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3D processing map and hot deformation behavior of 6A02 aluminum alloy

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ABSTRACT

The high-temperature flow behavior of 6A02 aluminum alloy was studied through hot compressive experiments. Based on the experimental data, the values of strain rate sensitivity, efficiency of power dissipation and the instability parameter under the condition of various hot working parameters were investigated. Processing maps were established by superimposing the instability map over the power dissipation map, this being connected with microstructural evolution analysis in the hot deformation processes. It was found that flow stress grows with increases in the strain rate and with decreases in the deformation temperature. The studied alloy isn't suitable to be processed at temperatures exceeding 490 °C or under strain rates which are too low, when intending to acquire uniform fine recrystallization structure. The processing map with a strain of 0.6 is divided into four characterization regions for researching microstructure evolution. The optimum hot working domains are the areas of 450–470 °C/0.1-1s^{-1} and 430–450 °C/0.01–0.1s^{-1}.

1. Introduction

The 6000 series (Al-Mg-Si) aluminum alloys have been extensively used in automotive and aerospace industries because of their high specific strength, strong corrosion resistance and desired plasticity. For instance, the 6061 and 6A02 aluminum alloy are crucial structure materials for saving weight, and in particular the 6A02 aluminum alloy is widely used in the field of aerospace. However, the workability of such alloys is greatly limited at elevated temperatures due to inhomogeneous phase distribution, microscopic and macroscopic segregation and large grain sizes [1–3]. Therefore, it is necessary to come up with a solution to solve this poor formability problems. Thermo-mechanical processing is considered to be the desired method to be conducted to improve the workability and acquire satisfactory mechanical properties. The deformation ability of alloys are usually expressed using a form of true stress-true strain curves under certain conditions [4]. However, the quality of hot processing is highly dependent on the extremely complex nonlinear relationship between the processing parameters and microstructural changing of the alloy. As a result, it is imperative to reveal the hot deformation characteristics of the alloys. Furthermore, constitutive equations can be applied to present the variation of flow stress under different conditions of hot working parameters like deformation temperature, strain and strain rate [5]. More importantly, it can be concluded from pioneer works that the processing map, initially put forward by Prasad [6], is a powerful tool to control hot working parameters and enhance hot workability of various kinds of alloys.

Recently, the flow behavior of the 6xxx series of aluminum alloy during hot processing has attracted ever-increasing attention by numerous materials researchers [7–9]. G. Mrówka-Nowotnik et al. [10] studied the hot deformation behavior of 6xxx aluminum alloys (including 6005, 6061, 6063 and 6082) using compression tests in the temperature range of 100–375 °C with strain rates from 10^{-4}s^{-1} to 4×10^{-4}s^{-1} by employing a dilatometer DIL 805 BAHR thermal analyzer, which can provide a vacuum and inert gas atmosphere. Chen et al. [11] established three different kinds of mechanical models of 6061 aluminum alloy (AA 6061-Ti) including the Arrhenius, Fields-Backofen, and artificial neural network flow stress models; which were compared with experimental data collected during isothermal compression under different

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Table 1
Chemical compositions of the studied alloy (wt.%).

Chemical composition	Mg	Si	Fe	Mn	Cu	Ni	Ti	Zn	Al
wt%	0.62	0.73	<0.05	<0.05	<0.01	<0.01	<0.01	<0.01	Bal.

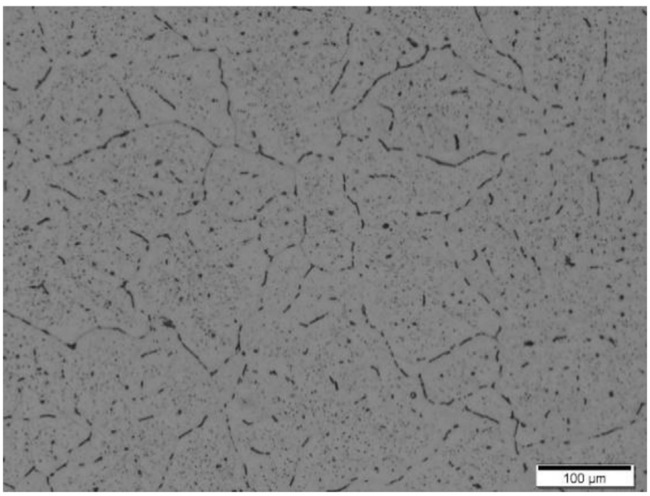

Fig. 1. The initial microstructure of the 6A02 aluminum alloy.

deformation conditions. Jin et al. [12] built a processing map of aluminum alloy based on the constitutive equation, achieving an optimum hot processing window (683–733K/10^{-4}-$10^{-3}s^{-1}$) with a peak power dissipation efficiency of around 50%. Liao et al. [13] constructed the processing maps by studying the hot workability of three aluminum alloys with different silicon content, and found a relationship between the instability region and the amount of silicon. Also, the processing maps of various Al-based nano-composites consisting of temperature and strain rate were constructed by Ahamed et al. [14] and Senthilkumar et al. [15].

It is cognized from the establishment process of the processing map that intrinsic parameters such as strain rate sensitivity (m), power dissipation efficiency (η), and instability parameter (ξ) have decisive effects on the processing map. Unfortunately, preliminary research regarding processing maps were limited in presenting the relationship between processing domains and corresponding microstructure characteristics. Therefore, further investigations regarding those important parameters need to be conducted. To study the hot deformation behavior of the 6A02 alloy, hot compression tests were applied at temperatures of 410–510 °C with strain rates of 0.001-1s^{-1}. Under the condition of various hot working parameters, the values of strain rate sensitivity as well as efficiency of power dissipation were discussed. Built on the base of the Dynamic Material Model, hot processing maps of 6A02 alloy were established to explore the effects of hot deformation

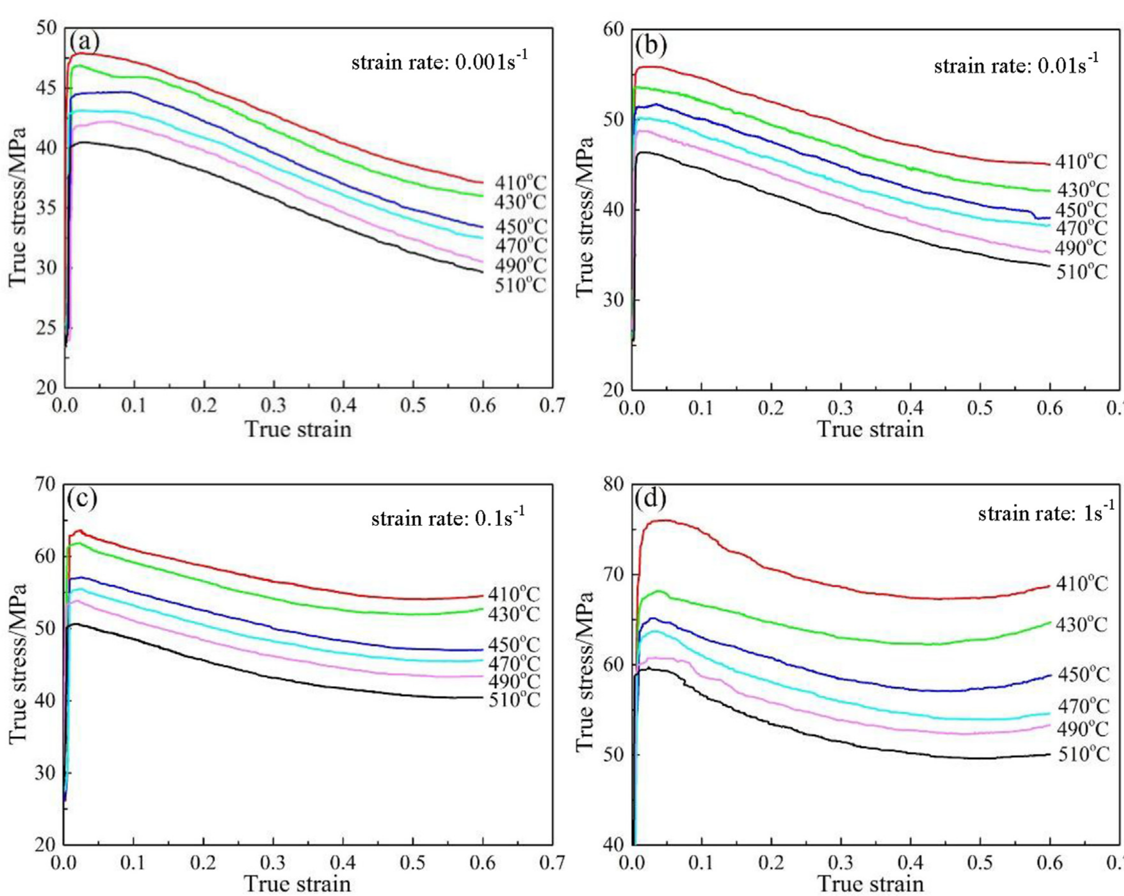

Fig. 2. Typical true stress-true strain curves of 6A02 aluminum alloy at different strain rates of (a) 0.001s^{-1}; (b) 0.01s^{-1}; (c) 0.1s^{-1} and (d) 1s^{-1}.