Mechanics of Materials 100 (2016) 209–218

Contents lists available at ScienceDirect

Mechanics of Materials

journal homepage: www.elsevier.com/locate/mechmat

Strain-dependent constitutive equations to predict high temperature flow behavior of AA2030 aluminum alloy

H.R. Rezaei Ashtiani*, P. Shahsavari

School of Mechanical Engineering, Arak University of Technology, Arak, Iran

ARTICLE INFO

Article history:
Received 26 September 2015
Revised 16 June 2016
Available online 29 June 2016

Keywords:
Hot deformation
AA2030
Constitutive equation
Flow stress
Compensation of strain

ABSTRACT

The experimental strain–stress data from isothermal hot compression tests were used to develop constitutive equations for hot deformation behavior prediction of AA2030 aluminum alloy. For this purpose, hot compression tests were carried out at the deformation temperatures from 350 to 500 °C and strain rate range of 0.005–0.5 s^{-1}. The microstructure and flow stress of AA2030 alloy were evidently affected by both the deformation temperature and strain rate which the effects of these parameters on deformation behaviors were represented by Zener-Holloman parameter in an exponent type equation. The influence of strain was also incorporated in the constitutive equation by considering activation energy (Q) and all material constants as different functions of strain. The very good agreement between the measured and predicted results indicates the high accuracy of developed model and established strain-dependent constitutive equations in analyzing and predicting the hot deformation behavior of AA2030, at different temperatures and strain rates conditions.

1. Introduction

Aluminum alloys due to their optimal combination of mechanical and physical properties have many applications in various industries such as aeronautical applications, automobile industries and etc. In particular, Aluminum alloys of the 2000 series such as Al-Cu-Mg (AA2024) and Al-Cu-Mg-Pb (AA2030) alloys are very used in aeronautical applications due to the high strength to weight ratio associated with good fracture toughness, good corrosion resistance and excellent high temperature characteristics. Generally, these series of aluminum alloys will be subject to various hot forming processes, such as rolling, forging and extrusion (Kaufman, 2000, Lin et al., 2012, Malas et al., 2004, Huang et al., 2010).

Nearly 80% of all metals products including aluminum alloy undergo hot forming during some part of their processing history (Brown et al., 1989). Hot deformation processes are a fundamental step in the production of engineering parts which require not only dimensional accuracy but also proper microstructural and mechanical properties. Therefore investigation and prediction of materials behavior during hot deformation is very essential and considerable. Material flow behaviors during hot forming processes are often complex and significantly influenced by metallurgical phenomena such as work hardening, dynamic recovery and dynamic recrystallization (Rezei Ashtiani et al., 2014).Hot deformation behavior of material is often simulated by hot compression and hot tensile tests due to their similarity to hot forging, extrusion and rolling processes (Li et al., 2011, McQueen et al., 2001, Cavaliere et al., 2010, Huang et al., 2014).

Constitutive equations are generally used to describe the behavior of materials, which are correlated with the flow stress, strain rate and deformation temperature. Various phenomenological, analytical, physical, empirical and artificial neural network models have been established to predict constitutive behavior in a wide range of metals and alloys (Lin and Chen, 2011, Wu et al., 2012, Gholamzadeh and Karimi Taheri, 2009).It provides a definition of the flow stress based on empirical observations, and consists of some mathematical functions. The empirical Johnson–Cook model (Johnson and Cook, 1985, Lin et al., 2010a, Samantaray et al., 2011, Li et al., 2013a) and the physical based Zerilli–Armstrong model (Li et al., 2013a, Zhang et al., 2009, Li et al., 2013b) or combination of Johnson–Cook and Zerilli–Armstrong (Lin and Chen, 2010) are usually used for a wide range of metals and alloys. Artificial neural network-based models can provide a fundamentally different approach to materials modeling and material processing control techniques than statistical or numerical methods (Gholamzadeh and Karimi Taheri, 2009, Ji et al., 2010, Rezaei Ashtiani et al., 2012). Also, a number of research groups have attempted to develop constitutive equations of materials based on the experimentally measured data to describe the hot deformation behaviors of metals and alloys by the hyperbolic laws in an Arrhenius type of equation. The

* Corresponding author. Fax: +98 861 3670020.
E-mail address: hr_rezaei@arakut.ac.ir (H.R.R. Ashtiani).

http://dx.doi.org/10.1016/j.mechmat.2016.06.018
0167-6636/

Table 1
Chemical composition (wt. %) of AA2030 alloy.

Cu	Mg	Pb	Si	Fe	Mn	Cr	Zn	Ti
3.85	0.92	1.12	0.37	0.58	0.25	0.01	0.37	0.01

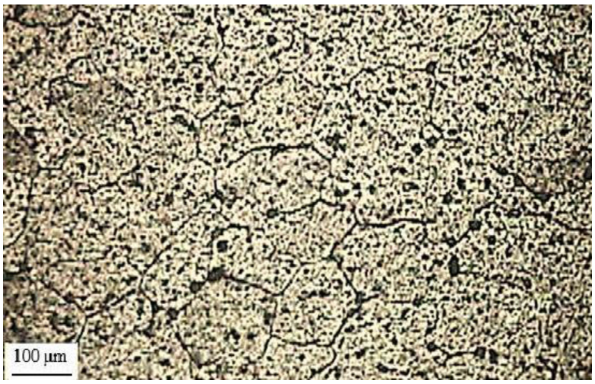

Fig. 1. Optical micrograph of the homogenized AA2030.

Arrhenius equation is most widely used to describe the relationship between the strain-rate, flow stress and temperature, especially at high temperatures by taking the effect of strain (Ma et al., 2012, Xu et al., 2013, Woll et al., 2015, Lin et al., 2010b, Ou et al., 2014, Li et al., 2012, Mandal et al., 2009, Haghdadi et al., 2012, Khamei and Dehghani, 2010, Wu et al., 2013, Samantaray et al., 2010, Zhang et al., 2014, Chaia et al., 2012).

In this paper, the effects of deformation temperatures, strain rates and strain on the hot deformation characteristics of AA2030 (Al-Cu-Mg-Pb alloy) are investigated by isothermal hot compression tests. The main objective of this study is to derive constitutive equations relating flow stress, strain rate and deformation temperature with compensation of strain for the deformation of AA 2030 at high temperatures.

2. Experimental procedure

The chemical composition of the AA2030 employed in this work has been given in Table 1. Cylindrical samples with 8 mm in diameter and 12 mm in height were machined out the extruded bars with the longitude axis parallel to the extrusion direction. Annealing heat treatment was employed to achieve proper and similar initial microstructure in aluminum alloy samples which were hot extruded. The optical micrograph of extruded and then annealed AA2030 alloy specimen has been shown in Fig. 1, which is mainly the homogenized texture area with uniform grains. Meanwhile, the second phase can be seen as the black particles that distributed in the microstructures, irregularly.

In order to determine the stress-strain behavior of the AA2030 at elevated temperature, uniaxial one-hit hot compression tests were carried out using a Gotech-AI7000 servo-controlled electronic universal testing machine equipped with an electrical resistance furnace. A very thin mica sheet was used to minimize the friction effect between the press indenters and the specimens. Each specimen was heated to test temperature and held for 5 min for the purpose of heat balance. The hot compression deformation tests of AA2030 were carried out according to the test schedule illustrated in Fig. 2, at temperatures of 350 °C, 400 °C, 450 °C and 500 °C, with the strain rates of 0.005 s^{-1}, 0.05 s^{-1} and 0.5 s^{-1}. The specimens were deformed to a strain 0.6 and then immediately water-quenched for prevent the undesirable microstructural alterations and/or preservation of hot deformed microstructure.

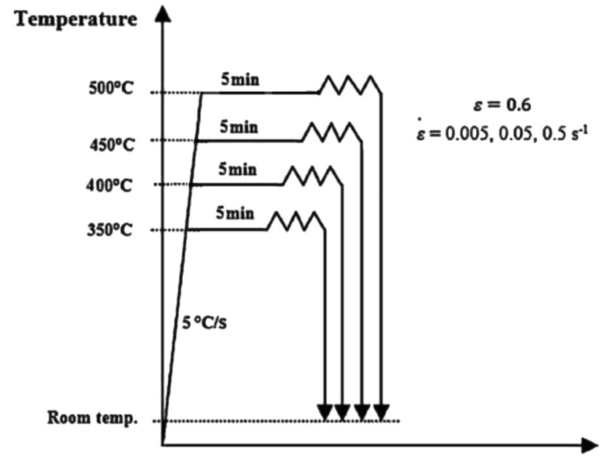

Fig. 2. Thermo-mechanical schematic used to compress samples that represents processing conditions.

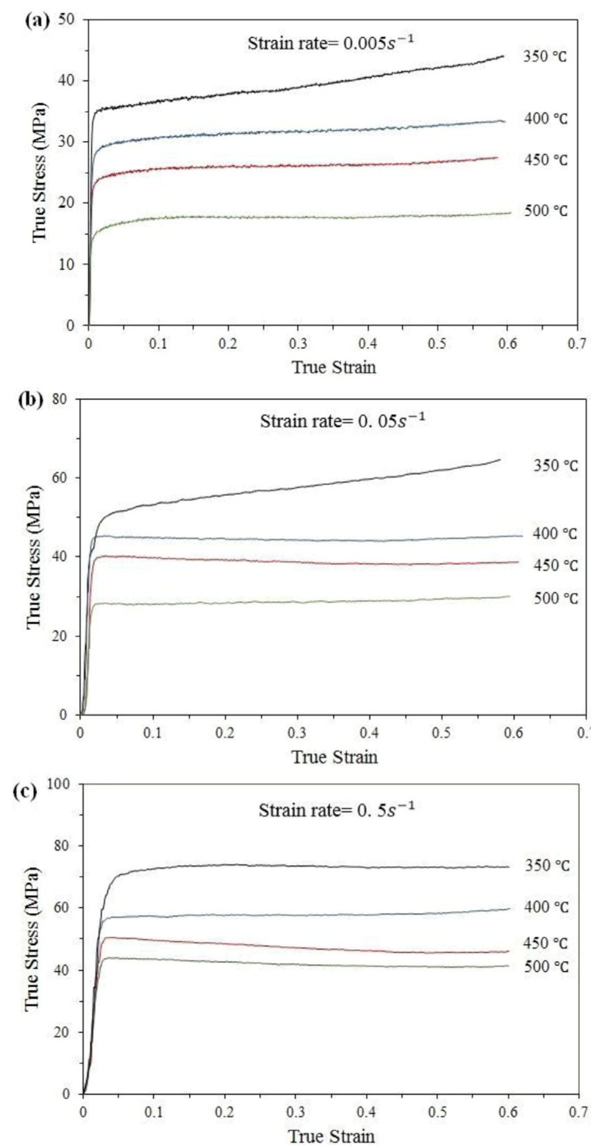

Fig. 3. True stress–true strain curves for various temperatures at different strain rate of (a) 0.005 s^{-1}, (b) 0.05 s^{-1} and (c) 0.5 s^{-1}.