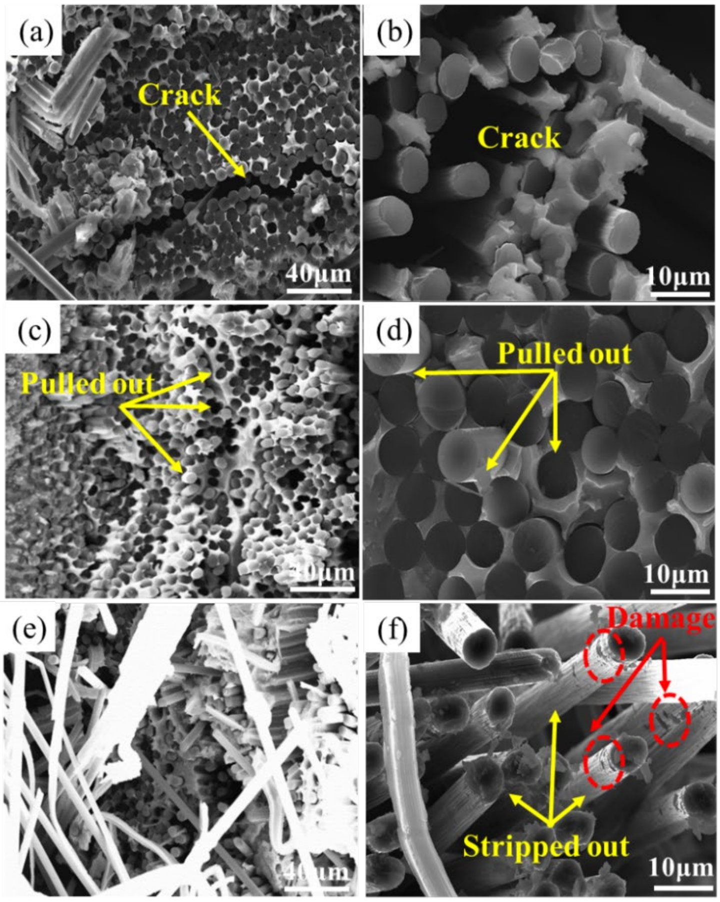

Fig. 5. Fracture surface of Cf/Mg composites at different preparation temperatures.
(a) PRT-450℃, CAT-750℃; (c) PRT-550℃, CAT-760℃; (e) PRT-550℃, CAT-780℃;
(b)、(d) and (f) are the magnification of (a)、(c) and (e).

4. Conclusion

M40/AZ91D composites were prepared by pressure infiltration method in this paper. The main purpose of the study was to optimize the interface of Cf/Mg composites by adjusting the preheating temperatures of the preform and casting temperatures of the melting, so as to improve the performance of composites. Here the following conclusions are drawn:

(1) When the preheating temperature of the preform was 550 ℃ and the casting temperature of the melting was 760 ℃, a moderate interface reaction occurred. A moderate amount of interfacial reaction products Al_4C_3 and second phase $Mg_{17}Al_{12}$ were observed at the interface. The moderate interface reactions enabled the load to be transferred effectively at the interface, which was favorable for the strength improvement of the Cf/Mg composites.

(2) The lower preheating temperatures of the preform easily cause casting defects at the interface to make composites prone to brittle fracture. The higher casting temperatures of the melting result in excessive interface reactions, which will damage the surface of fibers and reduce the mechanical properties of the composites. When the Cf/Mg composites were fabricated at 550℃ preform preheating temperature and 760℃ casting temperature, the fractures mode of composites exhibited in a cumulative mode, which improved the plasticity of the composites and the maximum bending strength reached to 1793MPa, a pretty high value in Cf/Mg composites.

Acknowledge

This work was supported by “National Natural Science Foundation of China” (Grant

Nos. 51871074, 51971078 and 51671066) and “The Project National United Engineering Laboratory for Advanced Bearing Tribology, Henan University of Science and Technology” (Grant No. 201911).

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