

Impression Creep of Lightweight Alloys

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ABSTRACT

Conventional creep testing requires many samples and therefore is time consuming and inconvenient. The impression creep technique is a new creep test wherein a cylindrical, flat-tipped punch is pressed into the material and the displacement recorded as a function of time. Due to the constant contact area between the punch and specimen, a steady-state deformation can be reached underneath the punch, from which the creep parameters can be obtained. In the present study, the creep behaviors of two lightweight magnesium alloys were studied by using impression creep tests in the temperature range of 408-443K and under the punching stress range of 1.68-60.4MPa. Using a power law between the steady-state impression velocity and the punching stress, it was found that the stress exponent changes with both stress and temperature. In the high temperature range, the stress exponent n for MRI 230 is ~ 6.7 while for AZ91D is ~ 5.5 . The activation energy for MRI 230 is 78.9 kJ/mol and for AZ91D is 59.5 kJ/mol.

INTRODUCTION

On account of their low densities, the lightweight alloys (aluminum and magnesium) have been used increasingly in automotive applications. One issue in the application of lightweight alloys is related to the creep resistance at elevated temperatures. The creep deformation of aluminum and magnesium alloys has been conventionally studied by using the tensile tests, in which the steady-state creep rate $\dot{\epsilon}$ was related to the tensile stress and temperature through the Norton power law:

$$\dot{\epsilon} = A\sigma^n \exp\left(\frac{-Q}{RT}\right) \quad (1)$$

where A is a constant, σ is the tensile stress, n is the stress exponent, Q is the activation energy, R is the gas constant and T is the absolute temperature.

Different techniques have been used to study the creep deformation of materials, including tensile creep, compressive creep, and impression creep. In the impression creep as introduced by Li and co-workers [1,2,3], a flat-ended cylindrical punch is pushed onto a material under a constant load. During the test, the contact area between the punch and the sample remains the same and a constant punching stress (the normal load divided by the cross-sectional area of the punch) is obtained. The impression technique has been used to study the creep behavior of metallic materials [4,5,6,7,8,9,10,11,12], polymers [13,14,15,16], and amorphous material [17]. The advantage of using the impression technique includes that multiple impression tests can be made on one sample of small size, which reduces microstructural variation and offers a simple and inexpensive way for the preparation of samples.

The purpose of this work is to study the creep deformation of lightweight magnesium alloys by using the impression technique. The impression tests were performed at different temperatures and punching stresses. The dependence of the steady state impression velocity on the punching stress is analyzed using the power law relation, from which the creep coefficients are estimated.

EXPERIMENTAL PROCEDURE

The materials tested included two magnesium alloys: MRI 230 and AZ91D. The samples were ground and polished with up to 4000 grid WC grinding paper and 0.05 micron alumina powder. The impression creep tests were then performed on the polished specimens. The RSA III (Rheometric Solids Analyzer, Rheometric Scientific Inc. Piscataway, NJ) was modified to perform the impression creep test. The flat-ended

cylindrical punch of 0.3 mm in diameter was made of stainless steel. Before performing the impression test on the specimen, the temperature of the chamber in the RSA III was raised to the desired temperature and stabilized for at least 30 min. Then the sample stage was lifted slowly to be in touch with the punch until the prescribed load was applied to the indenter. After some transient period, a steady state impressing velocity was observed similar to the tensile creep test. During the test, the impression depth was measured continuously by an LVDT with a resolution of 0.5 μm . The tests were conducted over a temperature range from 408 to 443 K under the impression stress from 250 to 381 MPa. The time dependent penetration depth was recorded for further analysis.

RESULTS AND DISCUSSION

IMPRESSION CREEP CURVES

During the impression creep test, the load applied to the punch was maintained as a constant. For a constant cross-sectional area of the punch, the punching stress remained as a constant. Figures 1 and 2 show the impression creep curves of MRI 230 and AZ91D at different impression stresses. Figures 3 and 4 show the impression creep curves of MRI 230 and AZ91D at different temperatures. Similar to the compression creep, the creep deformation can be divided into two stages: (1) transient and (2) steady state. The transient stage is controlled by the system compliance and elastoplastic behavior of the materials, which depend on the load and temperature as shown in Figs. 1, 2, 3, 4. In the steady state, the elastic deformation has no effect on the creep behavior, and the impression depth is a linear function of the impression time. The impression velocity can be calculated from the slope of the steady state. This impression velocity V is correlated with the strain rate $\dot{\epsilon}$ in conventional creep test that $\dot{\epsilon} = V/d$, where d is the diameter of the impression punch.

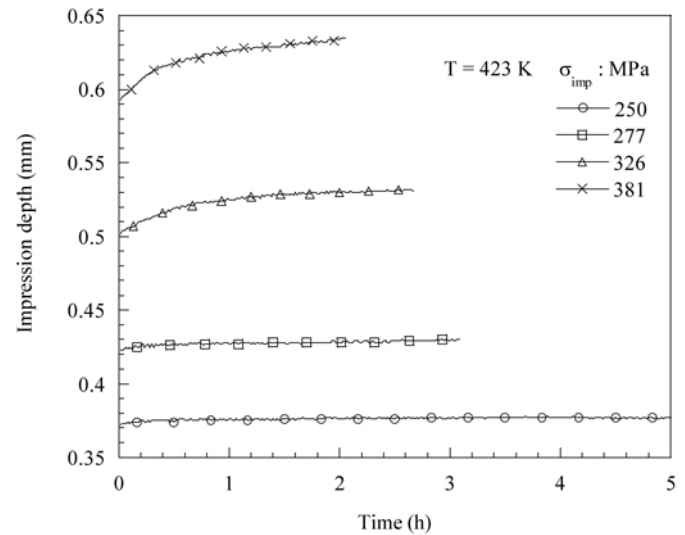


Figure 1. Impression curves of MRI 230 under different impression stresses at 423 K

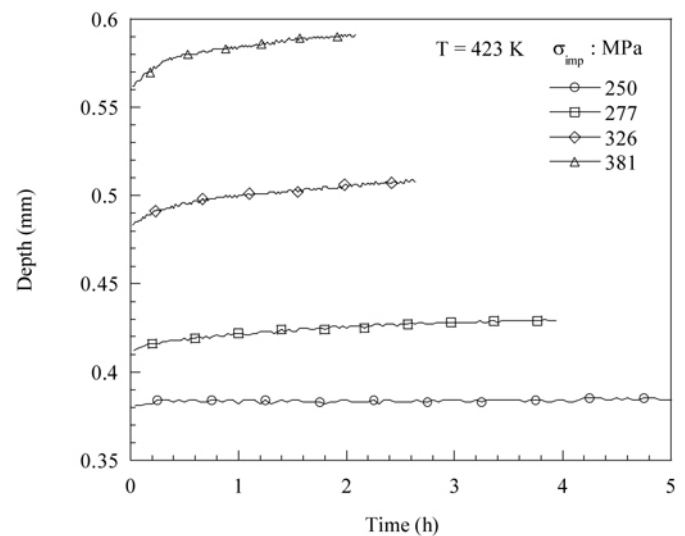


Figure 2. Impression curves of AZ91D under different impression stresses at 423 K.