Achievements in Mechanical and Materials Engineering

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

Mechanical properties of an AS21 alloy reinforced by short Saffil fibres and SiC particles

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Abstract: The high temperature behaviour of composites with the AS21 magnesium alloy matrix, reinforced with short Saffil fibres and SiC particles were investigated in the temperature range from room temperature to 300°C. The yield stress and the maximum stress decrease with increasing temperature. Two types of specimens were investigated – one with fibres plane oriented parallel to the stress axis and the other with perpendicular fibres plane orientation. Possible hardening and softening mechanisms are discussed. The shear stress at reinforcing phase/matrix interfaces was of greatest importance in this regard, though the contribution resulting from the dislocation density increase was also significant.

Keywords: Magnesium alloys; Composites; Mechanical properties; Hardening; Softening;

1. INTRODUCTION

Light alloys reinforced with short fibres or particles allow adapting more exactly the work piece material properties to requirements. There is an increasing trend in the automotive industry to use these materials for various parts. Magnesium matrix composites show better wear resistance, enhanced strength and creep resistance and keep low density and good machinability [1]. Investigations of mechanical and physical properties of light metals composites (among them magnesium alloys based composites) is important not only for applications but also for better understanding of the processes responsible for their behaviour. The objectives of the present paper are to study the deformation behaviour of the AS21 alloy based hybrid composite and to discuss possible contribution of Saffil fibres and SiC particles to strengthening as well as softening of these materials.

2. EXPERIMENTAL PROCEDURE

Commercial AS21 (2.2Al-1Si-0.1Mn-balance Mg-in wt%) alloy was used as the matrix material. Composites with 30 vol.% short fibres of δ-Al_2O_3 (Saffil®) (hereafter AS21(f)) and hybrid composites with 5 vol.% of Saffil short fibres and 15 vol.% of SiC particles (AS21(f+p)) were used in this study. Composites were prepared by squeeze casting technique. The performs consisted of planar randomly distributed Saffil fibres with equiaxial SiC particles. Characteristic feature of the matrix microstructure is the Mg_2Si phase having a characteristic Chinese-script form [2]. Samples used in this study exhibited two orientations of the fibres plane – perpendicular and parallel to the specimen longitudinal axis (the stress axis).

The mean fibre length and fibre diameter were ~78 μm and ~3 μm, respectively. Compression tests were carried out at temperatures between room temperature and 300 °C using an INSTRON testing machine. Specimens (5x5x10 mm^3) were deformed with an initial strain rate of 2.7×10^{-4} s^{-1}. The temperature in the furnace was kept with an accuracy of ±1°C.

3. EXPERIMENTAL RESULTS

Figure 1 shows the true stress-true strain curves obtained for AS21 hybrid composite with the fibres plane parallel to the stress axis, deformed at various temperatures. Samples were deformed either to fracture or at higher temperatures to predetermined strains.

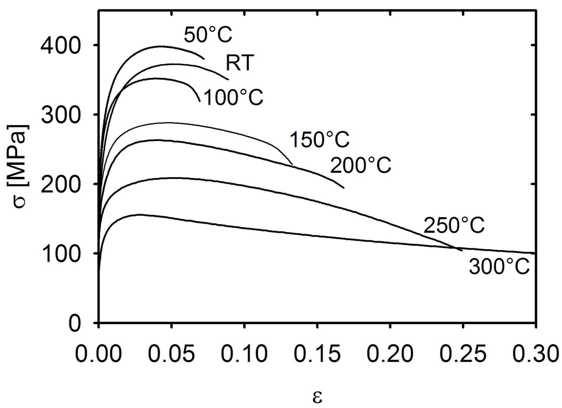

Figure 1. Stress strain curves obtained for ∥ orientation and various temperatures.

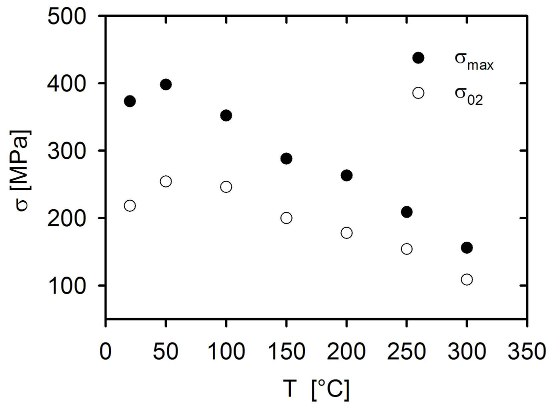

Figure 2.: Temperature dependences of characteristic stresses for ∥ orientation.

Similar experiments were performed for samples with the perpendicular orientation of the fibres plane. The stress-strain curves obtained at various temperatures of composite with perpendicular orientation of the fibres plane (⊥ orientation) are introduced in Figure 3. The temperature dependence of the characteristic stresses measured for perpendicular orientation of the fibres plane is shown in Figure 4.

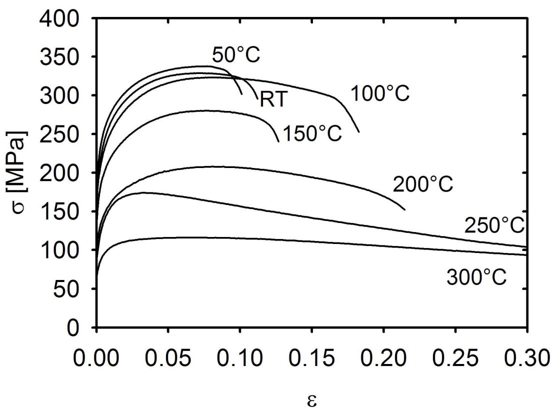

Figure 3. Stress-strain curves for samples in ⊥ orientation obtained at various temperatures.

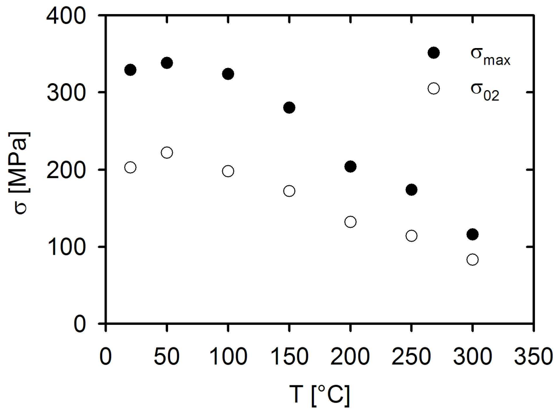

Figure 4. Temperature dependences of characteristic stresses for samples in ⊥ orientation

The yield stress exhibits a local maximum at 50°C for hybrid composite || as well as for hybrid ⊥. Such small local maximum in the temperature dependence of the yield stress was observed also in other magnesium alloys (AZ91, LA45) [3-5]. This local maximum in the temperature dependence of the yield stress is very probably a result of the dynamic strain ageing phenomenon, where mobile solute atoms interact with dislocations. The AS21 hybrid exhibits lower ductility than monolithic AS21 alloy (matrix of investigated materials [6].

4. DISCUSSION

Trojanová et al. [7] discussed various strengthening mechanisms in Mg alloys based composites. The most important contributions were found to be the load transfer from the matrix to the fibres and the influence of the increased dislocation density arising from internal thermal stresses. Other possible mechanisms do not influence the level of deformation stresses by a significant manner. The load transfer from the matrix to the fibres can be described by the shear lag theory [8], which assumes that the load transfer occurs between a high aspect ratio reinforcement and the matrix by means of shear stress at the interface between fibres and matrix. A contribution to the yield stress is than done by following equation:

$$\Delta\sigma_{LT} = \sigma_m\left[1+\frac{(L+t)A}{4L}\right]f + \sigma_m(1-f) \tag{1}$$

where $\Delta\sigma_{LT}$ is the contribution to the yield stress, σ_m is the yield stress in the matrix, L is the fibre length in the stress direction, t is the fibre diameter in the perpendicular direction, A is equal to L/t, f is the volume fraction of reinforcing fibres in the matrix. From the equation (1), it follows that possible influence of particles (with the same volume fraction) may be weaker due to low value of the aspect ratio A. It is probably reason why the stress increase in the composite reinforced only by short fibres is higher compared with the hybrid composite (Saffil fibres and SiC particles).

Typical great difference between the coefficient of thermal expansion (CTE) of the matrix and ceramic reinforcement $\Delta\alpha$ is very important factor in composites with a metallic matrix. CTE of a ceramic reinforcement is smaller than that of most metallic matrices. When the metal matrix composite is cooled from a higher temperature to room temperature, misfit strains occur because of differential thermal contraction at the interface. Thermal stresses may be sufficient to generate new dislocations at the interfaces between the matrix and the reinforcements. Therefore, after cooling the composite, the dislocation density in the matrix increases. This increase in the dislocation density near reinforcement fibres can be calculated as [9]:

$$\Delta\rho = \frac{Bf\,\Delta\alpha\Delta T}{b(1-f)}\,\frac{1}{t}, \tag{2}$$

where t is its minimum size of the reinforcing phase particles or fibres, b is the magnitude of the Burgers vector of the newly created dislocations, B is a geometrical constant, $\Delta\alpha\Delta T$ is the thermal strain. When the thermal stresses achieves the yield stress, plastic zones can be formed in the matrix near to the interfaces, especially, in the vicinity of fibre ends. The generation of thermally induced dislocations and the related dislocations density gradients increase also the yield stress of the composite according to the well-known relationship:

$$\Delta\sigma_{CTE} = \alpha_1\psi Gb(\Delta\rho)^{1/2}, \tag{3}$$

where α_1 is a constant, ψ is the Taylor factor and G is the shear modulus. This high matrix dislocation density as well as the reinforcement/matrix interfaces can provide high diffusivity path in a composite.

Observed steady state character of the stress strain curves, obtained at elevated temperatures, where maximum stress was achieved already at lower strain and subsequent stress is constant or decreases, indicates an effect of some recovery mechanism/-s. Cross slip in prismatic or pyramidal planes is very probably the main recovery mechanism. These mechanisms are strongly thermally activated. Increased activity of non-basal slip systems with <c+a> dislocations at higher temperatures provides explanation for observed decrease of the flow stress. The cross slip as well as the subsequent annihilation of dislocations results in a decrease in the work hardening rate. Plastic deformation in a composite begins by developing of the strain in the vicinity of fibres, where dislocation density is higher than elsewhere in the matrix. Dislocations cannot pass through the fibers without cutting them or leaving loops around fibers. This passing mechanism is similar to the Orowan mechanism and it is also athermal. Dislocations pile-ups behind of the fibres can act as stress concentrators. Screw dislocation components locally cross slip, forming superjogs having a height of about fibre diameter and at higher temperatures edge components are able to climb. Both may then annihilate in neighbouring slip planes. Possible annihilation of dislocations may be also support by the interfacial diffusion of vacancies in the thin layer at the matrix-fibre interface [10].

5. CONCLUSIONS

Parallel orientation of the fibres plane in hybrid composites increased the characteristic stresses. This fibres and particles impact decreases with increasing temperature. Main hardening mechanism in hybrid composite is probably the load transfer in which the part of the external load within the matrix is transferred to the reinforcement. Increased dislocation density plays also an important role. The cross slip and subsequent annihilation of dislocations cause very probably softening in the matrix. Local climb of dislocations in the vicinity of fibres supported by interfacial diffusion is probably important recovery mechanism.

ACKNOWLEDGEMENTS

This investigation was financially supported by the Grant Agency of the Academy of Sciences of the Czech Republic (Grant No. A2041203) and the Grant Agency of the Czech Republic (Grant No. 106/03/0901).

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