DETERMINING OF FLOW CURVE OF MAGNESIUM AZ61 ALLOY USING RING TEST

[1]FARZAN BARATI, [2]EHSAN BARAT

[1,2]Department of Mechanical Engineering, Islamic Azad University, Hamedan Branch, Hamedan, Iran
E-mail: [1]farzanbarati@yahoo.com, [2]ehsananbarati@yahoo.com

Abstract- A common method for the determination of flow curves is the application of a compression test. Using this method, friction in the interface between the die and the specimen leads to a bulging of the sample and thereby to an inhomogeneous stress and strain state. The calculation of the flow stress from experimentally determined force–displacement curves implies a uniaxial stress state, but this will produce an error because of the above-mentioned bulging, when friction occurs. One method of avoiding these sources of error is to use the bulge correction factor method, but this method can not cover errors at large strain. Another strategy, described in this paper, applies numerical correction factor method, the calculation of the flow curve being done by the use of an iterative procedure, applying a corrective function. This paper presents a complete characterisation of the AZ61 magnesium alloy flow curve at temperature ranging between 200°C and 240°C . Ring tests are utilised to determine the flow curve sensitivity to temperature and strain rate, and numerical correction factor was employed to reduce errors . By using numerical sigmoid curves more accuracy will be obtained, shown at load-displacement curves.

Keywords- High Temperature, AZ61, Flow Curve, Numerical Method, Ring Test

I. INTRODUCTION

Nowadays, magnesium alloys materials are more and more used in transportation industry in order to reduce the vehicles mass, and thus to minimize air pollution and fuel consumption. The weather changing is pushing the sensibility of the people all over the world towards environmental related topics, which fatally impact also on manufacturing processes. In fact, CO2 emissions reduction constitutes a must in transportation industry and not only. Thus, the investigation on lightweight materials aimed at the knowledge acquisition becomes of dramatic importance. Up to few years ago, magnesim alloys were considered the main candidate materials for reaching the goal of reducing vehicles mass (and thus CO2 emissions and fuel consumption), but, more recently, other interesting materials are becoming industrially suitable [1-2].

Among the light metal alloys, magnesium is the lightest structure material except for beryllium, and therefore, magnesium alloys are quite attractive for structural use in the aerospace and automotive industry. However, these alloys have not seen extensive use due to the high chemical reactivity and excessive oxidation tendency of magnesium during meltingand casting by conventional methods [3-4-5]. Further, lower mechanical strength and poor corrosion resistance of conventionally cast Mg alloys compared with aluminium alloys have also limited their use. Rapid solidification technology offers a possible solution to these problems and therefore has received increasing attention in recent years. Unfortunately, the HCP structure, in which dislocations movement is restricted only to the basal plane, makes magnesium alloys very difficult to deform at room temperature. As a matter of fact, HCP metals do not have enough independent slip systems to deform without extensive occurrence of twinning.[6-7]

On the other hand, formability of magnesium alloys greatly increases at high temperatures. In order to find a good trade-off between formability and processing costs, today it is a common opinion that the best frame to work magnesium alloys is warm forming, with a temperature ranging between 473K and 573K. Technical and scientific literature reports some papers related to magnesium formability in warm conditions. [7-8-9]

The aim of present paper is to obtain flow curve of AZ61 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 ring tests are carried out at three different temperatures and three different strain rates. Also numerical sigmoid curves were used to reduce erros.

II. EXPERIMENTAL

2.1. Material

The alloy used in this study was a commercial AZ31 (Mg–6.17Al–0.72 Zn–0.15Mn–0.05Si in wt.%) test was performed at high temperatures of 473K, 493K and 513K and strain rates of 0.000025 s^{-1}, 0.0025s^{-1} and0.025s^{-1} by using an15KN Santam testing machine.

2.2 Ring compression tests

In bulk forming processes, the compressive normal force being much larger in magnitude than that in sheet-metal forming, a friction factor m is usually applied to calculate the friction shear stress f

according to the formula f=mk, where k is the shear yield stress of the deforming material and 0≤m≤1. In order to determine the value of m under various lubrication conditions, ring compression tests with different lubricants applied at elevated temperatures were performed in conjunction with the finite element simulations employed in the present study. In the ring compression test, a short ring specimen is compressed between two flat, parallel plates. The diameter of the inner surface either increases or decreases as the height of the specimen is reduced, depending on the friction condition at the interface.

Because the change in internal diameter of the compressed ring is sensitive to friction at the die-blank interface, ring compression has been widely used as a test to evaluate the friction condition in metal-forming processes [10].

2.3. Hot compression tests

Isothermal compression tests were carried out using a 15 KN Santam testing machine. In the present study, specimens with geometry of 9 mm: 4.5 mm: 3 mm (outside diameter: inner diameter: height) were prepared from cast AZ61 magnesium-alloy.

Ring samples were used in order to obtain the true stress–true strain curves. The specimens were compressed, up to a height reduction of 50%, in isothermal conditions in the temperature and strain rate ranges of 473K–513 C and 0.00025s^{-1} - 0.025s^{-1}, respectively. In the present experiments, however, according to our investigation where the specimen temperature was measured continuously using the thermocouple directly connected to the specimen.

The tests were performed at temperatures of 200°C,220°C and 240°C and strain rates of 0.00025s^{-1}, 0.0025s^{-1} and 0.025s^{-1}. The specimens were compressed to various heights and the changes in internal and external diameters of the specimen were measured at each height.

The measured data were then compared with the so-called calibration curves, as shown in Fig. 1, which were constructed from the finite element simulation results [10], and the values of friction factor m could be evaluated. It can be seen that the effect of testing temperature and testing strain rate on the friction factor is insignificant, and the values of m vary from 0.24 to 0.38. In order to obtain stress-strain curve from ring test at least six testing points is required, therefore at each temperature and srtain rate, specimens at six different steps were compressed. Averge stress (P_a) and strain (ε) were obtained from Eq. 1and Eq2.

$$p_a = \frac{4p}{\pi(d_o^{\,2} - d_i^{\,2})} \qquad (1)$$

$$\varepsilon = \ln(\frac{t}{t_0}) \qquad (2)$$

After calculating p_a, by using sigmoid curve, as shown in fig. 2, stress could be calculated. Using the finite-element method, more accurate correction factor could be determined. For this reason, FE simulations of the compression test were conducted in Deform software. each value of axial true strain (ε), after determination of stress (σ_u) based on the FE results, a numerical correction factor (NCF) was calculated using Eq. (1) and sigmoid curves the relevant flow stress (σ_u) initially introduced to the software.

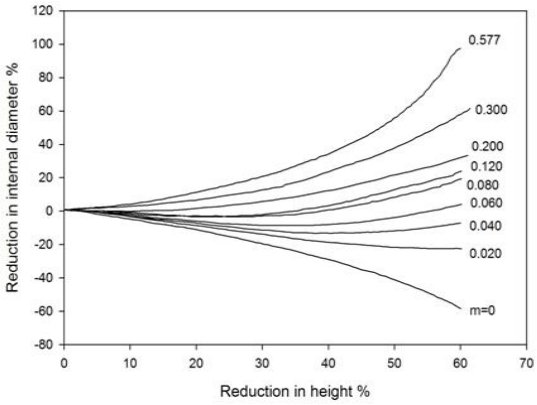

Fig1. Calibration curves for AZ61 magnesium alloy

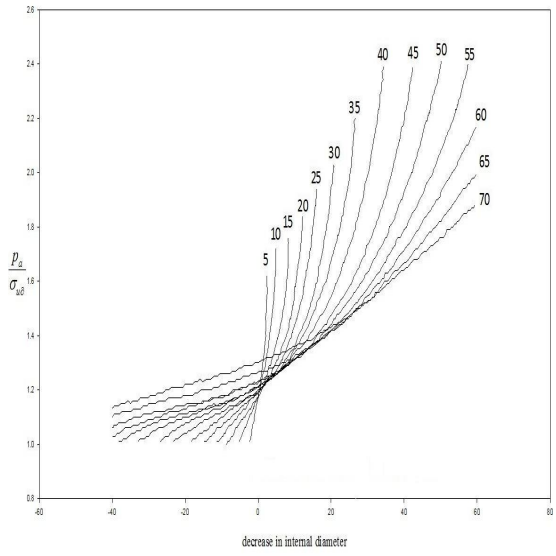

Fig2. Sigmoid curves for AZ61 magnesium alloy

RESULTS:

The typical compression curves based on numerical correction factor are illustrated in Fig. 3, Fig. 4 and Fig.5 at different strain rate and temperatures. The flow curves show a classical behaviour with a net increase in stress with strain up to the maximum followed by a limited flow softening. The flow stress of the material increases with increasing strain rate

and decreasing temperature, this behaviour is shown in Fig. 3, Fig. 4 and Fig. 5. At the high temperatures above 473 K, the flow stress increases to a maximum value at the three strain rates, then decreases with increasing strain and attains a steady state finally. Such a flow behavior is characteristic for hot working accompanied by dynamic recrystallization (DRX)[11−12]. At the point of the maximum stress value (peak-stress), the work hardening and DRX softening become balance, then the DRX softening is more pronounced than the hardening, so the stress decreases, the higher the deformation temperature is, the faster the DRX starts. The numerical sigmoid curve (NCFM) and the relevant flow curves, compared with the initial flow stress, provided more accurate load–displacement curve in the FE simulation of the compression test shown at Fig. 6 and Fig.7.

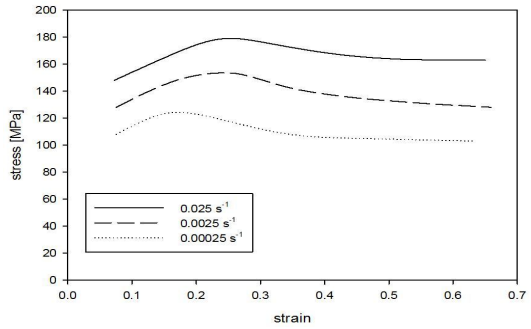

Fig 3. Flow curve of AZ61 magnesium alloy at 473K and different strain rates

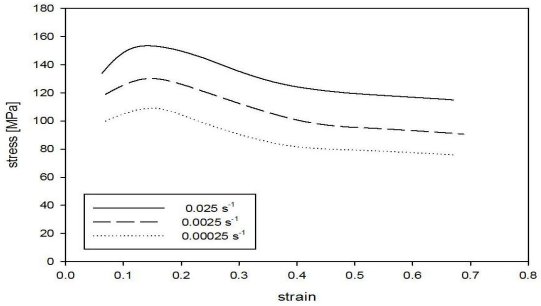

Fig 4. Flow curve of AZ61 magnesium alloy at 493K and different strain rates

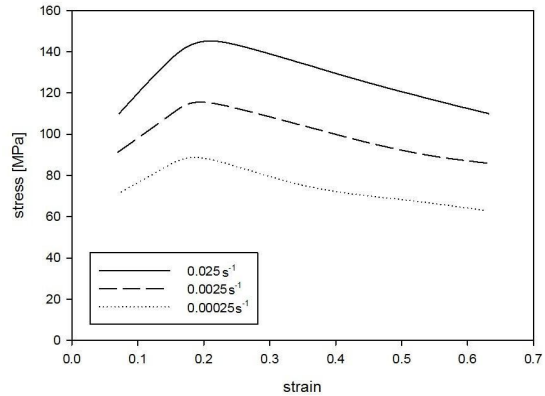

Fig 5. Flow curve of AZ61 magnesium alloy at 513K and different strain rate.

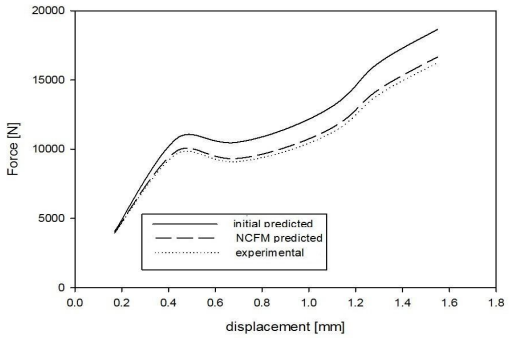

Fig 6.Load-displacement curve for AZ61 magnesium alloy at T=473 K and SR=0.0025s^{-1}

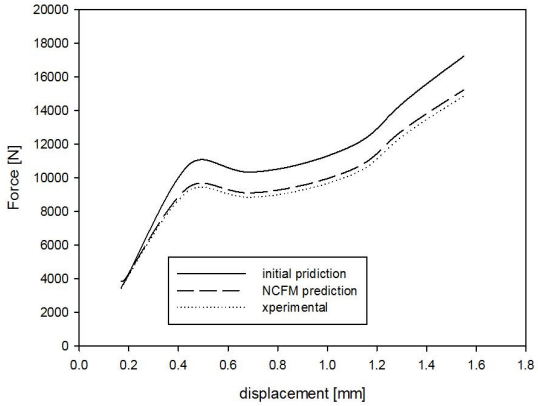

Fig 7.Load-displacement curve for AZ61 magnesium alloy at T=473 K and SR=0. 025s^{-1}

CONCLUSIONS

1) Flow stress curves of AZ61 magnesium alloy with at three different temperatures and three different strain rates, flow behavior is characteristic for hot working accompanied by dynamic recrystallization.

2) Numerical correction factor method (numerical sigmoid curve) gives better result in comparison with initial result obtained from software output and load-displacement curves are very good evidence for that.

3) The flow stress of the AZ61 magnesium alloy increases with increasing strain rate and decreasing temperature.

REFERENCES:

[1] S.F. Hassan and M. Gupta: Material science and engineering A Vol. 425 (2006), p. 22-27.

[2] S. Franchitti, G. Giulioiono, G. Palumbo, D. Sorgente and L. Tricario : Int J Matter form Vol.1 (2008) , p. 1067-1070.

[3] X. Haung, K. Suzuki and N. Saito : Scripta Materialia Vol. 60 (2009), p. 651-654.

[4] G. Ambrogio, C. Bruni, S. Bruschi, L. Filice, A. Ghiotti and M. Simoncini: Int J Mater Form Vol.1 (2008), p. 205–208

[5] F. Wang, H. Cai, M. Hong-lei and C.Tan: Nonferrous Met. Soc. China Vol. 17 (2007), p. 347-352

[6] M. Kleiner, M. Geiger and A. Klaus: Annals of the CIRP Vol. 52 (2003), p.521-543.

[7] R. Neugebauer, T. Altan, M. Geiger, M. Kleiner and A. Sterzing: Annals of the CIRP Vol. 55 (2006), p.793-816.

[8] A. Turetta, A. Ghiotti and S. Bruschi: Proc. of 10th Esaform (2007)

[9] G. Ambrogio, C. Bruni, L. Filice and F. Gabrielli : Key Engineering Materials Vol. 344 (2007), p. 55-62.

[10] F. Fereshteh-Saniee and F. Fatehi-Sichani: Journal of Materials Processing Technology Vol. 177 (2006), p. 478–482

[11] C.M. Zhang, X. Hui, Z.G. Liand and G.L. Chen: Materials letters Vol. 62 (2008), p. 1129-1131.

[12] T. Itoi, K. Takahashi, H. Moriyama and M. Hirohashi: Scripta materialia Vol. 59 (2008), p. 1155-1158.

★★★