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Deformation Microstructures and Textures of Cast Mg-3Sn-2Ca alloy under Uniaxial Hot Compression

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Abstract. The influence of deformation conditions on the microstructure and texture evolution during hot compression of Mg-3Sn-2Ca (TX32) has been studied. Cylindrical samples were compressed uniaxially at different combinations of temperatures and strain rates in the ranges 300-500 ^{o}C and 0.0003-10 s^{-1}. The crystallographic orientation information of the as-cast and deformed specimens was obtained by EBSD micro-texture analysis. Activation of different slip systems was investigated using Schmid factor analysis and the results reinforce the importance of non-basal slip for deformation at high temperatures. Samples deformed at 500 ^{o}C/0.1 s^{-1} resulted in a fully recrystallized microstructure with near random crystallographic texture.

Introduction

Magnesium and its alloy products are becoming more important in automotive and aircraft industries because of their low density, high specific strength and favourable recycling capability [1]. The deformation of magnesium alloys is extremely orientation dependent due to its hcp crystallographic structure and the limited number of available slip systems at room temperature. Basal slip and tension twinning are the only readily available systems at room temperature [2]. Basal (0001), prismatic $(10\bar{1}0)$ and second order pyramidal $(11\bar{2}2)$ planes are considered to be important in magnesium alloys. The geometric condition for the operation of a slip system can be expressed by Schmid's law [3]

$$T_c = \pm\, \sigma \cos\varphi \cos\lambda, \tag{1}$$

where T_c is the critical resolved shear stress (CRSS), σ is the applied stress, φ is the angle between the slip direction and compressive direction, λ is the angle between the normal direction of the slip plane and the compressive direction. The Schmid factor is defined as $m = \cos\varphi \cos\lambda$. The required yield stress for a given slip system with a CRSS T_c is determined by the Schmid factor 'm', with small Schmid factor being unfavourable for slip to operate. Increasing deformation temperature decreases CRSS and thus, non-basal slip modes get activated and become more important. The aim of the present work is to study the hot compressive deformation behaviour of Mg-3Sn-2Ca alloy in as-cast condition using the processing map technique [4] and to evaluate the influence of deformed conditions on microstructures and micro-textures using SEM based EBSD technique.

Experimental

Cylindrical specimens of 10 mm diameter and 15 mm height were machined from the TX32 as-cast billet for compression testing. The data for developing processing maps were obtained in isothermal uniaxial compression tests conducted at constant true strain rates in the range 0.0003 – 10 s^{-1} and temperature range 300 – 500 °C using a computer controlled servo-hydraulic testing machine. Details of the test set-up and procedure are described in an earlier publication [5]. The preliminary results have been presented elsewhere as part of the present work [6]. The deformed specimens were sectioned in the center parallel to the compression axis and the cut surface was mounted, polished and etched for metallographic examination. The texture of the deformed samples for selected deformed conditions was examined using a JEOL 5600 SEM equipped with a NordlysF EBSD detector and HKL Channel 5 software was used for data collection. Output texture data is shown as pole figures, in which the horizontal axis of the figure is the compression direction.

Results and Discussion

Processing Map. The processing map of Mg-3Sn-2Ca (TX32) alloy obtained at a strain of 0.5 is shown in Fig. 1 which exhibits two domains of dynamic recrystallization in the temperature and strain rate ranges given as follows: (1) 300–350 °C and 0.0003–0.001 s^{-1} with a peak efficiency of 42% occurring at 300 °C and 0.0003s^{-1}, and (2) 390–500 °C and 0.005-0.6 s^{-1} with a peak efficiency of 42% occurring at 450 °C and 0.03 s^{-1}. The apparent activation energy in the lower strain rate regime was 177 KJ/mole and 197 KJ/mole in the higher strain rate regime.

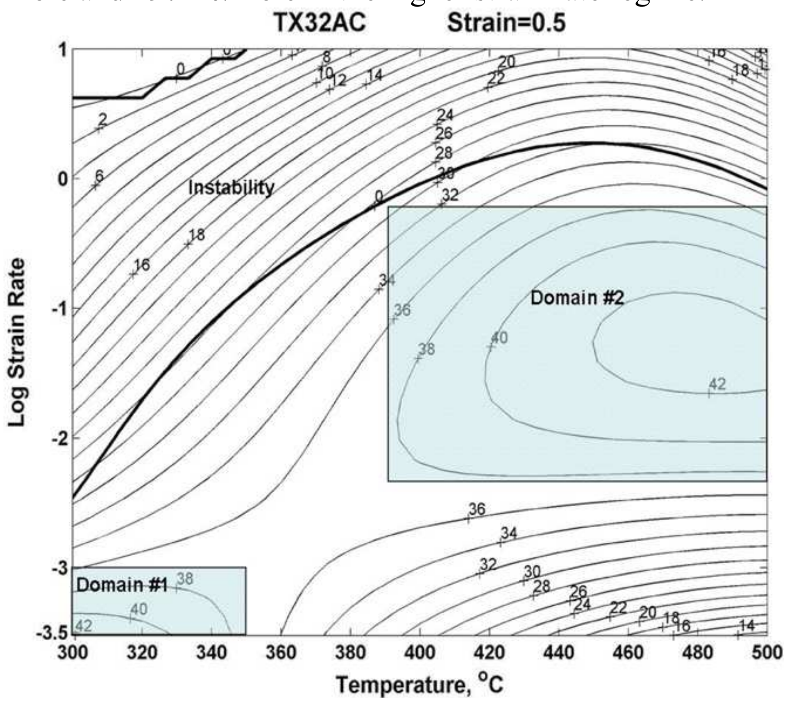

Fig. 1: Processing map for Mg–3Sn–2Ca alloy.

Texture Evolution. Fig. 2 shows pole figures for TX32 alloy in the as-cast condition, and the alloy exhibited near random crystallographic texture. During the room temperature deformation of magnesium, basal slip plays the dominant role as it has the lowest CRSS. If the original grains in the compressed specimens have their basal planes oriented perpendicular to the compression direction, crystallographic orientation in that position is unfavourable for basal slip. Fig. 3 shows pole figures for the specimens from domain #1 for the deformation conditions 300 °C/0.0003 s^{-1} (Fig. 3a) and 350 °C/0.0003 s^{-1} (Fig. 3b). From the pole figure of (0001) in Fig. 3(a), it can be noticed that maximum intensity of basal poles is located at about 30-40° to the compression direction. This crystallographic orientation favours basal slip. The maximum Schmid factor for basal slip system for both these conditions is about 0.43 which suggests that basal slip is predominant here. The other slip systems were also found activated at these conditions. As the temperature is increased to 350 ˚C, the basal poles are spread out towards the compression axis and $(10\bar{1}0)$ poles are normal to the compression axis. This occurrence suggests that both of basal and prismatic slip have increased.

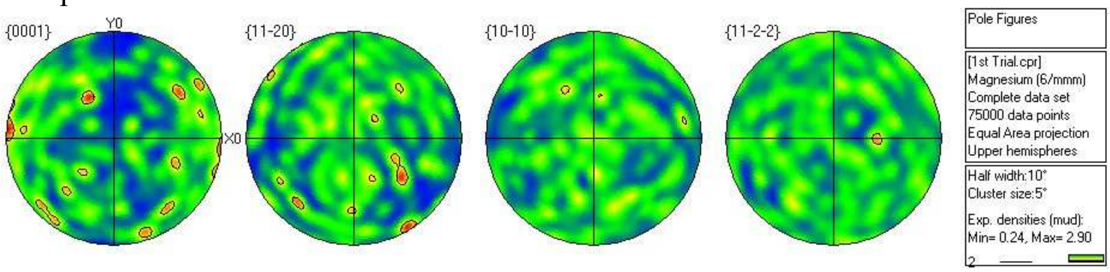

Fig. 2: Pole figures corresponding to Mg-3Sn-2Ca (TX32 alloy) in as-cast condition.

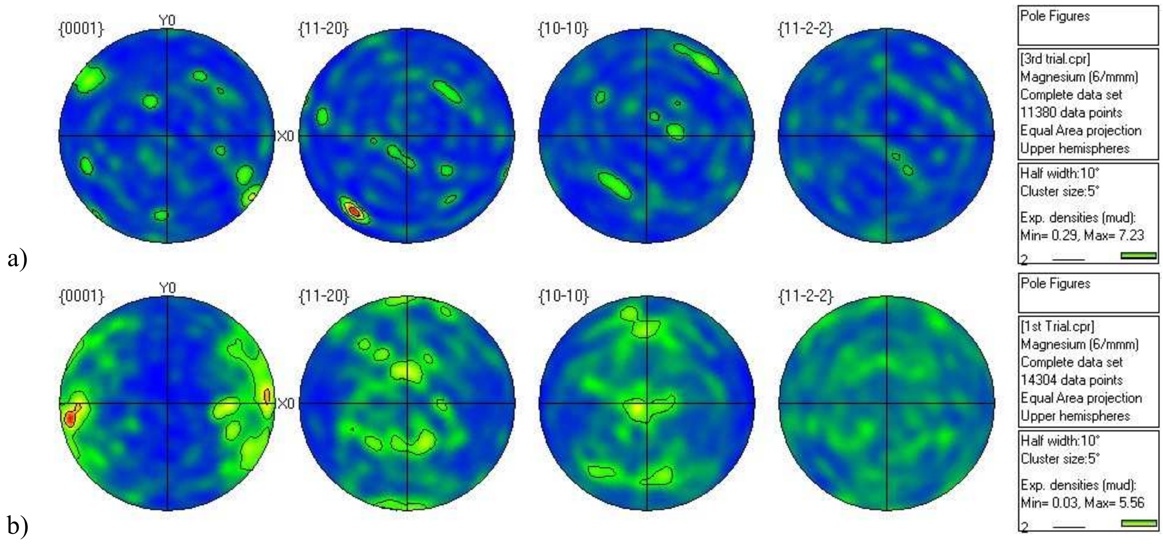

Fig. 3: Pole figures corresponding to (a) 300 ˚C/0.0003 s^{-1}, (b) 350 ˚C/0.0003 s^{-1} (domain #1).

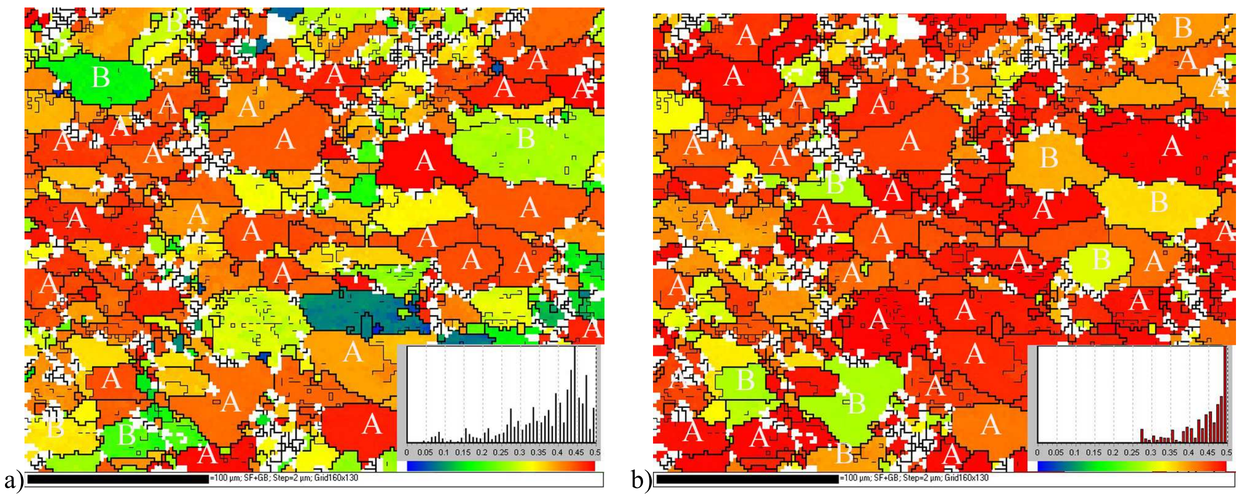

Fig. 4. EBSD Schmid factor distribution maps obtained for the sample deformed at 450 ˚C/0.1 s^{-1} — (a) (0001) <$11\bar{2}0$> basal slip (b) ($11\bar{2}2$) <$11\bar{2}3$> second order pyramidal slip. The red and green colours or dark and light regions marked as A and B represent high to moderate values.

Regarding texture development in domain #2, the EBSD orientation images are given in Fig. 4 for the sample deformed at 450 °C/0.1 s^{-1} with Schmid factor considerations for basal slip system (0001) $\langle 11\bar{2}0\rangle$ (Fig. 4a) and pyramidal slip system $(11\bar{2}2)$ $\langle 11\bar{2}3\rangle$ (Fig. 4b). It can be seen that high to moderate (red and green colours or dark and light regions marked as A and B respectively) values of Schmid factors dominate the entire images, implying favourable conditions for basal and pyramidal slip systems to operate under this deformation condition. Even if the stress level is high enough to initiate the prismatic slip, the CRSS on prismatic planes is practically zero due to new grain orientation. Fig. 5 shows the pole figures for the specimen compressed at 500 °C/0.1 s^{-1}. It can be noted that the texture evolved is weak and may be considered near random. With increase in temperature and strain rate progressively, the texture got randomized due to pyramidal slip activity. It may be noted that under these conditions, cross-slip on the pyramidal systems is favoured due to high stacking fault energy on pyramidal planes [7], which also helps destroying the texture.

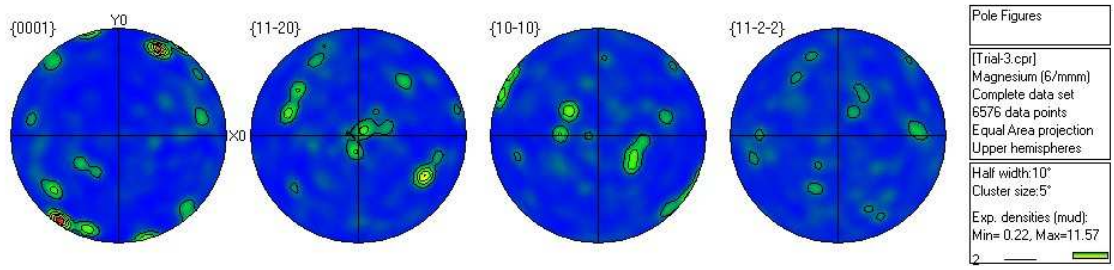

Fig. 5: Pole figures corresponding to deformation condition 500 °C/0.1 s^{-1} (domain #2).

Summary

The effect of deformation conditions at various temperatures and strain rates on the microstructure and texture evolution during hot compression of Mg-3Sn-2Ca (TX32) has been investigated. The better workable conditions were identified by using processing map. In the domain #1 samples (300 °C/0.0003 s^{-1} and 350 °C/0.0003 s^{-1}), deformation took place by the activation of all slip systems. The contribution of second order pyramidal slip has increased significantly with increase in deformation temperature. Basal texture was randomized at high temperature (450 °C, 500 °C) and at high strain rate (0.1 s^{-1}). All the three slip systems $\langle a \rangle$ basal, $\langle a \rangle$ prismatic, $\langle c + a \rangle$ pyramidal were activated at high temperatures for the accommodation of deformation.

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