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Flow curve correction and processing map of 2050 Al−Li alloy

Rui-hua ZHU[1], Qing LIU[1], Jin-feng LI[1], Yong-lai CHEN[2], Xu-hu ZHANG[2], Zi-qiao ZHENG[1]

1. School of Materials Science and Engineering, Central South University, Changsha 410083, China;
2. Aerospace Research Institute of Materials and Processing Technology, Beijing 100076, China

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Abstract: Hot compression tests of 2050 Al−Li alloy were performed in the deformation temperature range of 340−500 °C and strain rate range of 0.001−10 s^{-1} to investigate the hot deformation behavior of the alloy. The effects of friction and temperature difference on flow stress were analyzed and the flow curves were corrected. Based on the dynamic material model, processing map at a strain of 0.5 was established. The grain structure of the compressed samples was observed using optical microscopy. The results show that friction and temperature variation during the hot compression have significant influences on flow stress. The optimum processing domains are in the temperature range from 370 to 430 °C with the strain rate range from 0.01 to 0.001 s^{-1}, and in the temperature range from 440 to 500 °C with the strain rate range from 0.3 to 0.01 s^{-1}; the flow instable region is located at high strain rates (3−10 s^{-1}) in the entire temperature range. Dynamic recovery (DRV) and dynamic recrystallization (DRX) are the main deformation mechanisms of the 2050 alloy in the stable domains, whereas the alloy exhibits flow localization in the instable region.

Key words: 2050 Al−Li alloy; processing map; dynamic recovery; dynamic recrystallization; flow localization

1 Introduction

Compared with conventional Al alloys, Al−Li alloys typically possess lower density, higher elastic modulus and improved fatigue crack growth resistance. 2050 alloy is one of the 3rd generation Al−Li alloys targeting static and fatigue properties to be equal or better than 7050 alloy with 4% density reduction and 5% elastic modulus enhancement [1]. Heretofore, 2050 Al−Li alloy has many applications in transport aircraft from wing spars and ribs to other internal structures in wings and fuselages [2]. These components are usually formed by hot working, either by rolling or forging [2]; the high forming temperatures result in microstructural changes that significantly influence the final mechanical response of the alloy [3]. Though 2050 Al−Li alloy has been widely used in aircraft industry, limited works on the hot deformation behavior of this alloy are found in open publication so far. In view of this, the fundamentals of the thermomechanical process, hot deformation characteristics and microstructural evolution, specific to 2050 Al−Li alloy should be made clear.

The isothermal hot compression test has been widely used to determine a material's stress−strain response at elevated temperatures [4]. However, friction between sample and die during the compression process has to be considered before further investigation [5−7], because practical measured flow curve departs from the real response of the material to a certain degree. This is especially true in hot compression process, where the friction is hard to eliminate completely even when the lubricant is added [8]. Hence, reducing the friction coefficient during the metalworking and correcting the flow curve for real behavior are of great importance. In addition, compression test at elevated temperature usually leads to a temperature rise or decrease of the deformed specimen due to adiabatic heating or heat dissipation; the resulting flow stresses are therefore lower or higher than the actual flow stress for the desired test temperature under isothermal conditions [9,10]. This could also lead to some errors in further research. In view of the above factors, the true stress−strain data directly obtained from the compression test must be corrected for friction and temperature difference.

The processing map technique was widely used to understand the hot workability of many materials in terms of microstructural process operating over ranges

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Corresponding author: Jin-feng LI; Tel: +86-731-88830270; Fax: +86-731-88876692; E-mail: lijinfeng@ csu.edu.cn
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of temperatures and strain rates [11−16]. Developed on the basis of dynamic material model (DMM) [17], processing map not only presents the stable domains in which a decisive deformation mechanism of specific microstructure takes place, but also describes the instability regions which should be avoided during hot working [18]. Meanwhile, the processing map is a practical tool for optimizing hot working processing parameters. Therefore, processing map provides a strong method to design hot processes of materials and more effectively control microstructure by hot processes.

In this work, a detailed description of performing the friction and temperature difference correction was presented. Based on the DMM, the processing map of 2050 Al−Li alloy was developed in order to analyze the instability regions and optimize the hot working parameters. Moreover, various deformation mechanisms of the alloy were validated by microstructure observations.

2 Experimental

The chemical composition (mass fraction) of the 2050 Al−Li alloy used in this study was as follows: 3.4% Cu, 1.2% Li, 0.4% Mg, 0.4% Ag, 0.35% Mn, 0.1% Zr, 0.1% Zn, and balance Al. The rectangular ingot was prepared by melting in an electric furnace protected by argon atmosphere and pouring into a water-cooled copper chilled mold and then homogenized at 450 °C for 16 h and 500 °C for 18 h. Figure 1 shows optical metallographic images of the as-cast and homogenized alloys. The typical cast structure is shown in Fig. 1(a). After homogenization, dendrite segregation was almost eliminated and massive secondary phases along grain boundary dissolved into the matrix, as shown in Fig. 1(b).

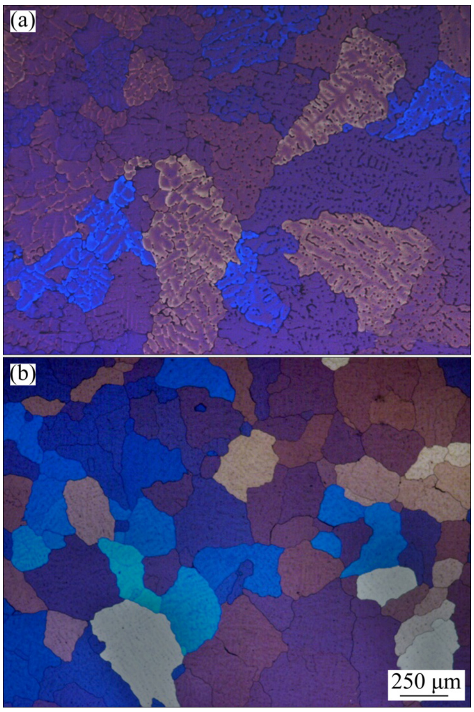

Fig. 1 Optical metallographic images of alloys: (a) As-cast; (b) Homogenized

Cylindrical specimens with a diameter of 10 mm and a height of 15 mm were machined from the homogenized ingot. Uniaxial compression tests were conducted on a Gleeble−3180D thermal-mechanical simulator (Dynamic Systems Inc., America) in the temperature range from 340 to 500 °C with an interval of 40 °C and the strain rate range from 0.001 to 10 s^{-1}. Graphite foils were placed between the specimen and die for lubrication. In order to capture the temperature changes occurring during the test, a thermocouple with a diameter of 0.25 mm and a response time of 0.1 s was welded on the specimen surface at the mid-height. The specimen was heated to the preset temperature at a rate of 5 °C/s, soaked for 180 s to homogenize the temperature in the whole sample, compressed by 40% in height and then quenched in water quickly, as illustrated in Fig. 2.

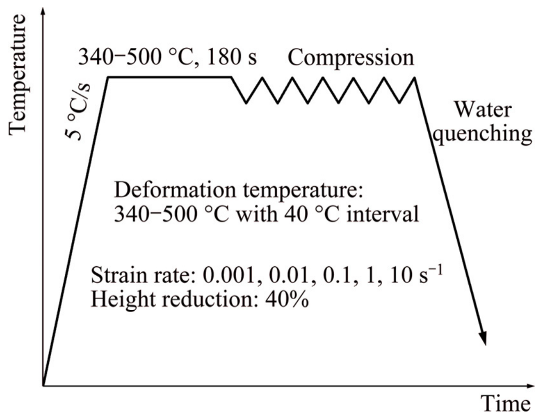

Fig. 2 Schematic diagram of hot compression test

The deformed specimens were sectioned parallel to the compression axis for microstructure observation. Their grain structures were viewed with cross-polarized light on a Leica DMILM optical microscope (OM, Leica Microsystems Wetzlar GmbH, Germany). The thermo-physical parameters (specific heat and thermal conductivity) of the 2050 Al−Li alloy were measured by a Laser Flash Apparatus JR-3 (Central South University Precision Instrument Co., Ltd., Changsha, China) for data correction.

3 Results and discussion

3.1 True stress−strain curves

Representative true stress−strain curves of the 2050 Al−Li alloy at various strain rates with a given