Achievements in Mechanical and Materials Engineering

COMMENT Worldwide Congress on Materials and Manufacturing Engineering and Technology
16th - 19th May 2005
Gliwice-Wisła, Poland

COMMITTEE OF MATERIALS SCIENCE OF THE POLISH ACADEMY OF SCIENCES, KATOWICE, POLAND
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE, POLAND
ASSOCIATION OF THE ALUMNI OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, MATERIALS ENGINEERING CIRCLE, GLIWICE, POLAND

13th INTERNATIONAL SCIENTIFIC CONFERENCE ON ACHIEVEMENTS IN MECHANICAL AND MATERIALS ENGINEERING

Compressive deformation behaviour of magnesium alloys

Z. Trojanová, P. Lukáč

Charles University, Faculty of Mathematics and Physics, Department of Metal Physics, Ke Karlovu 5, CZ 12116 Praha 2, Czech Republic, lukac@met.mff.cuni.cz, ztrojan@met.mff.cuni.cz

Abstract. The compressive deformation behaviour of magnesium alloys AE42 and AS21 has been studied. The alloys were tested in the temperature range 20-300 °C. The differences in the deformation behaviour of the alloys are discussed in terms of hardening and softening processes. Non-dislocation obstacles and forest dislocations are considered as the main obstacles for the moving dislocations, hence, responsible for hardening. Cross slip and climb of dislocations may control softening at higher temperatures.

Keywords: Deformation behaviour; Mechanical properties; Magnesium alloys;

1. INTRODUCTION

Lightweight materials are attractive for many applications. Although aluminium based alloys are used for a considerable number of components, the used of magnesium alloys, which are structural materials with lowest density, is limited. Recent research on both types of alloys has been focused on the deformation behaviour of the alloys. The magnesium-based alloys exhibit a high specific strength, i.e. the ratio of the yield stress (hardness) to the density at room temperature. The strength of Mg alloys decreases very rapidly with increasing temperature. On the other hand, magnesium alloys have a poor ductility, especially at room temperature. Usually, the ductility of magnesium alloys increases with increasing temperature. The use of equal channel angle pressing (ECAP) may improve the mechanical properties: an increase in the strength at 23 and 100°C and an increase in the ductility at temperatures between 23 and 300°C as was found for AZ91 magnesium alloy (e.g. [1]). Magnesium-based alloys possess a low corrosion resistance and low resistance to creep. Aune and Westengen [2] have reported that Mg-Al-Si (AS41 and AS21) and Mg-Al-RE (AE41 and AE42) alloys exhibit a major improvement in creep resistance due to a suppression of the formation of the $Mg_{17}Al_{12}$ phase.

The testing temperature influences significantly their deformation behaviour. In contrast to aluminium alloys, limited information are available on the deformation behaviour of magnesium alloys at elevated temperatures, i.e. above room temperature. The room temperature, (295 K = 0.32T_M, where T_M is the absolute melting temperature), is a high temperature. The differences in the deformation behaviour of aluminium and magnesium alloys are influenced by the limited crystallographic same slip systems in the hcp structure.

As known, homogeneous deformation of polycrystals is possible, if five independent slip systems are active. The dominant slip system in magnesium and magnesium alloys at room temperature is the basal one. The number of independent mode of the basal slip is only two, which is not sufficient for the satisfying of the von Mises criterion [3]. Thus, to fulfil von Mises [3] criterion, a non basal slip system should be active. The activity of a slip system depends on the critical resolved shear stress (CRSS); the activity of a non basal slip system requires a high stress. The critical resolved shear stresses for the non basal slip systems of Mg and its alloys depend very significantly on the testing temperature. It decreases rapidly with increasing temperature.
The aim of present paper is to give an information on the deformation behaviour of two magnesium alloys, to estimate the temperature variation of the yield stress as well as the maximum stress and to discuss possible hardening and softening mechanisms. Uniaxial compression tests are carried out.

2. EXPERIMENTAL

The materials used in this study are two magnesium alloys: AE42 (4 Al, 2 Nd) and AS21 (2 Al, 1 Si). The alloys exhibit a hexagonal close-packed structure. The alloys were squeeze cast. Tests specimens were machined from the bars and they had a rectangular section of 6x6 mm^2 and a gauge length of 12 mm.

Compression tests were performed in an Instron machine in the temperature range from 20 to 300 °C with a constant crosshead speed giving an initial strain rate of $1.33x10^{-4}$ s^{-1}. The yield stress, σ_{02}, was estimated as the flow stress at 0.2% offset strain and the maximum stress, σ_{max}, as the maximum value of the flow stress.

3. EXPERIMENTAL RESULTS

The true stress- true strain curves for AE42 magnesium alloy are plotted in Fig. 1. The temperature dependences of the yield stress and the maximum stress are shown in Fig. 2. It can be seen a significant influence of the testing temperature on the deformation behaviour. The values of the flow stress, the yield stress and the maximum stress decreases with

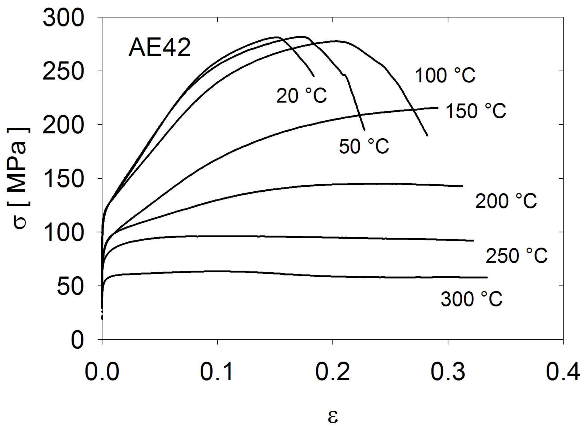

Figure 1. True stress-true strain curves obtained for AE42 alloy and various temperatures

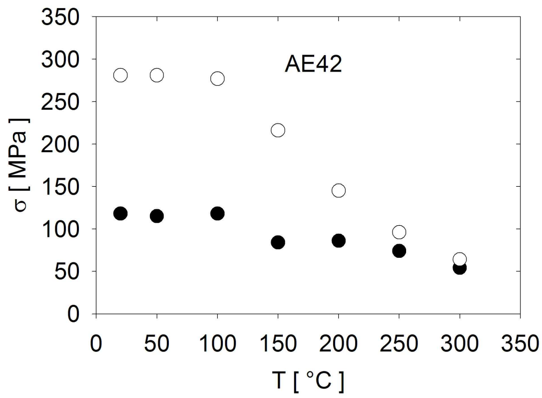

Figure 2. Temperature dependence of the yield stress and the maximum stress for AE42 alloy.

increasing temperature. The values of the yield stress as well as the maximum stress of AE42 at selected temperatures are lower than those of the AZ91 alloy. A dynamic equilibrium between hardening and softening of the AE42 alloy begins at a temperature of about 250°C, which can also be seen from the plots of the yield stress and maximum stress against the testing temperature (Fig. 2).

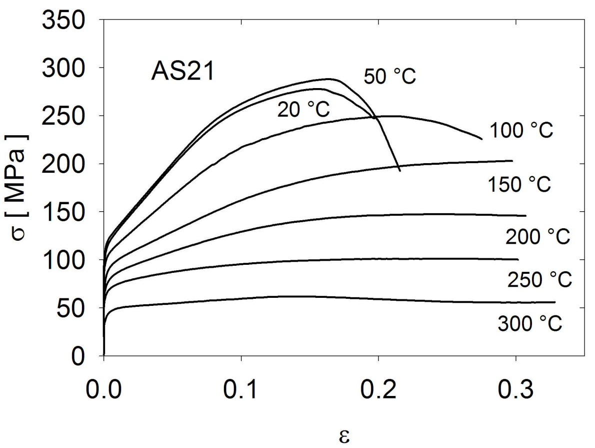

Figure 3. True stress-true strain curves obtained for AS21 alloy and various temperatures

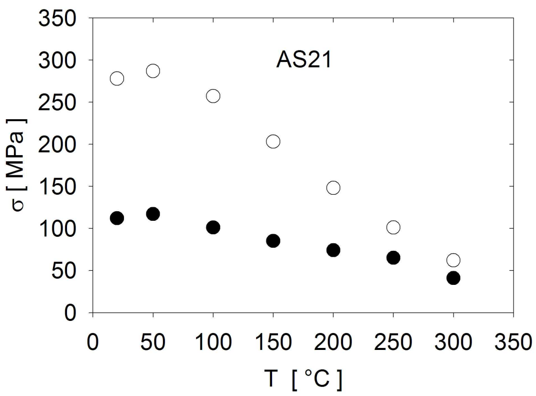

Figure 4. Temperature dependence of the yield stress and the maximum stress for AS21 alloy

Figure 3 shows the true stress-true strain curves of AS21 alloy for various testing temperatures. The influence of temperature on the course of the deformation curves of AS21 alloy is very similar to that observed for AE42 alloy. The values of the yield stress as well as the maximum stress of AS21 alloy and their variation with temperature (Fig. 4) are very close to those obtained for AE42 alloy.

4. DISCUSSION

It is evident that the shape of the stress-strain curves changes at certain temperatures. Above this temperature, the work hardening rate of the deformed specimens is very close to zero. The changes in the shape of the deformation behaviour indicate the activity of some softening processes.

As mention above, the activity of five independent slip systems is required for plastic deformation of polycrystals. In Mg and its alloys, the pyramidal slip systems can be considered. Thus, the von Mises [3] criterion is obeyed. The motion of not only **a** (basal) dislocations but also **c+a** (pyramidal) dislocations is assumed. Different dislocation reactions may occur [4]. One type of dislocation reactions may produce obstacles. Other can result in softening [4]. Screw components of dislocations can cross slip and then annihilate.

The flow stress, σ, of alloys depends on the average dislocation density, ρ, as

$$\sigma = \sigma_y + \alpha G b \rho^{1/2} \tag{1}$$

where σ_y is the yield stress and it is a function of the concentration of solute atoms, grain size, precipitates and temperature, α is a constant, G is the shear modulus and b is the magnitude of the Burgers vector. The change of the flow stress with strain is characterized by the work hardening rate $\Theta = \partial\sigma/\partial\varepsilon$, which decreases with strain.

In the alloys investigated, there are obstacles non-dislocation types such as precipitates and the dislocation obstacles (forest dislocations). Processes such as cross slip and climb of dislocations contribute to softening. For the sake of simplicity, the total dislocation density will be considered as the characteristic parameter of the evolution of microstructure. According to the model of Lukáč and Balík [5], the evolution equation has the following form

$$(\partial\rho/\partial\varepsilon) = K_1 + K_2\rho^{1/2} - K_3\rho - K_4\rho^{3/2}. \qquad (2)$$

Here $K_1 = 1/s$, s is the spacing between impenetrable (non-dislocation) obstacles, K_2 is a coefficient of the dislocation multiplication intensity due to interaction with forest dislocations, K_3 and K_4 are coefficients of dislocation recovery intensity due to the cross slip and climb of dislocations, respectively. The stress dependence of the work hardening rate for polycrystals can thus be expressed in the following form

$$\Theta = A/(\sigma-\sigma_y) + B - C(\sigma-\sigma_y) - D(\sigma-\sigma)^3 \qquad (3)$$

The parameter A is connected with the interaction of dislocations with the non-dislocation obstacles. The parameter B relates to the work hardening due to the interaction with the forest dislocations. Both parameter A and B do not change with temperature, except at higher temperatures, when the activity of non basal slip may change the forest dislocation density. The parameter C relates to recovery due to cross slip. The parameter D is connected with a local climb of dislocation. and should also increase with temperature. It is evident that the activity of non basal slip system increases with increasing temperature. At higher temperatures, cross slip becomes a significant recovery process responsible for softening. The work hardening rate should decrease, which is observed experimentally. To the decrease in the work hardening rate may contribute the B parameter decreasing with temperature.

5. CONCLUSIONS

The true stress-true strain curves of magnesium alloys indicates that the deformation behaviour of the alloys depends significantly on temperature. Above a certain temperature, softening processes influence the course of the work hardening curve causing the differences in the deformation behaviour.

ACKNOWLEDGEMENTS

The authors appreciate support from the Grant Agency of the Academy of Sciences of the Czech Republic under Grant Number A2112303 and the Grant Agency of the Czech Republic (Grant Number 106/03/0843).

REFERENCES

1. K. Máthis, A. Mussi, Z. Trojanová, P. Lukáč and E. Rauch, Kovove Mater., 41 (2003) 293.
2. T. K. Aune and H. Westengen, SAE Technical Paper No 950424, Detroit, Michigan, (1995).
3. R. von Mises: Z. Angew. Math. Mech., 8 (1928) 161.
4. P. Lukáč and K. Máthis, Kovove Mater., 40 (2002) 281.
5. P. Lukáč and J. Balík, Key Eng. Mater., 97-98 (1994) 307.