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Journal of Magnesium and Alloys 000 (2018) 1–11

www.elsevier.com/locate/jma

Modeling of hot deformation behavior and prediction of flow stress in a magnesium alloy using constitutive equation and artificial neural network (ANN) model

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Received 17 December 2017; received in revised form 26 April 2018; accepted 2 May 2018
Available online xxx

Abstract

The aim of the present study was to investigate the modeling and prediction of the high temperature flow characteristics of a cast magnesium (Mg–Al–Ca) alloy by both constitutive equation and ANN model. Toward this end, hot compression experiments were performed in 250–450 °C and in strain rates of 0.001–1 s^{-1}. The true stress of alloy was first and foremost described by the hyperbolic sine function in an Arrhenius-type of constitutive equation taking the effects of strain, strain rate and temperature into account. Predictions indicated that unlike low strain rates and high temperature with dominant DRX activation, in relatively high strain rate and low temperature values, the precision of the models become decreased due to activation of twinning phenomenon. At that moment and for a better evaluation of twinning effect during deformation, a feed-forward back propagation ANN was developed to study the flow behavior of the investigated alloy. Then, the performance of the two suggested models has been assessed using a statistical criterion. The comparative assessment of the gained results specifies that the well-trained ANN is much more precise and accurate than the constitutive equations in predicting the hot flow behavior.

Keywords: Hot deformation; Magnesium alloy; Modeling; Twinning; Hyperbolic sine equation; ANN model.

1. Introduction

Different magnesium alloys have exhibited a great prospective to be used as an advantageous light alloy solution for transportation and aerospace industries for which weight reduction is one of the indispensable concerns in materials selection [1,2]. However, unfortunate workability of such alloys limits their applications due to poor formability inherent to the crystal structure of magnesium, i.e., the hexagonal close-packed (HCP) structure [3]. Generally, during homogeneous straining of a polycrystalline material, at least five independent slip systems have to be activated. Though at room temperature magnesium takes limited number of slip systems [3,4], which is deficient to fulfill the von Mises criterion. In this regard, twinning plays a significant role in the deformation of magnesium alloys at relatively elevated temperatures [5]. Hence, the scaled-up industrialization of the Mg part fabrication is reliant on the hot deformation methods to increase the formability of these alloys. For reliable control and fully understand of industrial thermomechanical treatment, the identification of load-bearing capability of alloy in different working conditions is decidedly necessitated. This plays a vital role in performing numerical analysis and finding out the optimal hot forming parameters which really affect the concluding microstructure and subsequent mechanical features of the final products.

As mentioned, the formation of twinning phenomenon is conductive to the deformation of magnesium alloys. Among various twinning systems, the {1012} twins have been found

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https://doi.org/10.1016/j.jma.2018.05.002

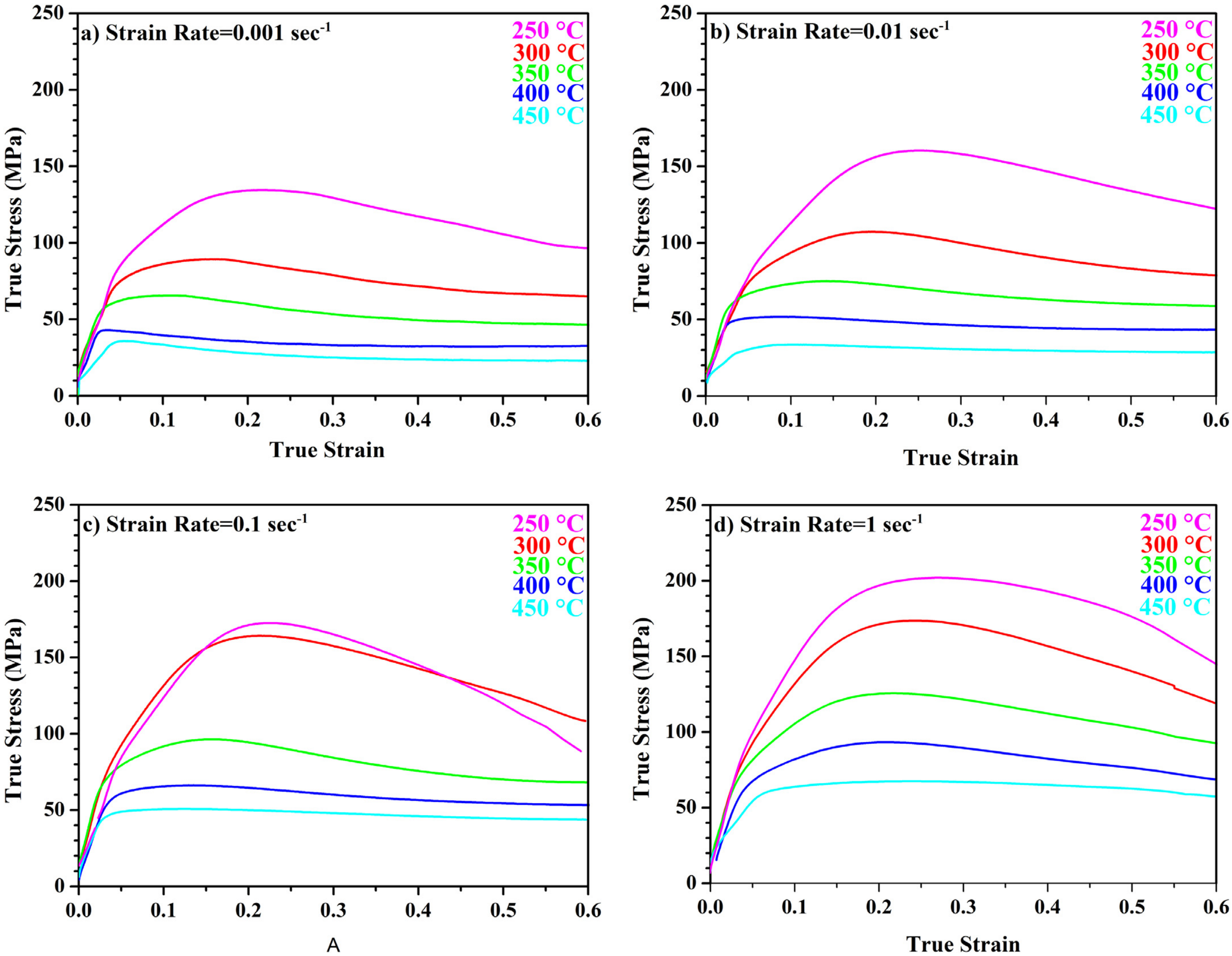

Fig. 1. Hot deformation flow curves of studied alloy at different defomation strain rates, a) 0.001 s^{-1}, b) 0.01 s^{-1}, c) 0.1 s^{-1} and d) 1 s^{-1}.

to come about most often during high temperature deformation of Mg alloys [6,7]. Lots of investigations [8–11] were done to recognize the development of twinning and its related consequences on the deformation performance of different magnesium alloys. In alloys which have twining as their dominant deformation phenomena, such steel and brass alloys [12–14], the strain-hardening rate is high and the true stress–strain curve typically displays a special form. In addition to that, the understanding of the meticulous mechanisms of twinning contribution and its influence on the work hardening rate is quite vague [11]. In many researches, the high stain-hardening rate was attributed to the Hall–Petch effect together with the crystallographic texture effect [11,13]. Moreover, twinning can affect strain softening trend such as dynamic recrystallization (DRX) kinetics and intra-grain twin-induced recrystallization [13–15].

The hot deformation characteristics of alloys can be interpreted considering both work hardening and work softening phenomena such as cell formation, dislocation tangle, twining, dynamic recovery (DRV), dynamic recrystallization (DRX) and grain growth [16]. In the case, establishing an accurate and rational relationships between the flow stress and these metallurgical phenomena is complicated due to high degree of non-linearity and complexity. In this regard, an extensive amount of research works have been conducted to tackle this matter using different exact analytical and numerical models based on empirical data to accurately describe the high temperature flow behavior of materials [17,18]. Each proposed approach has its own advantages and also negative points. For instance, dislocations dynamics-based exact analytical models of hot deformation entails very strong and comprehensive considerate of the involved controlling mechanisms that are hardly possible to be applied in applied norm. On the other hand, numerical solutions (with just relatively acceptable numerical errors) are less firmly related to the physical concepts, but still substantial physical understanding of continuum plasticity theory is required . In conclusion, some modeling troubles have be taken into account especially while facing with materials with HCP structures. In such materials, different twinning effects worsen the non-linearity

Please cite this article as: S.A. Sani et al., Modeling of hot deformation behavior and prediction of flow stress in a magnesium alloy using constitutive equation and artificial neural network (ANN) model, Journal of Magnesium and Alloys (2018), https://doi.org/10.1016/j.jma.2018.05.002