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INFLUENCE OF GRAIN REFINEMENT ON ANISOTROPY IN MECHANICAL PROPERTIES IN WROUGHT MAGNESIUM ALLOY AZ80

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A direct-chill (DC) cast magnesium alloys AZ80 has been forward-extruded in a single pass with total degree of deformation (φ = 2.5) at two temperatures 200 °C and 350 °C. The as-extruded round profiles have been analyzed for microstructural changes i.e. degree of recrystallization and recrystallized grain size, using optical microscopy. The crystallographic texture has been measured from X-ray diffraction using Co Kα radiation. The results show that the extent of grain refinement increases with the lowering extrusion temperature. The crystallographic texture in both conditions consists of a predominant $< 10\bar{1}0 >$ component accompanied by a relatively weaker $< 11\bar{2}0 >$ component in the extrusion direction. Although, the crystallographic texture at both extrusion temperatures remains fairly similar, a fine grain size achieved at lower extrusion temperature reduces the degree of anisotropy in yield stress. A fine grain size inhibits the nucleation of tensile twins under compressive loading and gives a higher compressive yield stress, thereby lowering the anisotropy in yield stress.

Keywords : *Anisotropy, Mg alloy AZ80, Extrusion*

1. Introduction

Extrusion is one of the most commonly used industrial forming processes, to produce metallic, ceramic or polymeric profiles of constant cross sections. In general, the metals and alloys having FCC lattice structure possess sufficient number of independent slip systems that can be activated at room temperature and therefore, can be extruded at room temperature. For metals and alloys having BCC or CPH structure, the independent active slips systems are few. Therefore, in order to deform these metals and alloys temperature, the temperature needs to be increased. Magnesium alloys exhibit rather poor ductility at room temperature and therefore, are extruded at elevated temperatures. At these temperatures, magnesium alloys undergo dynamic recrystallization during deformation. The recrystallized grains are usually much finer than the one in the as-cast condition. Consequently, as-extruded alloys show higher strength and ductility in comparison to the as-cast alloys [1-2]. However, Mg alloys suffer from anisotropy in mechanical properties due to the basal texture obtained after extrusion. Because of its closed packed hexagonal crystal lattice, the most active slip system in Mg alloys is the (0001) $< 11\bar{2}0 >$ basal slip. Since the burger vector <a> = $< 11\bar{2}0 >$ is the shortest burger vector in Mg CPH lattice, other slip systems i.e. prismatic and pyramidal, also slip in the same direction. Therefore, after a uni-directional deformation such as extrusion, most of the grains have their basal plane normal at 90° to the extrusion direction. Such an orientation causes anisotropy of the mechanical properties, which depend not only on the direction of measurement but also on sign of the applied stress. In addition to elemental alloying which affects the c/a ratio of the alloy and thus the activation of various slip systems and deformation twinning leading to the texture modifications, the degree of anisotropy in mechanical properties is affected by the recrystallized grain size. Recently, the rising cost of fuel and increased environmental concern has given a new impetus to the research in wrought Mg alloys [3-5]. Present study examines the effects of various degrees of grain refinement on the mechanical properties under tensile and compressive loadings. In particular, it shows that grain refinement leads to not only increase in strength but also lowers the degree of anisotropy in strength.

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2. Experimental

Direct chill (DC) cast Mg alloy AZ80 having a composition Mg- 8% Al – 0.5% Zn – 0.3% Mn was received in form of cylindrical billets having a diameter of 70 mm and a length of 200 mm. These billets were heated to the extrusion temperature for 1h (e.g. 200 °C and 350 °C) and lubricated with MoS_2 prior to extrusion. The extrusion die was also heated to the same extrusion temperature. A constant ram velocity of 1 mm/sec was used for both extrusions. The exit diameter of the extrusion die was 20 mm, this correspond to an extrusion ratio (ER) of 12 and a true degree of deformation φ = 2.5 (where φ = ln ER). After extrusion, the extruded round profiles were air cooled. Optical microscopy was performed on as-cast and as-extruded alloys to observe the microstructrual changes. Texture analysis was evaluated from XRD data using Co K_α radiation. The complete inverse pole figures were calculated by series expansion of the experimental data obtained by the Schulz reflection technique. All the quasi-static tensile and compressive tests were performed in air at an initial strain rate of 10^{-3} sec^{-1}.

3. Results and Discussion

The optical micrograph presented in Fig. 1 shows the microstructure of the AZ80 alloy in as-cast condition. The equi-axed grains are of the size ~ 100 um. Fig. 2 shows the optical micrographs of the alloy in as-extruded condition. The optical micrographs show that the alloy almost fully recrystallizes upon extrusion without requiring any subsequent heat treatment. The dynamically recrystallized (DRXed) grains are significantly finer (~ one tenth) than the grains in the as-cast condition. The distribution of grain size is also fairly homogeneous for a magnesium alloy. The mode of DRX in AZ series of Mg alloys is continuous, in which gradual rotation of the original grains leads to progressive development of high angle grain boundaries from the low angle sub-grain structures [3]. Although, second phase particles which can promote a discontinuous recrystallization mode are present in the alloy, but they are either weak ($Mg_{17}Al_{12}$) or too coarse and too apart from each other (Al-Mn particles) to make it happen. Fig. 2 shows that eutectic phase is broken during extrusion and forms parallel band in the extrusion direction.

The effect of temperature on DRX grain size is generally presented in form of Zener-Hollomon

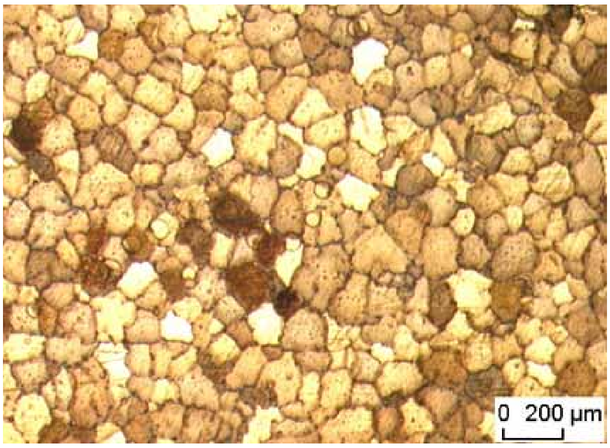


Figure 1. The optical micrograph of the DC-cast wrought Mg alloys AZ80.

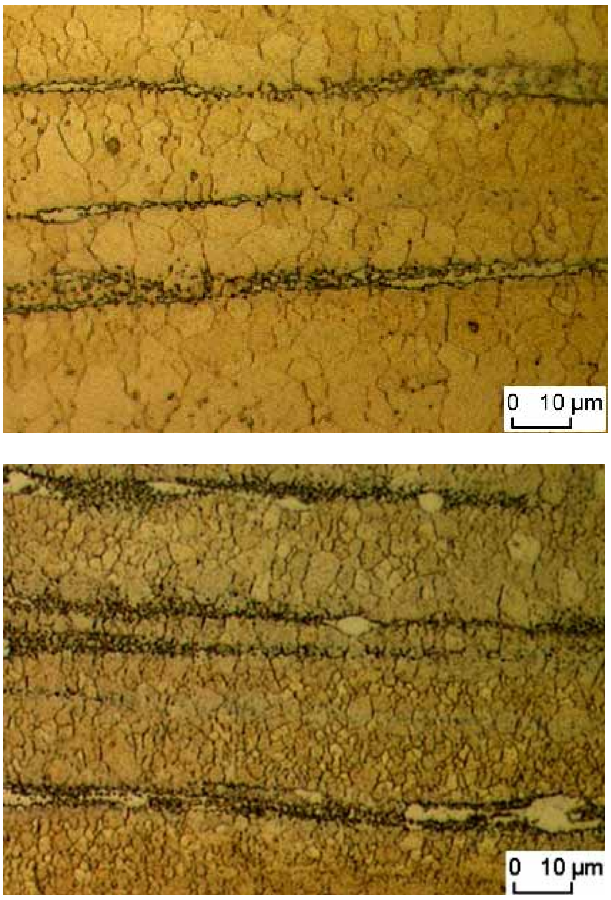


Figure 2. The optical micrographs of the Mg alloys AZ80 extruded at 350 °C (up) and at 200 °C (down).

parameter (Z). Z is defined as $= \dot{\varepsilon}\exp(Q/RT)$, where $\dot{\varepsilon}$ is strain rate, Q is activation energy similar to self diffusion and R is gas constant. Thus, grain refinement during plastic deformation can be achieved by increasing the strain rate and by lowering the temperature. The optical micrographs in Fig. 2 show that average grain size in as-extruded condition reduces from 8 um to 4 um when the extrusion temperatures reduced from 350 to 200 °C. The deformation temperature has significant effects on the activation of slip systems in Mg alloys. The basal slip (0002) $<11\bar{2}0>$ is the most easily activated slip system in Mg alloys. However, this system contains less than five independent slip systems and therefore does not satisfy the Von Mises criterion for homogeneous deformation. At low temperatures (less than 225 °C), the basal slip is supported by the deformation twinning. The contribution of deformation twinning in total strain reduces significantly as the deformation temperature is raised. At high temperatures (over 225 °C) the contribution of deformation twinning is insignificant and the basal slip is supported by other slip systems. In the case of high temperature deformation, DRX grains nucleate at original grain boundaries, whereas, at low temperature deformation, the twin interfaces provide additional nucleation sites. As a result, finer grain size is achieved at lower deformation (extrusion) temperature.

The crystallographic texture of the alloy in as-extruded condition is presented in Fig. 3 in the form of inverse pole figures in the extrusion direction calculated from X-ray diffraction data. The results reveal a rather weak $<10\bar{1}0>$ fiberous texture in the extrusion direction at both extrusion temperatures, indicating a higher degree of recrystallization. The $<10\bar{1}0>$ component is accompanied by a relatively weaker $<11\bar{2}0>$ component in the extrusion direction. The maximum intensity of $<10\bar{1}0>$ component is slightly lower in the case of lower extrusion temperature; however, this difference is not that large considering that the data was calculated using X-ray diffraction. Thus, the crystallographic texture is not much affected by the studied variation in extrusion temperature.

The stress-strain curves under tensile and compressive loadings are presented in Fig. 4, for both extrusion temperatures. The yield stress under compression loading is less than the one under tensile loading, in cases of both extrusion temperatures. The anisotropy in yield stress under tension and compressive loading (strength diffe-

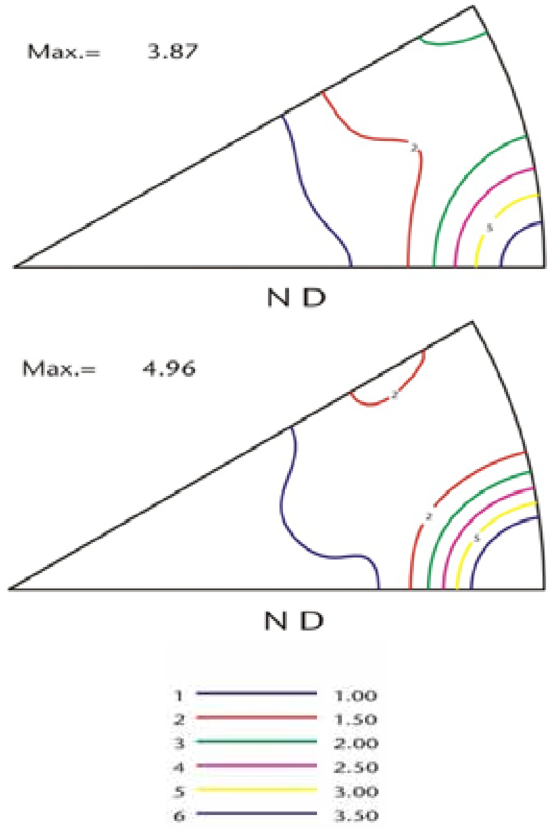
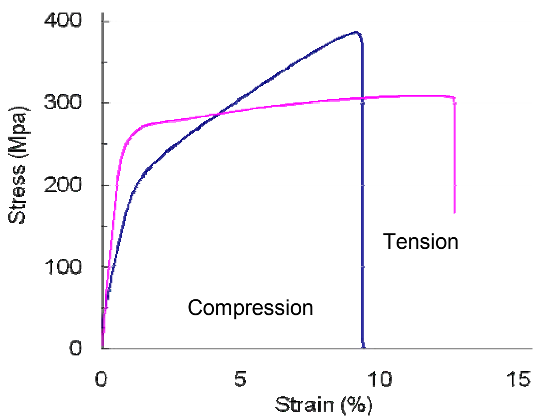


Figure 3. Inverse pole figures calculated from XRD data of AZ80 alloy extruded at 200 °C (up) and 350 °C (down).

rential effect, SDE) is a phenomenon observed in the wrought alloys having a closed plane hexagonal lattice structure [4]. It is caused by the textured microstructure after extrusion and is affected by the grain size. The basal slip (0001) $<11\bar{2}0>$ is the dominant mode of deformation in Mg alloys and requires much lower critical resolved shear stress (CRSS) for activation. Other deformation modes, e.g. the prismatic slip $\{10\bar{1}0\}$ $<11\bar{2}0>$ and the pyramidal slip $\{10\bar{1}1\}<11\bar{2}0>$ require many fold higher stresses for activation. Deformation twinning requires the second lowest CRSS for activation at room temperature. In the case of textured materials, such as extruded magnesium alloys, the CRSS for activation of $\{10\bar{1}2\}$ tensile twinning is the lowest under longitudinal compression. Therefore, under compression loading, the plastic deformation starts at a lower stress than the one under tensile loading

[5]. This gives a lower compressive yield stress than the tensile yield stress. The grain size affects the strength differential effect by affecting the nucleation of tensile twins. In order to nucleate in a small grain, the energy required per unit volume increases. Therefore, the tensile twinning is nucleated at higher stress in the case of lower extrusion temperature. This raises the compressive yield stress and lowers the difference between the tensile and compressive yield stresses.



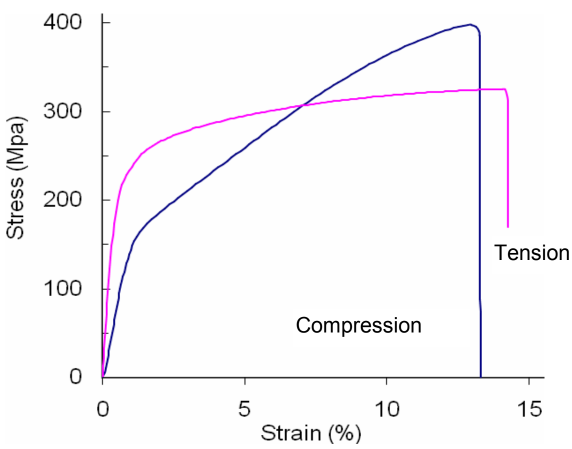


Figure 4. The stress-strain curves under tensile and compressive loadings of the AZ80 alloy extruded at 200 °C (up) and 350 °C (down).

4. Conclusions

The degree of anisotropy in yield stress under tension and compression can be effectively reduced in wrought magnesium alloy AZ80 by lowering the deformation temperature. This results in a higher degree of grain refinement which subsequently inhibits the activation of tensile twins. The twinning starts at a higher stress thereby lowering the difference between tensile yield stress and compressive yield stress.

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