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Thixotropic compression deformation behavior of SiC_p/AZ61 magnesium matrix composites

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Abstract：Compression tests on semi-solid SiC_p/AZ61 magnesium matrix composites were carried out using Thermecmastor-Z dynamic material testing machine. Influences of strain-rate, strain, temperature and volume fraction of SiC particles on flow stress were analyzed. The results show that the flow stress of semi-solid SiC_p/AZ61 composites is sensitive to temperature and strain rate. The lower the temperature and the larger the strain rate, the higher the flow stress. Meanwhile the flow stress increases with the increase of the volume fraction of SiC particles. This study helps establish the constitutive model of magnesium matrix composites and offers theoretic and experimental references for its thixoforming.

Key words: semi-solid; deformation behavior; SiC particles; magnesium matrix composites; thixotropic compression

1 Introduction

In recent years the semi-solid forming technology （SSF）is greatly developed as a new near net-shape forming technology for the general engineering materials[1−3]. A near spherical primary phase is the microstructural characteristics of semi-solid materials, whose thixotropic deformation behavior is different from not only liquid flow forming but also solid plastic deformation[4−6]. In order to improve and control the quality of products deformed by SSF, the thixotropic deformation behavior under the semi-solid state such as the influences of flow stress, deformation temperature and strain rate are analyzed[7−8]. The processing parameters are chosen and set reasonably based on the deformation features[9−10]. At the present the semi-solid deformation process has been widely studied[11−15], but few papers are concerned about the thixotropic deformation behavior for semi-solid magnesium matrix composites reinforced with particles. The characteristics of semi-solid SiC_p/AZ61 composites deformed mechanism can be understood well only when the relationships between stress and strain are described. So the semi-solid compression tests for SiC_p/AZ61 composites were conducted, whose mechanical properties and destruction model were investigated.

2 Experimental

The semi-solid SiC_p/AZ61 composites reinforced with 3%, 6% and 9% SiC (volume fraction) particles were fabricated by the stir-casting and isothermal heat treatment methods in this test. First the magnesium matrix composites were fabricated by the stir-casting method. Then the isothermal heat treatment process was done with the heat treatment temperature of 595 ˚C and holding time of 60 s, and the semi-solid SiC_p/AZ61 composites were obtained. They were machined into cylindrical specimens of 8 mm diameter and 12 mm height.

The experiments were conducted in a Thermecmastor-Z dynamic material testing machine, whose set-up is shown in Fig.1. The specimen was heated by electromagnetic wave, whose temperature was monitored by thermocouples. The graphite slices were placed between the specimen and the compression heads for reducing the influence of friction on experiment. In order to study and master the characteristic mechanics of semi-solid magnesium matrix composites at high solid volume fractions, the deformation temperatures were taken as 530, 545, 560 and 570 ˚C, respectively. According to the heating procedure shown in Fig.2, the initial heating rate was 10 ˚C /s; when the specimen

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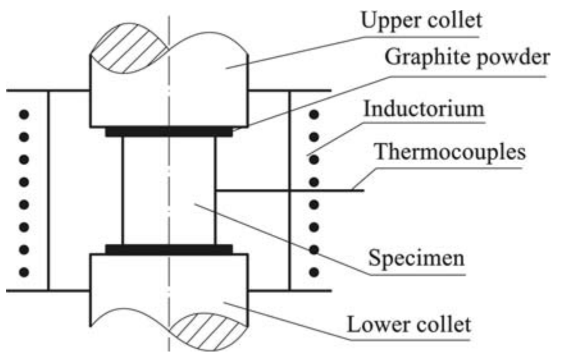

Fig.1 Schematic diagram for compressive tests of semi-solid material

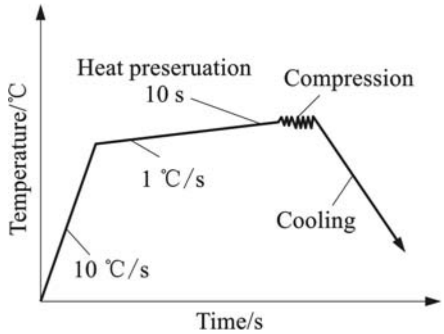

Fig.2 Heating procedure for compressive tests of semi-solid material

temperature reached 500 ˚C, the temperature rate was down to 1 ˚C /s. Then the semi-solid compression experiments were done under the strain rates of 0.1, 0.5, 5.0 and 10 s^{-1} respectively, in which the total strain was 0.6.

3 Results and discussion

3.1 Analysis of flow stress during thixotropic compressive deformation process

The stress-strain curves of semi-solid SiC_p/AZ61 composites with various volume fractions of SiC particles are shown in Fig.3. The tendency of curves implies that the deformation temperature has a significant effect on the flow stress. It is observed that for a constant strain rate and constant volume fraction of SiC in the composites, the flow stresses and peak stresses decrease with the increasing of deformation temperature, which presents that the thixotropic plastic deformation of the composites is highly sensitive to temperature. The tendency is thought to be the result of variation of volume fractions of solid α phase. When the specimens have high solid volume fractions, the solid grains contact with each other and form a net, sliding and rotation of grains become hard. The plastic deformation of solid particles is the main mechanisms. With the increasing of temperature, the solid volume fractions decrease, and the solid grains are surrounded by liquid phase, which makes the solid grains to slide and rotate easily. Thus the sliding and rotation of grains plays a more significant role in the thixotropic plastic deformation.

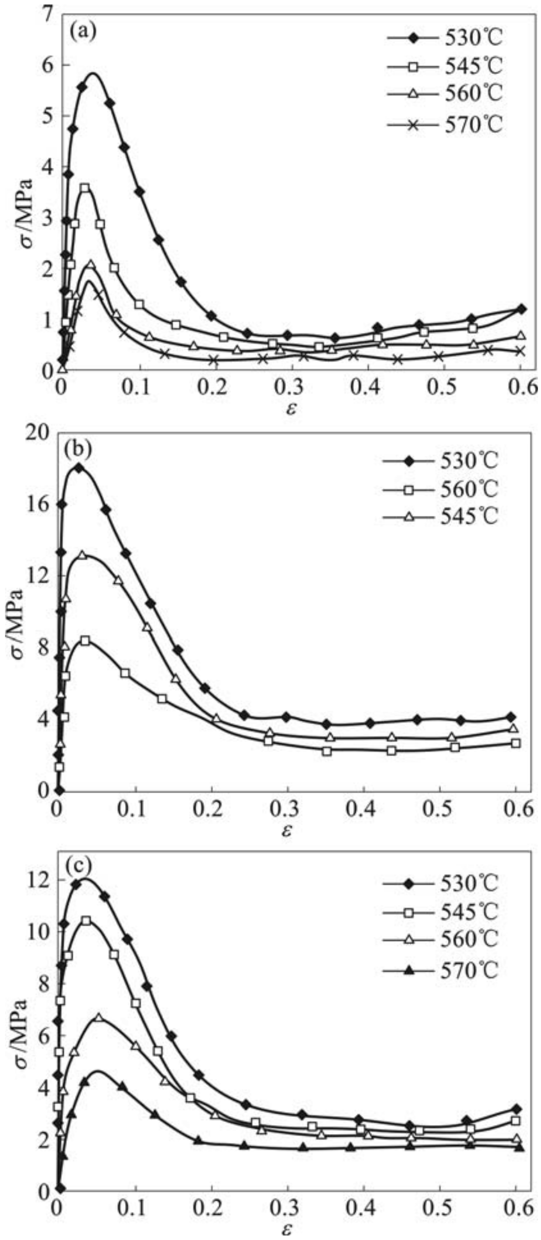

Fig.3 Curves of stress-strain relation at various temperatures for SiC_p/AZ61 composites: (a) φ_p=3%, $\dot{\varepsilon}$=0.1 s^{-1}; (b) φ_p=6%, $\dot{\varepsilon}$=5 s^{-1}; (c) φ_p=9%, $\dot{\varepsilon}$=10 s^{-1}

The relationships between peak stress and temperature of composites with strain rate of 10 s^{-1} are shown in Fig.4. It can be seen that the variation of volume fractions of SiC also has a significant effect on the peak stress of the composites. When the deformation temperature rises slightly higher than the solid phase line in semi-solid zone, the volume fractions of liquid phase is low in the matrix, and the peak stress decreases rapidly almost as linear form with the increasing of temperature initially, and then slows down as the temperature increases further. The results are thought to be of the lower volume fractions of liquid phase. When the specimens have high volume fractions of solid phase , the solid grains contact with each other to form a net, the sliding and rotation of grains become hard. The plastic deformation of solid particles is the main mechanism. Besides SiC particles increase the resistance to grain boundaries sliding and impose barriers to dislocation motion, which leads to higher resistance for plastic deformation. With the increase of temperature, the volume fractions of liquid phase increase, and the solid grains are surrounded by liquid phase, which requires smaller force for the solid grains to slide and rotate. Thus the peak flow stress decreases rapidly, and then slowly as the temperature increases further.

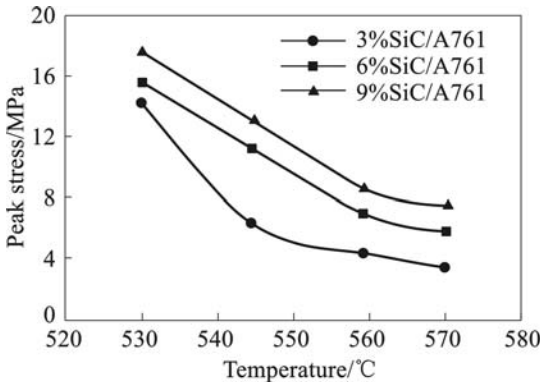

Fig.4 Relationships between peak stress and temperature of three SiC/AZ61 composites in semi-solid thixotropic compression

The relations of stress-strain rate at various strain rates are shown in Fig.5. It can be seen that the peak stress increases as the strain rate increases at the constant temperature. When the composites are compressed at high strain rate (for example 10 s^{-1}), the liquid phase can not be squeezed out timely, in which the flow stress is very high during the initial deformation stage, and then decreases as the result of high shearing rate. With further deformation, the liquid is squeezed out and pushed together, in which the solid particles are smashed. During this stage, the grain boundaries sliding and flow become easy and the flow stress decreases rapidly. At lower strain rate the solid grains are surrounded by liquid phase, which requires smaller force for sliding and rotation. So the flow stress is lower.

Fig.6 presents stress-strain curves of the SiC_p/AZ61 composite with different SiC fractions at 545 ˚C and 560 ˚C and constant strain rate of 0.1 s^{-1} and 10 s^{-1}. The fractions of SiC have a significant effect on the flow stress. The compression stress increases with the increase of volume fractions of SiC particles. The reason is that SiC particles are mainly located in the inter-granular and boundary regions in the composites. SiC particles impose

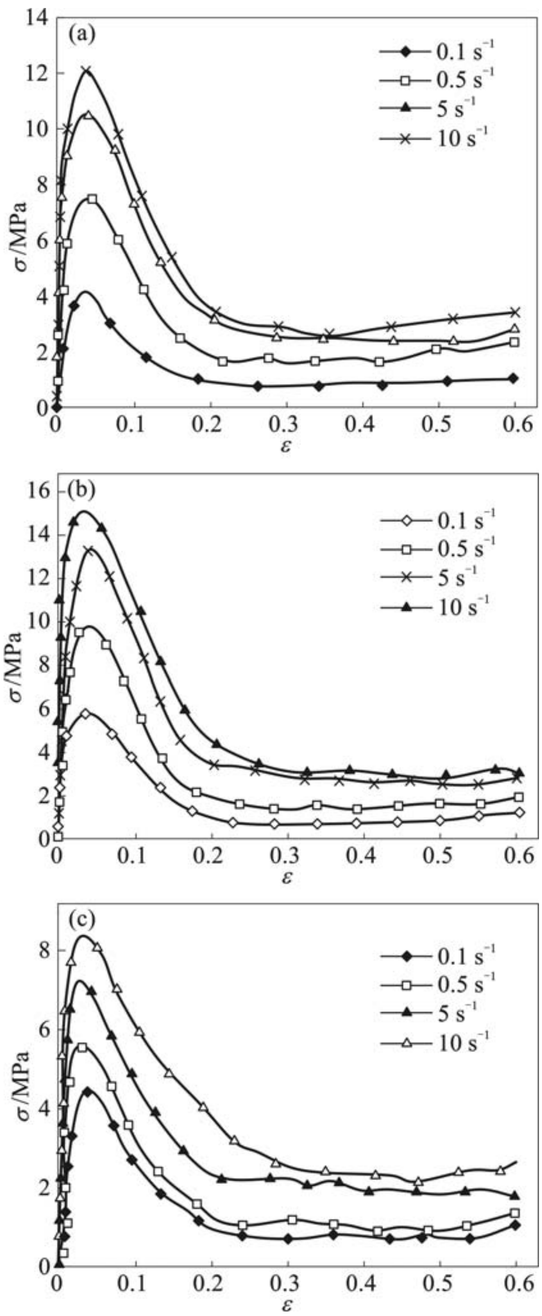

Fig.5 Curves of stress-strain relations at various strain rates for SiC_p/AZ61 composites: (a) φ_p=3%, t=530 ˚C; (b) φ_p=6%, t=545 ˚C; (c) φ_p=9%, t=570 ˚C

barriers to dislocation motion and resistance to the solid grains sliding during the steady-state compressive deformation. So it increases the resistance for dislocation and grain boundaries sliding with the increase of volume fractions of SiC particles.

3.2 Crack-up behavior of thixotropic compressive deformation process

The appearances of specimens compressed at semi-solid state are shown in Fig.7. It can be seen that the surface longitudinal cracks of specimen happen at compression ratio of 20% and the liquid phase is squeezed

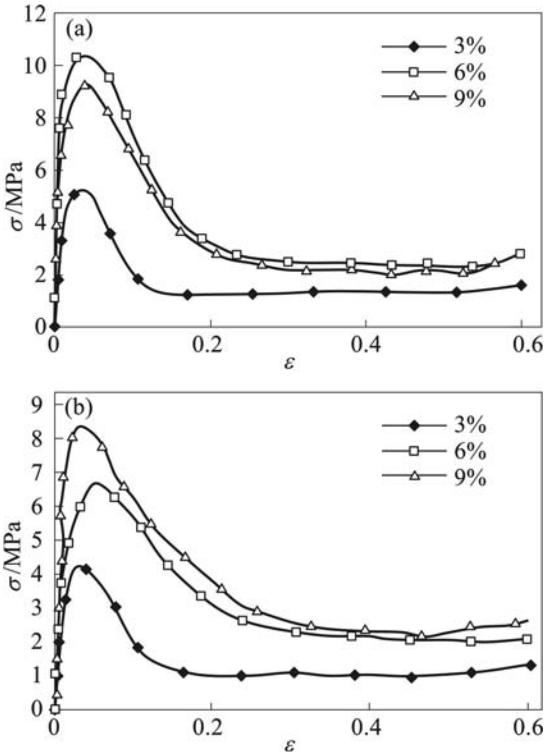

Fig.6 Curves of stress-strain relation at 545 ˚C and 560 ˚C for SiC_p/AZ61 composites with different SiC fractions: (a) t=545 ˚C; $\dot{\varepsilon}$=0.1 s^{-1}; (b) t=560 ˚C; $\dot{\varepsilon}$=10 s^{-1}

out along the cracks. When the compression ratio reaches up 30%, the volume fractions of liquid phase squeezed out of the surface increase, which generates the mixed liquid-solid outer surfaces. The surface strength is very low and generates cracks easily. When all of the liquid is squeezed out, the flow stress starts to ascend. At last the compressed specimen looks like popcorn.

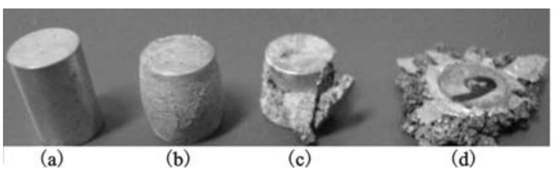

Fig.7 Appearances of specimens compressed at semi-solid state with different compression ratios: (a) 0; (b) 20%; (c) 30%; (d) 60%

4 Conclusions

1）The flow stress of SiC_p/AZ61 composites is highly sensitive to the temperature in the thixotropic compression deformation process, which decreases with the increase of temperature.

2）The flow stress of SiC_p/AZ61 composites increases with the increase of volume fractions of SiC particles.

3）The liquid phase is squeezed out of the specimen surface, which causes the increase of flow stress.

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