PLASTIC DEFORMATION TECHNOLOGY OF HIGH STRENGTH DEFORMED MAGNESIUM ALLOY

by

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The traditional plastic deformation technology of magnesium alloys is relatively poor at high temperature, so a plastic deformation technology of high strength wrought magnesium alloys is designed. Firstly, the slip surface and slip direction which affect the properties of magnesium alloy are analyzed, then the rolling finite element is simulated, the simulation results are visualized, and the simulation information required by the user is output. The results show that the temperature rise decreases with the increase of initial deformation temperature, the average grain size decreases and the uniformity of grain size distribution increases gradually due to dynamic recrystallization, and the cumulative strain and strain distribution in the strain field increases gradually with each pass due to the existence of shear stress in the stress field.

Key words*: high strength wrought magnesium alloys, plastic deformation technology, mechanical properties analysis*

Introduction

Of all the structural metals and alloy materials, magnesium alloy has the smallest density, high specific strength and stiffness, good casting property, thermal conductivity, machinability, damping and vibration reduction, strong electromagnetic shielding ability, stable size of parts, easy recovery and utilization, important application value in automobile, computer, communication, electronics, aerospace and other industrial fields, and broad development prospects [1]. It is another kind of metal structure material developed rapidly after steel and aluminum alloy, and is praised as *21st century green engineering material*, especially the wrought magnesium alloy sheet. In recent years, with the decrease and depletion of many kinds of metal mineral resources, magnesium has been paid more and more attention to by the industry because of its rich resource advantages. Due to the requirements of environmental protection and energy saving, traditional steel materials in many fields are gradually being replaced by new materials with higher comprehensive performance [2, 3]. It is of strategic significance to develop magnesium alloys and improve the properties of magnesium

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alloys for the economic and social development of our country according to the proportion and production of magnesium alloys [4-6]. Since the 1960's, materials scientists at home and abroad have devoted themselves to the research and development of Mg-based composites to improve the comprehensive properties of Mg-based alloys by strengthening ceramic particles or fiber reinforcements [7-10]. How to optimize the processing technology of wrought magnesium alloys is a long-term research goal. The plastic deformation theory of magnesium alloys is the theoretical basis of sheet rolling and other plastic forming technologies. The innovation of this paper is to simulate the temperature field, stress field and strain field of the billet in the process of closed die forging. It shows that there is shear stress in the process of forging.

Study on plastic deformation technology of high strength wrought magnesium alloy

The plastic deformation theory of high strength wrought magnesium alloys is the theoretical basis of sheet rolling and other plastic forming technologies. Up to now, many scholars at home and abroad have done a lot of research in this field. Pure magnesium and most magnesium alloys have typical close-packed hexagonal crystal structure, and the main slip systems are shown in tab. 1.

Table 1. Independent slip systems in high strength wrought magnesium alloys

Slip system	Slip surface	Direction of slip	Number of independent slip systems
Base-plane slip	{0002}	$\langle 11\bar{2}0\rangle$	2
Prismatic slip	$\{10\bar{1}0\}$ $\{11\bar{2}0\}$	$\langle 11\bar{2}0\rangle$	2
Conical slip	$\{10\bar{1}1\}$ $\{11\bar{2}1\}$ $\{11\bar{2}2\}$	$\langle 11\bar{2}0\rangle$ $\langle 11\bar{2}3\rangle$	4 5

Among all the slip systems, the critical shear stress of {0002}plane slip is the smallest, which is also the main plastic deformation mechanism of magnesium alloy at room temperature. The base slip can only provide three geometric slip systems and two independent slip systems, which cannot meet the von Mises criterion. Prismatic slip includes $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$ slip, which can provide two independent slip systems. Both base plane slip and prismatic plane slip belong to a-slip, that is to say, the unit dislocation with $a/3$ $\langle 11\bar{2}0\rangle$ Berlusconi vector slips along the $\langle 11\bar{2}0\rangle$ direction, which cannot co-ordinate the strain along the c-axis. The $\{10\bar{1}1\}$ cone slip can provide five independent slip systems, and the cone slip belongs to c+a slip. The slip of all dislocations with $(c^2+a^2)^{1/2}\langle 11\bar{2}3\rangle$ Berlusconi vector along the $\langle 11\bar{2}3\rangle$ crystal direction can produce strain along the c-axis direction. Therefore, c+a slip is very beneficial to improve the plastic deformation ability of magnesium alloy [11]. Non-base slip is a potential slip system in magnesium. When the temperature is low, its CRS is much larger than base slip, which can be activated only under certain conditions. In particular, the bergheit vector of the c+a dislocation is large, the dislocation core is narrow, and the movement ability is poor, which is not easy to occur [12]. It can be seen that although there are only two basic slip systems in magnesium alloy, there are also potential slip systems such as prisms and cones. It is of great significance to make clear the activation mechanism of these slips systems and then to take corresponding technological measures to give full play to and improve the plastic deformation ability of magnesium alloy. From the previous analysis, it can be seen that although the formation of{0002}-BASE texture is extremely unfavourable to the plastic forming of magnesium alloy sheet, appropriate process measures can be taken to adjust and control the texture type of sheet, so as to improve and improve the processing and forming performance and mechanical properties of magnesium alloy [13, 14]. On the basis of the comprehensive analysis of the forming mechanism and influencing factors of the deformation texture of magnesium alloy, it is expected to be one of the most effective methods to solve the aforementioned problems to develop or adopt the special rolling technology of magnesium alloy plate to change the stress characteristics in the deformation process without changing the alloy composition [15].

The model was created by AutoCAD. The dxf. file is generated. Then it was imported into DEFORM 2-D. The geometrical model includes upper roll, lower roll and rolling sheet. According to the experimental conditions, the model parameters are set as shown in tab. 2. In order to reduce the amount of calculation, the length of sheet metal is 100 mm, less than the actual length of sheet metal. The boundary conditions are:
– the forming material is AZ31 magnesium alloy,
– the original workpiece blank size is: $L \times H$ = 100 mm × 9.5 mm,
– the initial roller temperature is 30 °C, and
– the initial workpiece temperature is 400 °C, and the friction coefficient is 0.4.

Table 2. Finite element calculation conditions

Computational condition	Parameter value	Unit
Upper roll diameter.	234.0	mm
Lower roll diameter.	255.0	mm
Center distance of upper and lower roll	252.6/ 253.1/ 253.5	mm
Length of plate	100.0	mm
Sheet metal thickness	9.5	mm
Upper roll angular velocity.	2.62	rad/s
Lower roll angular velocity	2.62	rad/s
Pass reduction.	5.0/10.0/15.0	%

Based on the previous conditions, the geometry model of the finite element analysis is shown in fig. 1.

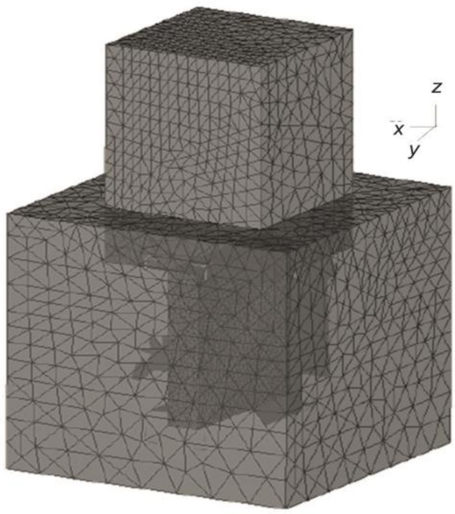

Figure 1. Geometric model for finite element analysis

Due to the high preheating temperature and large deformation of magnesium alloy, the effect of elastic strain can be neglected, so the rigid-plastic finite element model is used [16]. Tools can be regarded as rigid bodies and rigid models are selected. The grid method is one of the most common methods to study the macroscopic flow law of metals during plastic deformation. By observing the changes of the grid shape and size before and after deformation, the characteristics of metal particle flow and deformation in deformation can be directly reflected [17]. It can be seen from the change of mesh size that when the pass deformation is small, the mesh height near the surface of the sheet metal after deformation is large, which indicates that the compression deformation is small. With the increase of pass deformation, the compression deformation in the thickness direction tends to be uniform. In addition, under the shear stress of *rolling zone*, the rectangular mesh element becomes parallelogram after asynchronous rolling, which indicates that the shear deformation occurs in the plate [18]. Like the compression deformation, the shear deformation is not uniform. From the angle of parallelogram, it can be seen that the shear deformation near the surface of the plate is greater than the center. It is worth noting that the deformation near the surface of the plate is usually larger than that at the center because of the difficulty of deep deformation in ordinary rolling. From the previous analysis, it can be seen that the compression deformation near the surface is smaller than that at the center when the pass deformation is asynchronous. This is because there is additional shear stress in the cross rolling, and the shear stress near the surface is larger than the center, so the shear deformation is easy to occur near the surface. In fact, the strain can be divided into positive strain and shear strain. The former refers to the length of the change in size. The shear strain refers to the angle of the change in size. Although the compressive deformation near the surface is small, its shear strain and equivalent strain are large.

Results

Experimental preparation

In the smelting process of Mg-based composites, the key of the process is to prevent oxidation, combustion and sputtering of melts. The experimental smelting equipment is composed of a smelting furnace and a protective gas supply device. The furnace is a SG2-3-10 crucible resistance furnace with a rated power of 3000 W, its rated temperature is 1000 °C, and the furnace size is 150 × 200 mm. Ladles, crucibles, casting molds, *etc*. are preheated to ~150 °C before using, and a coating of about 0.2 mm thick is sprayed on the surface, with 6% talc powder 90% water + 4% sodium silicate (wt.%), and then dried for use [19]. The raw material AZ31 alloy is shown in fig. 2(a). It is a cylindrical semi-continuous casting ingot with a diameter of 150 mm on the underside and broken crystalline silicon particles are shown in fig. 2(b). The surface of AZ31 alloy ingot is polished to remove impurities such as oxide scale and then insulated for 5 hours in a 200 °C oven with crystalline silicon, 1.5 wt.% refining agent and casting mold. The crucible is preheated to a dull red state (~500 °C) after spraying the paint, then the preheated ingots of AZ31 alloy and crystalline silicon are placed, and the protective gas 0.5% SF6 99.5% CO_2 (vol.%) is injected. The molten metal liquid to be melted shall be kept warm for 20 minutes at the temperature of 780 °C, and then be cooled to 740 °C. After being refined for 8 minutes without power cut by adding refining agent, the molten metal shall, under the protection of protective gas, be freely cooled to 710 °C for skimming, and be cast into a metal mold and solidified into a 100 mm × 100 mm × 160 mm ingot. Figure 2(c) shows the as-cast AZ31-2 wt.% Si in-situ composite material.

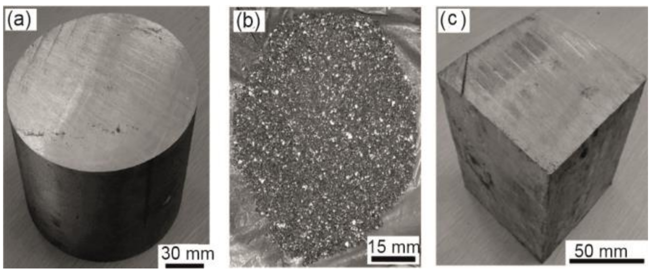

Figure 2. Different materials; (a) AZ31 alloy, (b) Si particles, and (c) AZ31-2 wt.%

The actual silicon content of the composites with nominal composition of AZ31-2 wt.% Si and AZ31-5 wt.% Si was 1.7 wt.% and 4.3 wt.%, respectively, as sampled from ingots and analyzed by inductive coupled plasma plasma coupled plasma coupled plasma emission spectrometry (ICP-OES).

Experimental results and discussion

Different upsetting temperatures have different effects on grain refinement. Better upsetting conditions can be selected by understanding the temperature field at different initial upsetting temperatures. Figure 3 shows the temperature rise distribution along the thickness direction of the billet after one pass of upsetting at the initial temperatures of 300 °C, 350 °C, 400 °C, and 450 °C.

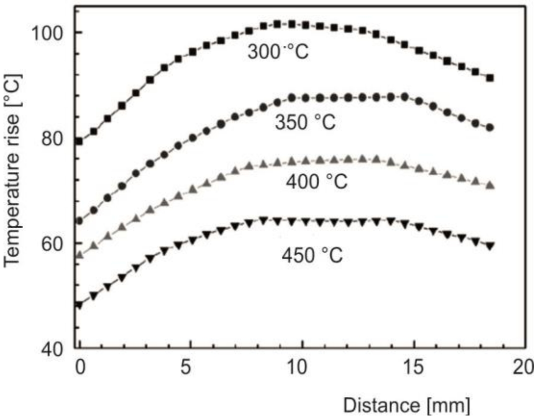

Figure 3. Variation of temperature rise with billet thickness after 1 pass upsetting at different temperature

The results in fig. 4 show that the temperature rise of the billet decreases with the increase of the initial deformation temperature. The initial upsetting temperature increases from 300 °C to 101 °C, from 79 °C at the minimum, and from 64 °C to 48 °C at 450 °C. The higher the upsetting temperature is, the greater the internal friction force is, the greater the deformation resistance is, the more deformation work is required, and the more heat energy is converted [20].

The large plastic deformation technique can refine the micro-structure of the alloy dramatically due to the extremely high cumulative strain during multi-pass processing. The distribution of strain is a key parameter in machining process, and the uniformity of strain distribution determines the degree of uniformity of material structure to some extent [21]. The machining Path A is selected. The friction coefficient is set to 0.3. The starting speed is set to 4 mm/s. The upsetting finite element simulation was repeated at 350 °C. Figures 4(a)-4(f) are billet before upsetting, 1-5 passes after repeated upsetting, respectively.

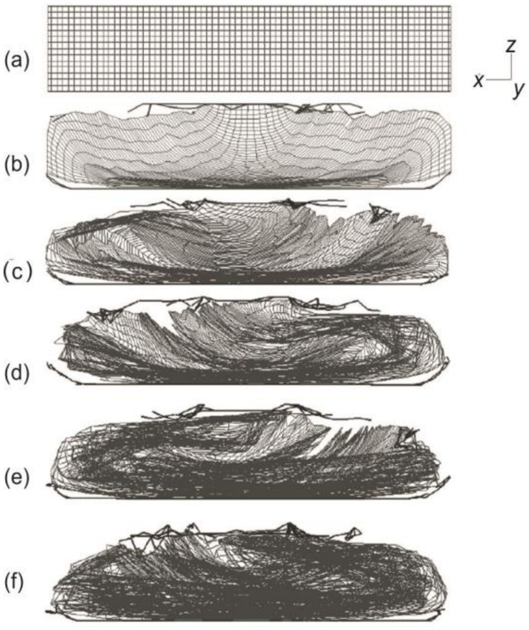

Figure 4. Flow grid diagram of billet before upsetting and after repeated upsetting of 1-5 passes

With Y plane as the reference plane, the streamline mesh of the billet is a regular square. With the upsetting, the lower part of the billet is subjected to the shear stress in the direction of 45° from Z-axis. At the end of the upsetting process, the deformation of the upper surface layer of the blank is minimal. Because it does not pass through the corners of the mold, and the bottom of the blank is stretched and deformed during the upsetting process. This caused severe deformation of the mesh. With the increase of upsetting passes, the flow line becomes disordered, and the strong deformation zone gradually extends from the lower part to the upper part of the billet.

To sum up, under the treatment of this technology, the grain structure, mechanical properties, and hardness of magnesium alloy materials have been significantly improved [22].

Conclusions

Magnesium and its alloys are one of the most excellent materials in engineering at present. The density of magnesium alloys is 30% to 75% lower than that of aluminum and steel. Nowadays, the use and research of magnesium alloys are of great significance.

- With the increase of the times of cyclic closed die forging and repeated upsetting from 0 to 5, due to dynamic recrystallization, the average grain size of composite matrix gradually decreases, and the uniformity of grain size distribution gradually increases. During deformation, the shearing stress produced by matrix will gradually break up into small polygonal blocks in the form of large Chinese characters and branches, and then flow repeatedly and redistribute in the process of multi-pass processing, and its distribution uniformity gradually increases, and after five passes, the distribution is small and dispersive.
- After the first pass upsetting, the strain distribution in the billet is very uneven, and the homogeneity of the strain distribution increases with the pass increasing. The finite element simulation of stress field shows that most of the billets are in the state of compressive stress in three directions, and the shear deformation always exists in the process of die forging.
- Under the same repeated upsetting and pressing conditions (350 °C, five passes), the effect of grain refinement and homogenization of AZ31 alloy by adopting Path B is stronger than that of adopting Path A. Therefore, the AZ31 alloy prepared by adopting Path B has higher strength and elongation.

In order to master several kinds of large plastic deformation techniques and prepare magnesium matrix composites with higher properties, the following aspects should be studied continuously:

- The enlargement of sample size and the improvement of processing efficiency will lay a foundation for the transformation from laboratory scale to industrial production.
- Research shall be carried out on the preparation of nanometer composite materials based on rare earth magnesium alloy by large plastic deformation to obtain Mg-based nanometer composite materials with higher performance.

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