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Preparation and thixoforging of semisolid billet of AZ80 magnesium alloy

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Abstract: Semisolid billet of AZ80 magnesium alloy was prepared by new strain induced melt activated (new SIMA) process and thixoforging experiment was performed. The results show that after as-cast AZ80 magnesium alloy is processed by equal channel angular extrusion, microstructure is refined well due to heavy dynamic recrystallization occurring in severe plastic deformation. Compared with semisolid isothermal treatment and conventional SIMA, semisolid billet with fine and spheroidal grains are achieved in new SIMA. Thixoforging process of semisolid billet prepared by new SIMA has many advantages such as good surface quality of final component, high ability to fill cavity and net-shape. The fine and spheroidal grains and high mechanical properties such as tensile strength of 298 MPa and elongation of 28% can be developed in final part thixoforged.
Key words: AZ80 magnesium alloy; semi-solid forming; thixoforging; semisolid billet; strain induced melt activation

1 Introduction

Magnesium alloy is one of the lightest materials used as structural materials which is characterized by many merits such as high specific strength and stiffness, high electromagnetic shielding and good thermal or electrical conductivity[1−2]. In recent years, as a forming method of magnesium alloy, semisolid processing has been paid more attention due to many advantages such as net-shape, high mechanical properties of final component and high production efficiency[3−5]. For example, thixomoulding technology has been applied successfully on magnesium alloy components in automobile and 3C fields[6−7]. However, thixomoulding technology also has many disadvantages such as high cost of starting materials and equipment.

Developing thixoforming technology on universal hydraulic press is very important to apply semisolid processing in manufacturing magnesium alloy parts. The key procedure is to solve the difficulty of preparing semisolid billet of magnesium alloy. Various routes have been developed for obtaining the non-dendritic spheroidal microstructure, e.g. semisolid isothermal treatment (SSIT)[8], mechanical stirring[9], electro-magnetic stirring[10], conventional strain induced melt activation (conventional SIMA)[11]. JIANG et al[12−16] developed a new method called “new SIMA” in which equal channel angular extrusion (ECAE) was applied in the fabrication of semisolid billets of an AZ91D magnesium alloy. The process combined equal channel angular extrusion of a cast AZ91D magnesium alloy at 498 K as strain induced step and subsequent semisolid isothermal heating at 818 K as melt activated step. It was demonstrated that the new SIMA process gave fine spheroidal grains with better thixotropic behavior and improved mechanical properties of the AZ91D magnesium alloy.

New SIMA method is employed for preparing semisolid billet of AZ80 magnesium alloy and the thixoforging characteristics, mechanical properties and microstructure of final parts are assessed.

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2 Experimental

AZ80 magnesium alloy was used as experiment material. It has a composition of Al 8.5%, Zn 0.5 %, Mn 0.12%, Fe 0.003%, Cu 0.02%, Ni 0.002% and Mg balance (mass fraction). Semisolid billet was prepared by new SIMA method. During this process, as-cast AZ80 magnesium alloy with the diameter of 57 mm and the height of 118 mm was firstly processed for 5 passes at 280 °C with an equal channel die that consists of two channels with equal cross-section, intersecting at an angle of 90°. The as-cast AZ80 magnesium alloy was rotated by 90° between consecutive passes. Then, these billets processed by ECAE were machined into rectangular samples with 92.5 mm×31 mm×8.0 mm in dimension and held for 10 min at 540 °C.

After semisolid billet was prepared successfully, it was carried into die cavity with some preheating device. The preheating temperature of the die cavity was 400 °C. Thixoforging process was done on universal hydraulic press of 2 000 kN. In order to compare the effect of various preparation methods on microstructure and mechanical properties of final component, semisolid isothermal treatment (SSIT) and conventional SIMA were also employed in preparing semisolid billet. During conventional SIMA, as-cast alloy was upsetted by 25% at 280 °C. Cutting regions of microstructure observation and tensile experiment samples are shown in Fig.1. The samples for microstructure observation were cut from region 1 to region 5, as indicated in Fig.1. The microstructure observations were performed by optical microscopy after specimens were ground, polished and etched in ethyl alcohol with 3% nitric acid. The tensile samples were cut from region 4, as indicated in Fig.1. Tensile tests were carried out to study the room temperature mechanical properties with INSTRON 5582 universal testing machine. In order to measure accurately room temperature mechanical properties of processed materials by ECAE, average value of tensile experiment results of four specimens was regarded as final mechanical property value.

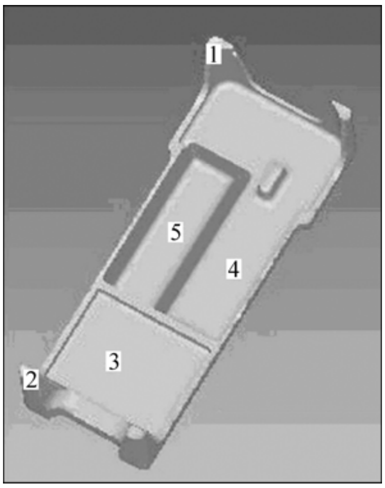

Fig.1 Cutting regions of microstructure observation and tensile experiment samples

3 Results and discussion

Fig.2 shows the microstructures of semisolid billets prepared by SSIT, conventional SIMA and new SIMA. As indicated in Fig.2, compared with SSIT and conventional SIMA, new SIMA can give semisolid billet more uniform and finer spheroidal grains. The grain size of semisolid billet prepared by SSIT is very coarse and its microstructure is non-uniform. Grain size of semisolid billet prepared by conventional SIMA is smaller than that of semisolid billet made by SSIT. Grain size of semisolid billet prepared by new SIMA is the smallest among above-mentioned three methods.

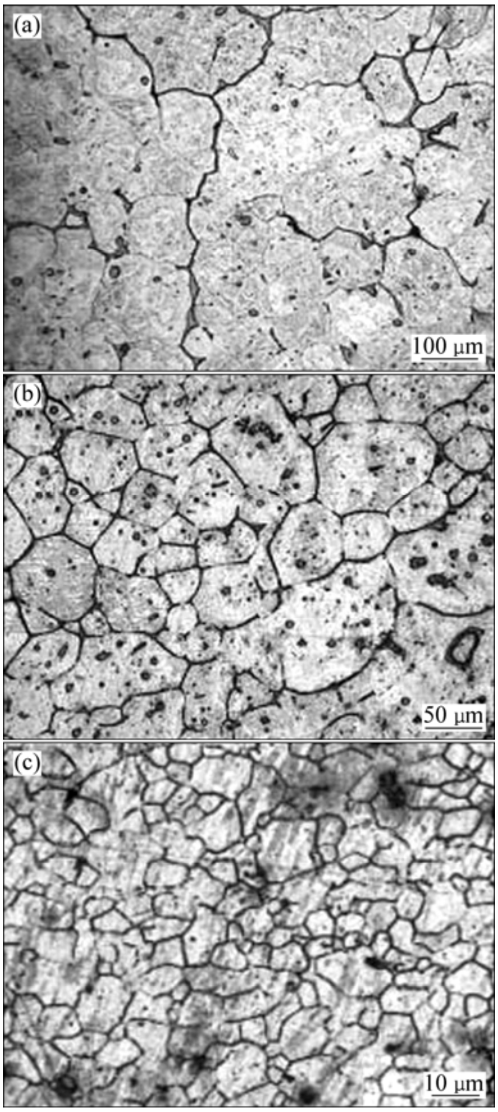

Fig.2 Microstructures of semisolid billets prepared by SSIT (a), conventional SIMA (b) and new SIMA (c)

Different preparing methods have effect on microstructure of semisolid billet of AZ80 magnesium alloy, as shown in Fig.2. For semisolid isothermal treatment (SSIT), coarse dendrite is difficult to be broken up during holding and is developed into non-dendrite (spheroidal grain) due to no induced procedure. Furthermore, the grain size of semisolid billet is very coarse due to starting coarse dendrite of as-cast AZ80 magnesium alloy. For conventional SIMA, upsetting was employed to make as-cast alloy deformed in limited degree. So, some fine equiaxed grains are created due to dynamic recrystallization in the upsetting process. However, the deformation degree of upsetting is limited in AZ80 magnesium alloy due to little slip system. It weakens refining degree of as-cast grains and influences the grain size of semisolid billet. Equal channel angular extrusion (ECAE) was introduced into induced procedure of as-cast AZ80 magnesium alloy in new SIMA. It solves the difficulties in obtaining severe plastic deformation for refining the grains of as-cast AZ80 magnesium alloy[13]. The as-cast AZ80 magnesium alloy is refined well due to dynamic recrystallization during severe plastic deformation. After pre-deformation, most of the deformation energy is released as heating energy, although there is some energy stored in the alloy, which increases the density of vacancies and dislocations. In order to decrease the free energy, the vacancies will combine, and dislocations will climb and cross slip with increasing heat-treatment temperature, which results in the occurrence of recrystallization[17−19]. When the processed as-cast AZ80 magnesium alloy was heated to semisolid temperature, solid grains boundary is wetted by liquid phase because energy between solid recrystallized grains is higher than that of liquid phase and solid grains. Due to fine grains of processed as-cast AZ80 magnesium alloy by ECAE, fine and spheroidal solid grains are achieved successfully during wetting process of solid grain boundary. Therefore, new SIMA, a combination of ECAE and SSIT, can prepare semisolid billet with fine uniform spheroidal grains.

Fig.3 shows macrograph and microstructure in different regions of the final part thixoforged. As indicated in Fig.3(a), the final part thixoforged has good surface quality. It is demonstrated that semisolid billet prepared by new SIMA gives high ability to fill the die cavity and net-shape of the final part can be performed during thixoforging. Microstructure of the final part thixoforged in regions 1, 2, 3, 4 and 5 shown in Fig.1 is very fine and has good spheroidization degree (Figs.3(b)−Fig.3(f)). Furthermore, microstructure is very fine and grain size of part ranges from 10 μm to 50 μm. From region 1 to region 5, the grain size of part is very fine. It is demonstrated that new SIMA is a good method for preparing semisolid billet of AZ80 magnesium alloy.

Net-shape, good surface quality and fine uniform spheroidal grains of final components can be present in the final part thixoforged due to semi-solid billet with high quality prepared by new SIMA (Fig.3). New SIMA can prepare desirable semisolid billet of AZ91D magnesium alloy[20]. As indicated in Fig.2, it is demonstrated that new SIMA can be used to prepare good semisolid billet of AZ80 magnesium alloy. The semisolid billet prepared by new SIMA can influence well the thixoforging process and microstructure of final part (Fig.3). Under low pressure, semisolid billet can fill well the die cavity of final part due to fine uniform grains. After filling die cavity, the pressure of hydraulic press is continuously increased to compact the microstructure of final part, resulting in no shrinkage void or porosity. This leads to the improvement of mechanical properties of the final part due to dense microstructure. Fine uniform semisolid billet can promote surface quality and filling ability during thixoforging. Furthermore, it lays good foundation for fine uniform microstructure of final part. Fine uniform microstructure of the final part has good effect on the improvement of mechanical properties.

Fig.4 shows the effect of different methods for preparing semisolid billet on mechanical properties of final part thixoforged. In order to decide accurately the mechanical properties of final part, four group samples were measured and average values were used as final mechanical properties. For final part made of semisolid billet prepared by SSIT, the average tensile strength and elongation are 163 MPa and 10.7%, respectively. For final part made of semisolid billet prepared by conventional SIMA, the average tensile strength and elongation are 212 MPa and 16.6%, respectively. For final part made of semisolid billet prepared by new SIMA, the average tensile strength and elongation are 298 MPa and 28%, respectively. It is demonstrated that the mechanical properties of the final part made of semisolid billet prepared by new SIMA are the highest.

Fig.5 shows the microstructures of the final parts made of semisolid billets prepared by different methods including SSIT, conventional SIMA and new SIMA. As indicated in Fig.5, compared with SSIT and conventional SIMA, new SIMA gives finer and more uniform microstructure of the final part during thixoforging process. Grain size of the final part made of semisolid billet prepared by SSIT is very coarse. The grain size of the final part made of semisolid billet prepared by conventional SIMA is decreased a little. Grain size of the final part made of semisolid billet prepared by new SIMA is the smallest.

Different microstructures of semisolid billet prepared by SSIT, conventional SIMA and new SIMA lead to difference in mechanical properties of the

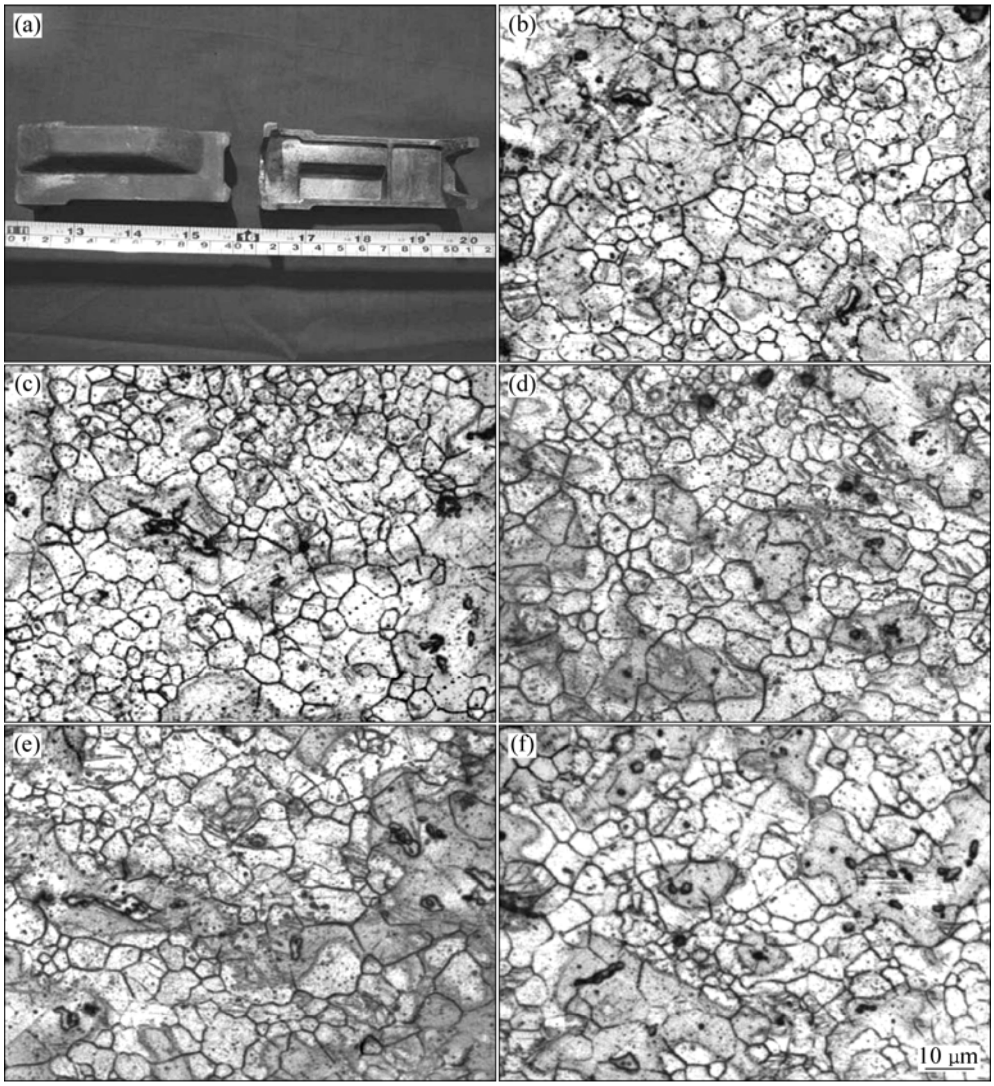

Fig.3 Macrograph of final part thixoforged (a) and microstructures in region 1 (b), region 2 (c), region 3 (d), region 4 (e) and region 5 (f) in Fig.1

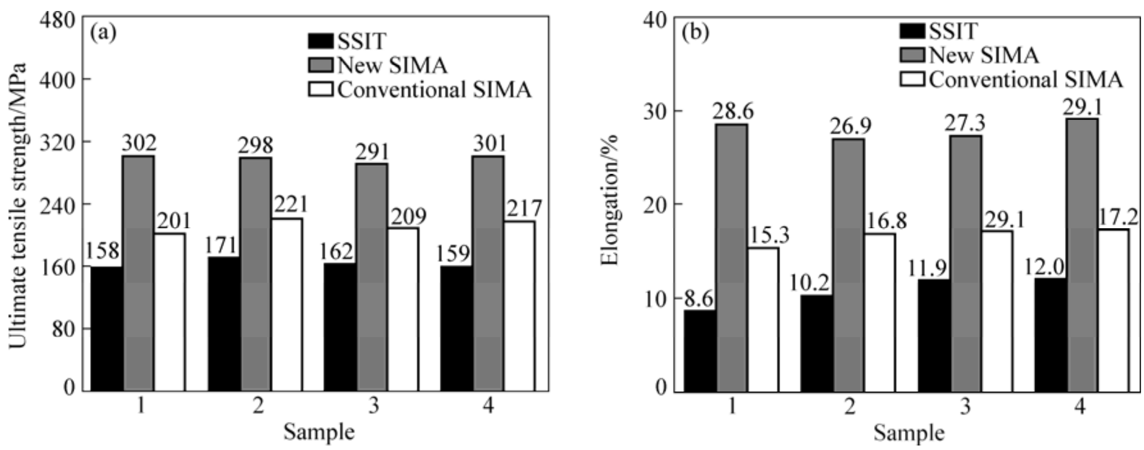

Fig.4 Mechanical properties of final part thixoforged: (a) Tensile strength; (b) Elongation

thixoforged part (Fig.4 and Fig.5). Semisolid billet with fine and spheroidal grains are present in new SIMA, which leads to fine grains of final thixoforged part. The important characteristics can be indicated in microstructure of final part made of semisolid billet prepared by new SIMA. Firstly, the grain size in microstructure of thixoforged part is very fine. Secondly, its microstructure is very uniform. Lastly, its

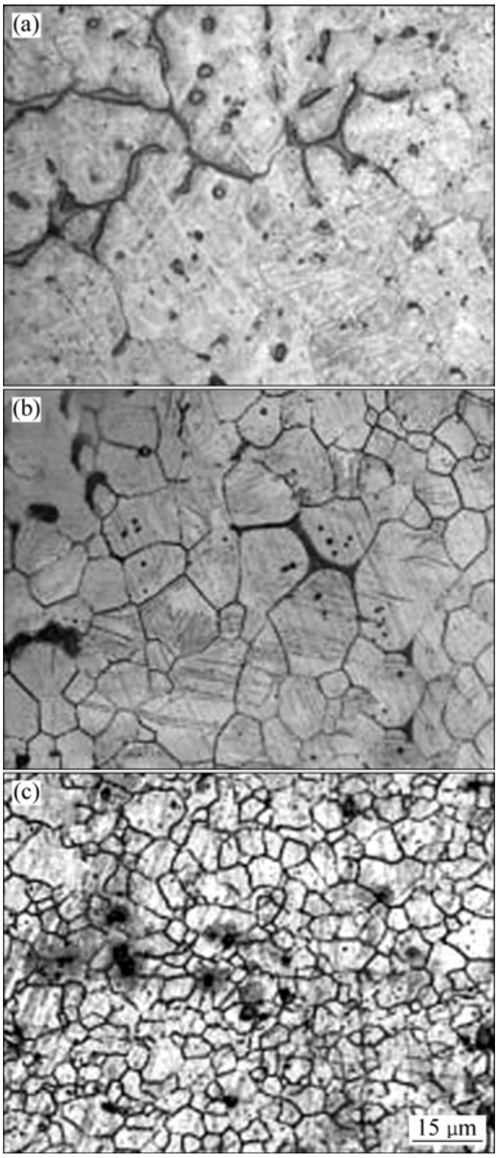

Fig.5 Microstructures of final parts manufactured by thixoforging semisolid billet prepared by different methods: (a) SSIT; (b) Conventional SIMA; (c) New SIMA

microstructure is very dense. The above-mentioned three aspects have great effect on enhancing mechanical properties of the thixoforged part.

4 Conclusions

1) After as-cast AZ80 magnesium alloy is processed by ECAE, microstructure is refined well due to heavy dynamic recrystallization occurring in severe plastic deformation. Semisolid billet with fine spheroidal grains can be prepared by new SIMA. Furthermore, compared with SSIT and conventional SIMA, the grain size of the semisolid billet by new SIMA is the finest.

2) Thixoforging process of semisolid billet prepared by new SIMA has many advantages, such as good surface quality, high ability to fill cavity and net-shape. The fine spheroidal grains and homogeneous microstructure without segregation can be developed in final part thixoforged.

3) Compared with SSIT and conventional SIMA, the final parts made of semisolid billet prepared by new SIMA have high mechanical properties such as average tensile strength of 298 MPa and elongation of 28%. Isothermal temperature has effect on mechanical properties of final part thixoforged. When the isothermal treatment temperature is 540 °C, mechanical properties of the final part are the highest.

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