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ScienceDirect
Trans. Nonferrous Met. Soc. China 27(2017) 1327−1337
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Optimization of deformation parameters of dynamic recrystallization for 7055 aluminum alloy by cellular automaton

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Received 6 April 2016; accepted 22 November 2016

Abstract: In order to simulate the microstructure evolution during hot compressive deformation, models of dynamic recrystallization (DRX) by cellular automaton (CA) method for 7055 aluminum alloy were established. The hot compression tests were conducted to obtain material constants, and models of dislocation density, nucleation rate and recrystallized grain growth were fitted by least square method. The effects of strain, strain rate, deformation temperature and initial grain size on microstructure variation were studied. The results show that the DRX plays a vital role in grain refinement in hot deformation. Large strain, high temperature and small strain rate are beneficial to grain refinement. The stable size of recrystallized grain is not concerned with initial grain size, but depends on strain rate and temperature. Kinetic characteristic of DRX process was analyzed. By comparison of simulated and experimental flow stress–strain curves and metallographs, it is found that the established CA models can accurately predict the microstructure evolution of 7055 aluminum alloy during hot compressive deformation.

Key words: 7055 aluminum alloy; cellular automaton; dynamic recrystallization; hot compression; grain refinement

1 Introduction

Aluminum alloy plates with high strength and high toughness are widely used in main frames, wing boxes, stringers and other key components of aircraft. 7055 aluminum alloy is an ultra-high strength aluminum alloy developed by Alcoa Company in the United States, which was used in the aircraft airfoil of B777. The use of aluminum alloy plates makes about 635 kg reduction compared with the designed mass in B777 [1,2]. With the development of manufacture of aircraft, higher requirements of the properties (strength, toughness, ductility and corrosion resistance) of aluminum alloy were put forward. Mechanical properties strongly depend on the internal microstructure of the material. It is known that finer grain is beneficial to improving the mechanical properties. Therefore, control of the microstructure evolution during hot deformation plays a vital role in the optimization of the mechanical properties. Dynamic recrystallization (DRX) is a common phenomenon in the hot plastic deformation and it has a great influence on the microstructure and mechanical properties of the material. Many models and methods have been applied to studying the DRX process in metal material, such as empirical models [3], method phase field (PF) [4,5], Monte-Carlo method (MC) [6−8] and cellular automaton method (CA) [9,10]. The values of DRX fraction and grain size can be calculated in empirical models fitted by experiment, while the grain morphology cannot be simulated. The disadvantages of PF and MC are that model parameters are difficult to be determined and the computing efficiency for huge amount of calculation is low. Compared with other methods, the evolution law can be applied to physical system in discrete space-time and the CA method is more flexible in simulating the DRX process. HESSELBARTH and GOBEL [11] first studied the static recrystallization by CA method and the effects of neighbor types and nucleation types on DRX kinetics were studied. The simulation of DRX process was first studied by GOETZ and SEETHARAMAN [12] and the processes of dynamic recovery, nucleation and grain growth were taken into account. SHI et al [13] established a modified CA model to simulate three-

Foundation item: Projects (51175257, 51405520) supported by the National Natural Science Foundation of China
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DOI: 10.1016/S1003-6326(17)60154-7

dimensional dendrite growth. JIN et al [14] put forward an adaptive response surface method to acquire identification of nucleation parameter for cellular automaton model. RAABE [15−17] established a probabilistic CA model determined by driving force on the basis of deterministic CA model. The combination of physical metallurgy principle and random algorithms was applied in CA model by DING and GUO [18,19]. Effects of strain rate and temperature on the flow stress and DRX process in hot deformation for different metals were studied [20].

However, studies on prediction of the micro-structure evolution during DRX process of aviation material, especially for 7055 aluminum alloy, were rarely published. The effects of deformation parameters (strain, strain rate, temperature and initial grain size) on DRX process were not studied comprehensively in previous researches and they need to be further studied as the DRX behavior varies under different deformation conditions. What is more, the kinetic rule of DRX can describe the DRX speed and the Avrami exponent is a vital parameter to describe the accuracy of the CA models. In this study, the hot compression experiments for 7055 aluminum alloy on Gleeble 3180 machine were conducted and models of cellular automaton were built. The equations of dislocation density, nucleation rate and grain growth were fitted by least square method. The microstructure evolution during hot deformation by CA was simulated and the effects of strain, strain rate, temperature and initial grain size on the microstructure were investigated. Simulated microstructures by CA method were compared with experimental isothermal compression tests. In addition, kinetic equation of DRX was analyzed and Avrami exponent agrees well with the theoretical value.

2 Models of cellular automaton

DRX is a common phenomenon when the dislocation density reaches the critical value during hot deformation. CA models are adopted to describe the relationship between the flow stress, DRX fraction and grain size. In CA model, the complex object is divided into cells discrete in time and space, and complex issues can be described through random algorithm and transition rules between the cell and its neighborhood. Status values of each cell are updated at each time step according to the transition rules between the cell and its Moore neighborhood. The CA models established in this study contain four modules: initial microstructure module, dislocation density module, nucleation rate module and grain growth module, which are described as follows.

2.1 Model of initial microstructure

The homogenization treatment should be conducted before the thermal deformation for 7055 aluminum alloy ingot casting. The objective of homogenization treatment is to decrease microsegregation and acquire super saturated solid solution in the casting process. After homogenization treatment, equiaxial structure with uniform grain size can be obtained. In CA model, the nucleation points were spread uniformly into the simulation zone and they grew into equiaxial grains in all directions with the same probability. Figure 1 shows the initial microstructure of 7055 aluminum alloy with the grain sizes of 100 and 150 μm, respectively.

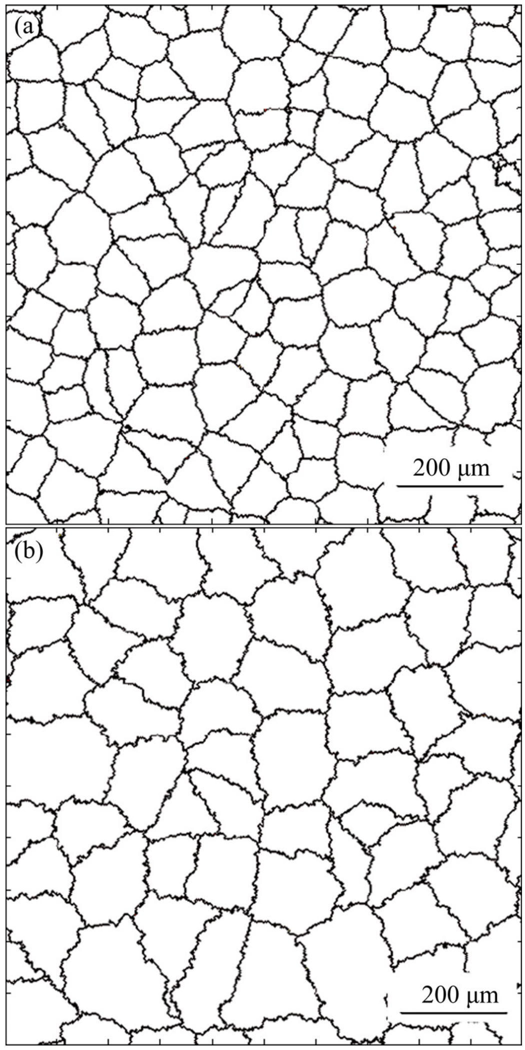

Fig. 1 Initial microstructure of 7055 aluminum alloy with grain sizes of 100 μm (a) and 150 μm (b)

2.2 Model of dislocation density

The dislocation density in material plays a vital role in microstructure evolution during DRX. The variation of dislocation density depends on two processes: work hardening and dynamic softening. Dislocation density is increased with the increase of strain during hot