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Creep of AZ31 Mg alloy: A comparison of impression and tensile behavior

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ABSTRACT

Creep behavior of AZ31 magnesium alloy was investigated in temperature range of 423–498 K by the localized impression creep and the conventional tensile creep testing methods, in order to evaluate the correspondence of the creep results obtained by these two testing techniques. Impression creep tests were conducted under punch stresses in the range of 125–600 MPa, while tensile creep tests were performed under tensile stresses in the range 35–140 MPa. According to the obtained results, the creep behavior could be divided into two stress regimes with different stress exponents and activation energy values. Based on the steady-state power-law creep relationship, the average stress exponents of about 3 and 6 were, respectively, obtained at the low- and high-stress regimes in both impression and tensile creep tests. The respective average impression creep activation energies of 96.9 and 139.2 kJ/mol, at the low- and high-stress regimes, were close to 93.8 and 126.6 kJ/mol determined in the tensile creep tests. Based on the obtained stress exponents and activation energies, it is suggested that the dominant creep mechanism is pipe-diffusion-controlled dislocation viscous glide in the low-stress regime, and dislocation climb in the high-stress regime. The achievement of similar creep characteristics in the employed tests implies that the localized impression creep test is capable of acquiring reliable information on the creep behavior of the present wrought Mg alloy.

1. Introduction

Magnesium alloys have received great attention especially in the automobile industry in recent years. This is mainly due to the increasing demand for weight savings, which can be offered by Mg alloys with high specific strength and low density. Among cast magnesium alloys, those based on the Mg–Al system are more attractive because of a combination of mechanical properties, corrosion resistance and castability [1,2]. On the other hand, wrought alloys are generally preferred over cast ones, since better mechanical properties can be obtained compared to the cast alloys [3]. One of the most commonly used wrought magnesium alloys is the Mg–Al–Zn base AZ31, which has reasonable formability and strength at moderate temperatures [4].

Although most of the research work on the creep of Mg alloys is focused on the cast alloys, wrought alloys have recently received some attention due to their possible application in structural parts working at elevated temperatures [5,6]. Researches on creep deformation mechanism of AZ31 have shown that, depending on the applied stress level, creep behavior of the material can be divided into two regimes. At low stress levels ($\sigma/G < 4 \times 10^{-3}$), deformation could be well described by solute drag creep, while at high stresses ($\sigma/G > 4 \times 10^{-3}$), deformation is characterized by dislocation climb creep associated with pipe diffusion or lattice diffusion [7]. Somekawa et al. [8] studied tensile creep of the coarse-grained AZ31 and other Mg–Al–Zn alloys in the temperature range 473–623 K. At high temperatures, the stress exponent was five and the activation energy of 126–132 kJ/mol was close to that for lattice diffusion of magnesium, whereas at low temperatures, the stress exponent was seven and the activation energy of 94–102 kJ/mol was close to that for pipe diffusion for all alloys. They suggested that the climb-controlled dislocation creep was governed by pipe diffusion at low temperatures and by lattice diffusion at high temperatures in these alloys.

Although there are many reports on creep of AZ31 alloy, almost all of them have used conventional tensile creep tests for the evaluation of creep properties. Only recently, Kim has studied the correlation between the impression and double shear creep of AZ31 magnesium alloy [9]. It is thus the aim of this study is to investigate the creep properties of the AZ31 alloy by means of the localized impression creep technique and compare the results with those obtained by the tensile creep test. Impression creep technique is a modified version of indentation creep test, in which a flat-bottomed cylindrical punch is pushed into test specimen under an applied load and the depth of penetration is recorded as a function of time. In contrast to the conventional testes which require large specimens, in this method all mechanical data can be obtained from small volumes of material. Another

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advantage of this kind of test is that a constant stress can be attained during the entire creep test period. The impression creep test has recently been employed for the creep study of some cast magnesium alloys [10–14]. This test has proved to yield very similar stress exponent and activation energy values to those obtained by the conventional creep tests [15–17].

2. Experimental procedures

2.1. Materials and processing

The material used was a commercial AZ31 (Mg–3 wt% Al–1 wt% Zn–0.3 wt% Mn) sheet with a nominal thickness of 2.5 mm. The as received sheets were annealed at 623 K for 30 min to create a stable microstructure for creep testing at temperatures as high as 498 K. The annealed sheets were then cut into 10 mm × 10 mm × 2.5 mm pieces for impression testing.

2.2. Impression creep tests

The details of the impression creep testing arrangement are explained elsewhere [18] and will only be briefly described here. These tests were performed using a SANTAM universal testing machine equipped with a three-zone split furnace to carry out constant-load impression tests in the air atmosphere. A flat-ended cylindrical punch of 2 mm diameter was mounted in a holder positioned in the center of the vertical loading bar. The 2.5-mm-thick specimen was located on a stand below the loading bar, and the assembly of the specimen and indenter was accommodated by the furnace. Impression creep tests were performed on each sample in the temperature range 423–498 K, corresponding to $0.46 < T/T_m < 0.54$ and under punch stresses in the range 125–600 MPa for dwell times up to 3600 s. After application of the load, the impression depth was measured automatically as a function of time by the machine; the data were acquired by a computer. Using this configuration, it was possible to control the load with the accuracy of ±1 N, and to record the impression depth with the resolution of ±0.001 mm.

2.3. Tensile creep tests

Tensile specimens were taken along the rolling direction. The parallel gage length was 28 mm long and 6.5 mm wide. Tensile creep tests were carried out using the same tensile testing machine and furnace configurations employed for impression tests. The specimens were fixed in the high temperature tensile fixtures, and the assembly required 20 min to equilibrate at the testing temperature prior to the initiation of loading. The conventional tensile creep tests were then conducted in temperature range of 423–498 K and under tensile stress in the range of 35–140 MPa for dwell times up to 20 h. Extension–time curves were obtained over the whole gage length, from which the true strains were calculated and strain–time curves were produced. Having the initial dimensions of the samples (L_0 and A_0), the recorded displacement (ΔL) was converted to true strain (ε) through the basic formula, $\varepsilon = \ln(1 + \Delta L/L_0)$. The initial true stress was calculated from $\sigma = (F/A_0)(1 + \Delta L/L_0)$.

3. Results and discussion

The impression creep behavior of the material was carried out by testing the alloy under the stress in the range 120–600 MPa, and in the temperature range of 423–498 K. Typical impression creep curves obtained by plotting impression depth against dwell time at the test temperatures of 448 K and 498 K are shown in Fig. 1a and b, respectively. These curves indicate that increasing stress at a constant temperature results in higher penetration rates. Furthermore, it is observed that after a rather short primary creep stage almost all of the curves exhibit a secondary-state region, in which the depth increases linearly with time. Since the impression creep test is compressive in nature, necking and fracture of the specimen do not occur, and thus, it is not possible to record a third stage of the curve, as would be possible in conventional tensile creep testing. To be sure about the reproducibility of the impression creep data, at least three separate tests were taken at random places on the surface of the specimens for each condition and the creep curves were almost the same. This may reflect the structural homogeneity of the industrially processes sheets that results in the impression creep data with a high level of reliability.

The creep strain–time results obtained from specimens tested at 448 K and 498 K under different constant tensile loads are shown in Fig. 2. Although all of the curves are not plotted up to the occurrence of fracture, typical creep stages are observed for some cases at lower stress levels. Similar to the impression creep, with increasing the applied stress and/or temperature, the secondary-state region becomes shorter and creep fracture occurs more readily. From the creep curves, the minimum creep rates were obtained by plotting creep rate versus impression depth and creep strain for the impression and tensile tests, respectively. Fig. 3a and b, respectively, shows such plots obtained under a punch stress of 200 MPa and tensile stress of 65 MPa at three investigated test temperatures of 448, 473, and 498 K. As can be seen in Fig. 3a, there is a steep drop in the impression creep rate

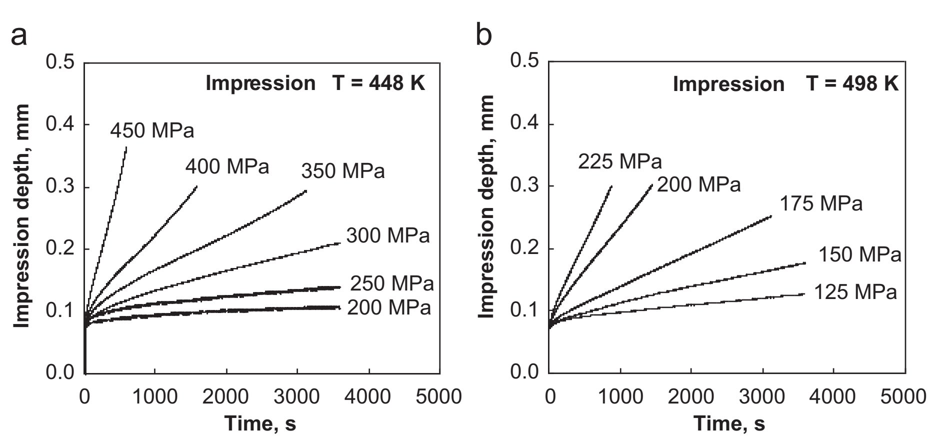

Fig. 1. Impression creep curves expressed as impression depth against dwell time obtained at: (a) 448 and (b) 498 K.