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Constitutive equations for high temperature flow stress prediction of Al–14Cu–7Ce alloy

Wei Li[a,b,*], Hai Li[a,b], Zhixiu Wang[a,b], Ziqiao Zheng[c]

[a] School of Materials Science and Engineering, Changzhou University, Changzhou 213164, China
[b] Key Laboratory of Advanced Metallic Materials of Changzhou City, Changzhou 213164, China
[c] School of Materials Science and Engineering, Central South University, Changsha 410083, China

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ABSTRACT

In order to find material parameters of established Zener–Hollomon constitutive equations and predict high-temperature flow stress of Al–14Cu–7Ce alloy, isothermal hot compression tests were conducted using a Gleeble 3500 thermomechanical simulator at constant stain rates of 0.001, 0.01, 0.1 and 1 s^{-1} and at temperatures ranging from 300 to 550 °C at intervals of 50 °C. The effects of strain rate and temperature on hot deformation behavior were represented by Zener–Hollomon parameter including Arrhenius term. Four material constants α, n, A and activation energy Q in the equations were calculated by compensation of strain. The results show that the proposed constitutive equations give a precise estimate for high temperature flow stress of Al–14Cu–7Ce alloy, which means it can be used for numerical simulation of hot deformation process and for choosing proper deformation parameter in engineering practice accurately.

1. Introduction

The phase diagram of the Al–Cu–Ce system had been studied by Belov et al. [1,2]. The eutectic reaction was determined as L → (Al) + Al_8CeCu_4 (610 °C, 14 wt.%Cu and 7 wt.%Ce). This eutectic has good casting properties due to the narrow solidification range. Ce-containing ternary phase Al_8CeCu_4 is difficult to fragment and spheroidize because of the small Ce element diffusion coefficient in aluminium matrix, and such trend make it a promising alloy with thermal resistance in certain high temperature applications. However, after annealing at elevated temperature, the ternary phase is liable to fragment and spheroidize which will improve the workability of this alloy for major production processes such as forging, rolling, and extrusion. So, it is important to study hot deformation behavior of this alloy in order to optimize the hot deformation process.

Hot deformation behavior is often simulated by compression tests due to their similarity to forging processes [3–10]. Recently, there is a wide spread use of FEM simulation to study material forming process and numerical simulation can be truly reliable only when a proper material flow stress relationship is built which can be used in computer code [11–13]. Therefore, great efforts have been made to propose constitutive equations which are essential to describe the flow stress behavior during hot deformation [14–21].

The main objective of this work is to find material parameters by fitting established Zener–Hollomon equation against the experiments and predict high temperature flow stress of Al–14Cu–7Ce alloy through verifying the material parameters against the experimental observations.

2. Experimental

The experimental material alloy Al–14Cu–7Ce (in wt.%) was prepared with pure Al ingots and Al–Ce, Al–Cu master alloys. The alloy was melted in a graphite crucible at 780 °C, followed by casting into a cuboid ingot. The ingot was annealed at 580 °C for 3 h in order to obtain spheroidized second phase Al_8CeCu_4 [1] and then machined to cylindrical specimens with a diameter of 10 mm and a height of 15 mm using electrospark wire-electrode cutting machine. The chemical compositions and microstructures of Al–14Cu–7Ce alloy are given in Table 1 and Fig. 1 respectively. Isothermal hot compression tests were conducted using Gleeble 3500 thermomechanical simulator. Graphite lubricant was used for reducing the friction between the press indenters and the specimens. The testing temperatures ranged from 300 °C to 550 °C at intervals of 50 °C and the stain rates were 0.001, 0.01, 0.1 and 1 s^{-1}. Each specimen was heated to the deformation temperature at a rate of 2 °C/s by thermo coupled feed-back-controlled AC and held for 3 min for the purpose of heat balance. The deformation temperature was measured

* Corresponding author at: Changzhou University, School of Materials Science and Engineering, Gehu road 1, Changzhou 213164, China. Tel.: +86 0519 86330099; fax: +86 0519 86334791.
E-mail address: liweijyg@163.com (W. Li).

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Table 1
Chemical composition (in wt.%) of Al–14Cu–7Ce alloy.

Cu	Ce	Si	Fe	Mn	Zn	Al
13.814	6.791	0.100	0.107	0.125	0.063	Bal.

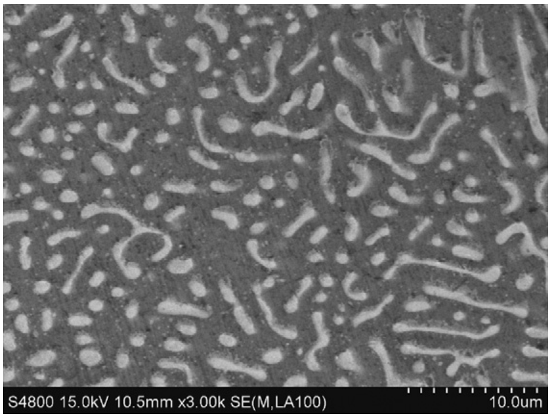

Fig. 1. Microstructure of Al–14Cu–7Ce alloy after annealing at 580 °C for 3 h obtained from SEM.

by thermocouples which were spot-welded to the outer surface at the center along the length of the specimens. The specimens were subsequently quenched in water to retain the microstructures at elevated temperature and the reduction in height was 60% at the end of the tests.

3. Results

3.1. Characteristics of the true stress–true strain curves

A series of typical true stress–true strain curves obtained at various temperatures and strain rates are shown in Fig. 2. Generally, the effects of temperature and strain rate on flow stress are momentous. It is a general trend that the flow stress decreased with decreasing strain rate at a given temperature. At a constant strain rate, higher the deformation temperature is, lower the flow stress will be. During the early stage of the deformation, the flow stress increased rapidly due to work hardening. After reaching the peak flow stress, the curves exhibited remarkable steady stage as

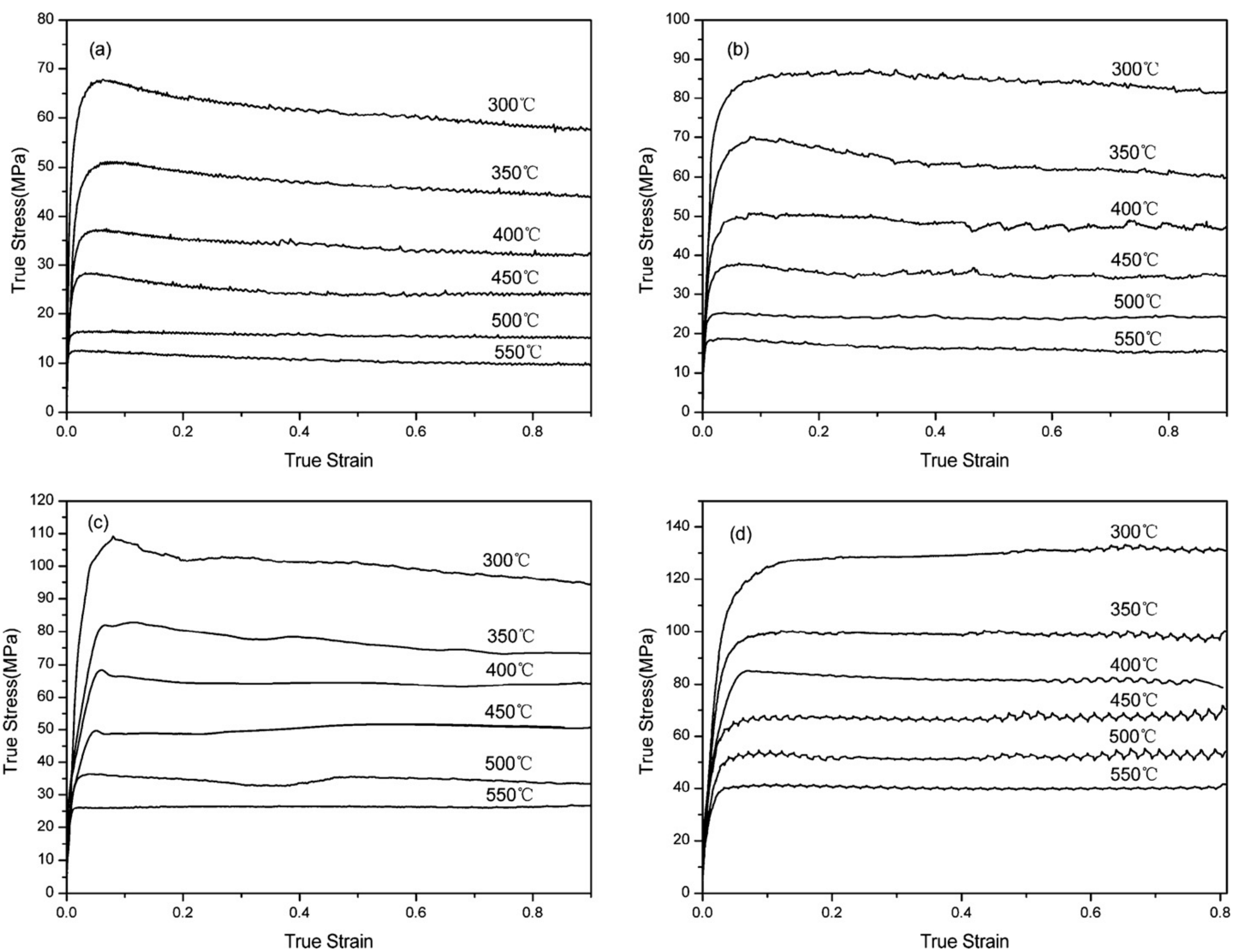

Fig. 2. True stress–true strain curves for Al–14Cu–7Ce alloy during hot deformation: (a) $\dot{\varepsilon} = 0.001\ s^{-1}$; (b) $\dot{\varepsilon} = 0.01\ s^{-1}$; (c) $\dot{\varepsilon} = 0.1\ s^{-1}$; (d) $\dot{\varepsilon} = 1\ s^{-1}$.