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Compressive behavior of C_{sf}/AZ91D composites by liquid–solid extrusion directly following vacuum infiltration technique

J. Liu [a], L.H. Qi [a,b,*], J.T. Guan [a], Y.Q. Ma [a], J.M. Zhou [a]

[a] School of Mechatronic Engineering, Northwestern Polytechnical University, Xi'an 710072, PR China
[b] Education Ministry Key Laboratory of Modern Design and Integrated Manufacturing Technology, Northwestern Polytechnical University, Xi'an 710072, PR China

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ABSTRACT

10 vol. % short carbon fiber reinforced AZ91D composites (C_{sf}/AZ91D) were fabricated by liquid–solid extrusion directly following vacuum infiltration (LSEVI) technique. Liquid–solid extrusion of the composite induced reasonably uniform distribution and oriented arrangement of the carbon fibers. Compressive behaviors of the composites were investigated in the temperature range from room temperature to 300 °C. The shapes of the compressive stress–strain curves at temperatures below and above 200 °C are very different, which can be attributed to the combined influence of matrix work hardening and strain softening induced by the rotation of the fibers. The ultimate compressive strength (UCS) and compressive yield strength (CYS) of the composites are enhanced by 86.5% and 123% than those of matrix alloy at room temperature, respectively. The composites are thermal stable up to 200 °C, where the CYS is approximately 2.8 times as high as that of the AZ91D matrix. However, both the UCS and CYS of the composites are slightly less than those of monolithic AZ91D at 300 °C. The plastic deformation of the C_{sf}/AZ91D composites mainly localizes in a shear band along the diagonal axis, 45° to the loading axis at the center of samples. The main failure mechanism of the composite samples is shear fracture or plasticity instability induced by shear deformation, and the failure strain increases with the increasing test temperature.

1. Introduction

Carbon fiber reinforced magnesium composites are gaining increasing interest as structural materials for applications in high-precision aerospace system, automotive industry and sports equipment owing to their low density, high specific strength, high damping capacity and excellent dimensional stability [1–3]. Short carbon fiber reinforced magnesium composites (C_{sf}/Mg) are generally fabricated by stir casting [4], vacuum pressure infiltration method [5], squeeze casting method [6] and liquid–solid extrusion process following vacuum infiltration (LSEVI) developed by our team [7]. LSEVI is a special forming technique that combines the principles of vacuum infiltration, squeeze casting and liquid–solid extrusion. The major advantages of this process are elimination of porosity and shrinkage, low deformation resistance at liquid–solid state and near-net forming [8]. The C_{sf}/AZ91D composites produced by this technique exhibited significantly improved room-temperature tensile properties with reasonably uniform distribution of fibers, good fiber–matrix interfacial bonding, and minimal amount of porosity [9].

In recent years, mechanical behavior of discontinuously reinforced magnesium matrix composites has been primarily investigated for their tension behavior, but a relatively little amount of research is conducted to investigate their compressive behavior, which is crucial in some engineering applications where compressive loads are dominant. Ataya and El-Magd [10] showed that the compressive yield stress of the magnesium matrix composites reinforced with 23 vol.% carbon short fibers increased approximately 3.5 times compared to AE42 matrix and approximately 2.5 times compared to AZ91 matrix. Towle and Friend [11] reported that an increase in compressive strength up to 92% and reduction of failure strain up to 79% was realized for magnesium matrix composites reinforced with saffil fibres (95 wt% δ-alumina and 5 wt% silica; 3 μm diameter and 150 μm length). Trojanová et al. [12] reported that the short Saffil fiber reinforcing phase increased both the yield and maximum stresses, but the difference between the matrix and composite decreased with the increasing deformation temperature. Trojanová et al. [13] also showed that there was remarkable strength improvement at temperatures up to 200 °C for (SiC_p + Si)/AZ91 composites, and enhancement in ductility was found at temperatures from 200 °C. These researches on the compressive behavior of magnesium matrix composites are

* Corresponding author at: School of Mechatronic Engineering, Northwestern Polytechnical University, Xi'an 710072, PR China. Tel.: +86 29 88460447; fax: +86 29 88491982.
E-mail address: qilehua@nwpu.edu.cn (L.H. Qi).

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Table 1
Physical properties of T300 short carbon fibers.

Fiber	Fiber diameter (μm)	Ultimate strength (MPa)	Young's modulus (GPa)	Elongation (%)	Density (g/cm^3)
T300	6–8	3500	230	1.5	1.76

mainly limited to the magnesium matrix composites produced using general liquid metal infiltration technique. While a systematic investigation on the effect of LSEVL process on the compressive behavior of the C_{sf}/Mg composites has not yet been conducted, especially on the compressive properties at the elevated temperatures.

In the present work, the room-temperature and elevated-temperature compressive strength of the C_{sf}/AZ91D composites by LSEVI were evaluated, and compared with AZ91D matrix. The deformation behaviors of the C_{sf}/AZ91D composites during compression at different temperatures were investigated with the combination of the microstructure observation. Furthermore, the related failure mode and strengthening mechanism of the composites were also studied.

2. Experimental procedure

2.1. Preparation of composites

The AZ91D alloy (Mg–9 wt%Al–1 wt%Zn–0.2 wt%Mn) was used as matrix alloy in the experiments. T300 short carbon fibers (Table 1 for physical properties) were selected as the reinforcement, and fabricated into preforms with a volume fraction of 10% by wet forming method without any binder. Then, the surfaces of carbon fibers were coated with pyrolytic carbon (PyC) using isothermal chemical vapor deposition (ICVD) process [14]. PyC layer can effectively reduce the degree of interfacial reaction by inhibiting the formation of brittle phase such as Al_4C_3 and Al_2CMg_2, because the chemical activity of PyC is lower than that of carbon fiber.

The schematic illustration of the LSEVI technique used to fabricate the C_{sf}/AZ91D composites is shown in Fig. 1. Prior to infiltration, the preform and the melt of the matrix alloy were preheated to 580–620 °C and 780–820 °C under argon atmosphere, respectively. After the preset temperatures were reached and maintained for 30–60 min, the container chamber was evacuated using a vacuum pump, and the melt was poured into container from crucible in melting unit (Fig. 1a). Then, argon gas pressure (0.3–0.6 MPa) was applied to the surface of melt to force the melt penetrate into the carbon fiber perform completely (Fig. 1b). After infiltration, the matrix melt was forced to solidify under high squeezing pressure of punch (Fig. 1c). Finally, the infiltrated composites containing a small fraction of liquid phase were extruded out of the female die when the die was cooled to the preset temperature of 380–420 °C (Fig. 1d).

2.2. Compression tests

Compression tests were performed on a computer-controlled servo-hydraulic testing machine in the temperature range of 20–300 °C, at a constant crosshead speed giving an initial strain rate of $6.9 \times 10^{-4}\,s^{-1}$. Cylindrical specimens of 8 mm diameter and 12 mm length were machined along the extrusion direction. Before the test, the samples were heat-treated at 180 °C for 24 h. The graphite powder was sprayed on two ends of the compression samples so that the effect of friction could be minimized. For comparison purpose, compression tests of monolithic AZ91D were also carried out under the same condition.

3. Results and discussion

3.1. Microstructure of the composites

Fig. 2 shows the microstructure of matrix AZ91D alloy and obtained C_{sf}/AZ91D composites by LSEVI. It can be seen that the microstructure of the matrix AZ91D alloy is characterized by coarse grains. By comparison, the grains in C_{sf}/AZ91D composites are

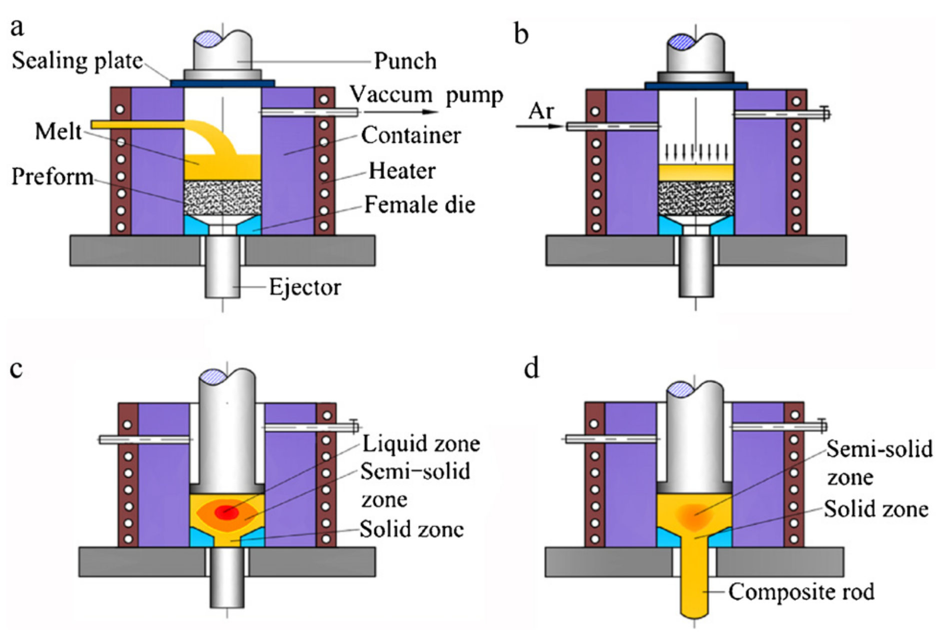

Fig. 1. Schematic illustration of the liquid–solid extrusion directly following vacuum infiltration technique: (a) vacuum casting, (b) gas pressure infiltration, (c) squeeze casting, and (d) liquid–solid extrusion.