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EFFECT OF STRAIN RATE ON THE MICROSTRUCTURAL DEVELOPMENT IN DC CAST AL-15SI ALLOY

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Abstract

Hot compression at 573K under different strain rates was conducted on DC cast Al-15% Si alloy. The effect of strain rate on the microstructure development was investigated. Microstructureal characteristics and deformation behavior of Al-15% Si alloy were discussed by analyzing of flow curves, optical microscope and electron back-scattering diffraction (EBSD). The results show that the peak and steady-state stresses are influenced by increasing of strain rate. The alpha-Al dendrits are almost disappeared and Si particle distribute homogeneously in the Al matrix with less of them cracked under every strain rate. The size of continuous dynamic recrystallized (CDRXed) grains decreases and the volume fraction of these grains increases with the strain rate increases. It is also observed that the fraction of HABs increases gradually and that of LABs decreases considerably as strain rate increases. It is realized that deformation under high strain rate help for CDRX to occur.

Introduction

Al-Si alloys are widely used in automotive and aerospace industries due to their higher strength, good wear resistance, low density and low thermal expansion co-efficient [1, 2]. However, these alloys exhibit poor ductility, which greatly restrict their potential applications. For metallic materials, hot working process, such as hot forging, extrusion and rolling, are usually used to optimize the microstructure and improve the mechanical properties. In general, it is widely accepted that Al-Si alloys are the materials to be difficult-to-deform because the existence of coarse primary Si particles which lead to the poor workability. However, a small amount of work has been focused on the hot deformation of Al-Si alloys recently [3-5]. Now, the present group improved the microstructure and mechanical property of direct chill (DC) cast Al-Si alloys by conventional hot working process [6, 7]. The microstructural evolution of materials during hot deformation is closely related to the deformation conditions [8-10]. To obtain a superior performance, the microstructure evolution of Al-Si alloys during hot deformation should be studied. However, the microstructural evolution of these alloys during hot deformation has not been investigated in great detail and there is little research work reported on the effect of strain rate on the microstructural development in these alloys.

Accordingly, in the present research hot compression testing under different strain rates at 573K is employed on direct chill (DC) cast Al-15% Si alloy (wt.% is used throughout, unless specifically indicated otherwise). The objective is to study the effect of strain rate on the microstructure development of Al-15% Si alloy and to give a quantified evolution of microstructure. Microstructural characteristics and deformation behavior of this alloy are discussed by analyzing of flow curves, optical microscope and electron back-scattering diffraction (EBSD).

Materials And Experimental Procedure

Al-15% Si Alloy Preparation And Heat Treatment

The experimental material Al-15% Si alloy was prepared with commercial pure aluminum and silicon by DC cast at temperature of 993K and cast speed of 62.4mm/min. A chemical analysis of the ingot by emission spectroscopy gave, in wt. %, 14.6% Si, 0.11% Fe, balance aluminum. The microstructure of as-cast Al-15% Si alloy consists of primary silicon particles about 10~30 μm in size, full developed alpha-aluminum dendrites and refinement of interdendritic Al-Si eutectic structure, as shown in Fig. 1a. Fe impurities in the alloy led to the formation of a small amount of Fe-containing phase.

Cylindrical specimens with a diameter of 10 mm and a height of 15 mm were machined from the 1/2 radius part of the ingot. The specimens were pre-heat-treatment at 773K for 2h followed by water quenching to room temperature. Following pre-heat-treatment at 773K for 2h, the as-cast interdendritic eutectic silicon have been replaced by fine Si particles with sizes about 0.3~3.5 μm distributing in the aluminum matrix, as shown in Fig. 1b.

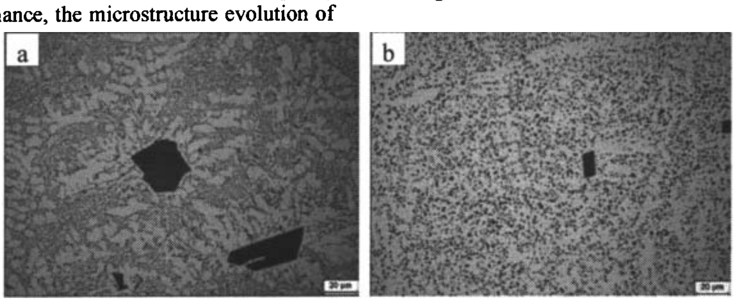

Fig. 1 Microstructure of Al-15% Si alloy: (a) DC cast and (b) heat-treated at 773K for 2h

Hot Compression And Microstructure Characterization

Hot compression tests were carried out on a Gleeble 1500D thermal simulation machine with different strain rates at 573K up to strain of 0.92. In order to reduce the frictional force between the press indenters and the specimens, a graphite lubricant was used during the isothermal compression tests. Each specimen was heated to the deformation temperature at a rate of 10K/s by thermocoupled feedback-controlled AC current and hold for 180s before deformation. The variation of true stress and true strain were obtained from the controlling computer equipped with an automatic data acquisition system. As soon as the compression deformation ended, the specimens were quenched with water jet sprays immediately and then sectioned parallel to the compression axis for microstructure characterization. There are no visible cracks or other defects were initiated in the Al-15% Si specimens during the hot compression.
The cutting specimens were prepared for optical metallography (OM) and EBSD analysis in the standard manner. OM measurements were conducted using a Lecia DMI5000M optical microscope. EBSD measurements were carried out using a JEOL-7001F Scaning Electron Microscope equipped with HKL software. In the data presented, boundaries with misorientations higher than 15° were defined as high angle boundaries (HABs) and low angle boundaries (LABs) as having a misorientation between 3° and 15°. LABs with misorientation less than 3° were not taken into account.

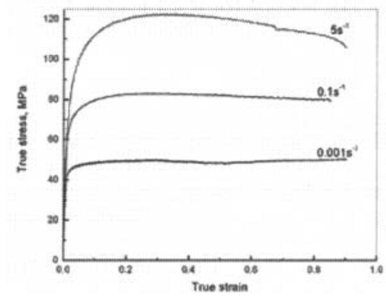

Fig. 2 True stress-true strain curves during hot compression deformation at 573K

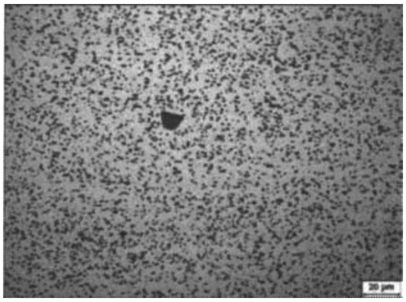
Fig. 3 The typical optical micrograph of Al-15% Si alloy deformed at temperature of 573K and strain rate of $5s^{-1}$ up to strain of 0.92

Result and discussion

Hot Compression Deformation Behavior

Fig. 2 presents typical true stress-true strain curves obtained from the hot compression of Al-15% Si alloy with different strain rates at 573K up to strain of 0.92. It can be seen that every flow curve increases and reaches its maximum at early stage then drops to a stable steady-state stress or until the end of compression. This suggests that dynamic softening due to possible dynamic recovery, dynamic recrystallization in aluminum matrix or Si particles damage has happened in the present alloy. And it shows that flow softening is more obvious at higher strain rate, whereas the steady state flow lasts longer at lower strain rates.

Development Of Microstructure

At a low magnification, the microstructure of the alloy with different strain rate has no great difference. Fig. 3 shows the typical optical micrograph of Al-15% Si alloy deformed at temperature of 573K and strain rate of $5s^{-1}$. It can be seen that the alpha-Al dendrites is almost disappeared and the Si particles distribute reasonably homogeneously throughout the material. The morphology and size of the Si particles is nearly the same as prior to deformation with less of them cracked by shear stress, as expected from their undeformable nature.
At a higher magnification, Fig. 4 shows the effect of strain rate on the aluminum matrix microstructure development during deformation. It is seen that the volume fraction of equiaxed fine grains considerably increases and the grain size of equiaxed fine grains decreases as strain rate increases. The results obtained are consistent with other studies where the final grain size at a given deformation temperature was shown to decrease with an increase in strain rate [9, 10]. Noticeably, the equiaxed fine grains mainly appeared in the Al matrix with high fraction of large Si particles and the boundaries with silicon particles composed to integrated equiaxed grains. However, there is little such grains appeared in the Al matrix with low fraction of large Si particles. It suggests that Si particles play an important effect on the formation of these fine equaxied grains. It can also be seen that small Si particles precipitate on the Al matrix and the volume fraction of small Si particles is much larger at low strain rate. This because the deformation temperature is lower than the pre-heat-treatment temperature and with low strain rate more time is available for small Si particles precipitate. But as can be seen from Fig. 4, these small Si particles have little effect on the formation of grains and grain growth in the Al matrix.
It is clearly visible that the microstructure on the Al matrix is mixed with a few numbers of equiaxed grains with size of 3.1 μm and relatively elongated grains, when the sample is deformed at low strain rate of $0.001s^{-1}$. With increasing strain rate at $0.1s^{-1}$, the fine equiaxed grains with size of 1.9 μm is appeared to develop and the volume fraction of this grains is noticeably increased. With further increasing of strain rate at $5s^{-1}$, the average grain size of fine equaxied grains decreases to 1.4 μm. It can be concluded that the kinetics of grain growth is diminished with increasing strain rate.

EBSD Analysis

To study the effect of strain rate on the evolution of the Al matrix microstructure in Al-15% Si alloy, the typical boundary misorientation maps of the deformed specimens were carefully analyzed by EBSD. Fig. 5 shows the EBSD data of the samples deformed at 573K up to strain of 0.92 with different strain rates. In the maps, HABs (≥15°) and LABs (3°~15°) are represented by

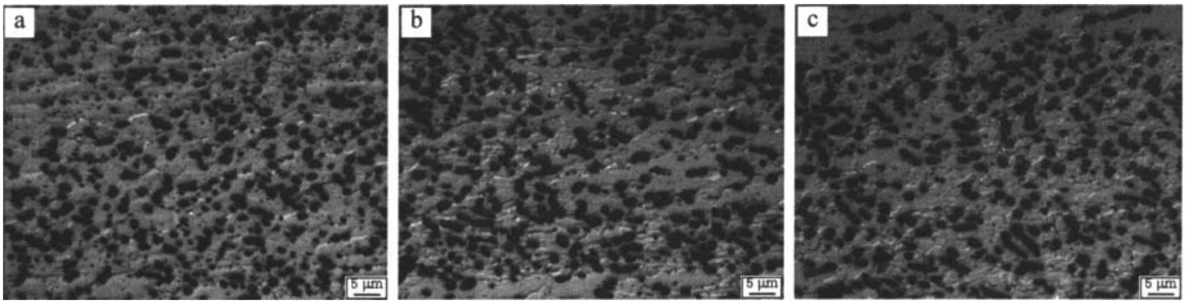

Fig. 4 Optical microstructure of specimens hot compression at 573K under different strain rates up to strain of 0.912: (a) 0.001 s^{-1}, (b) 0.1 s^{-1} and (c) 5 s^{-1}.

dark and light lines, respectively. The white areas represent the Si particles. It can also be seen that fine equiaxed grains surrounded by high angle boundaries mainly appeared in the high fraction of large Si particles and adjacent to the Si particles. This could be suggests that fine equiaxed grains have been generated as a result of particle stimulated dynamic recrystallization [11, 12]. There are a number of incomplete high angle boundaries present in the Al matrix grains. This evolution process is assisted by sub-boundaries gradual transformation into high angle boundaries and is called a continuous dynamic recrystallization (CDRX) [13, 14]. The CDRXed grains become very fine with increasing strain rate. It can be realized that the time necessary for grain growth is diminished and the growth rate decreases with increasing strain rate, so that the coalescence of CDRXed grains is inhibited.

Fig. 6 illustrates the percentage of LABs and HABs and the fraction of recrystallized grains with strain rate, which was calculated from the EBSD result. It can be seen from Fig. 6a that the fraction of HABs is increased gradually and that of LABs is decreased considerably with increasing strain rate. It can be realized that deformation with high strain rate can develop the HABs effectively. Fig. 6b shows that the fraction of recrystallized grains is increased gradually with increasing strain rate. At low strain rate deformation, more time is available for dislocation rearrangement and annihilation [15] the possibility for aluminium matrix to undergo polygonization is higher, and then particle stimulated dynamic recrystallization may become less viable. Therefore the fraction of recrystallized grains is increased gradually with increasing strain rate.

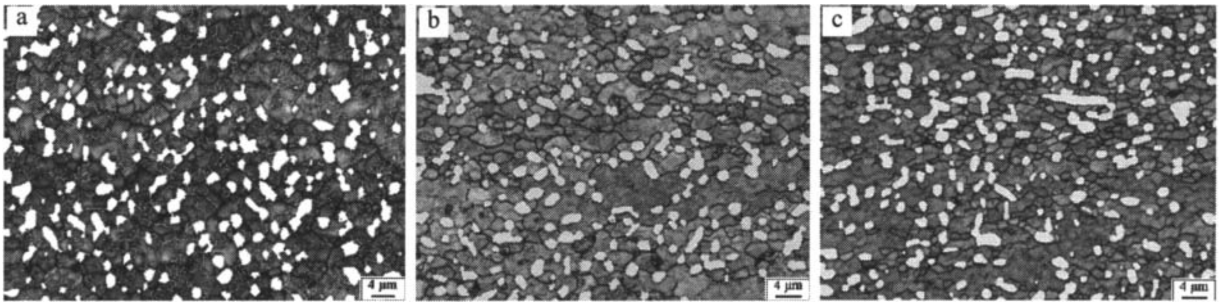

Fig.5 The EBSD maps of specimens hot compression at 573K under different strain rates up to strain of 0.912: (a) 0.001 s^{-1}, (b) 0.1 s^{-1} and (c) 5 s^{-1}.

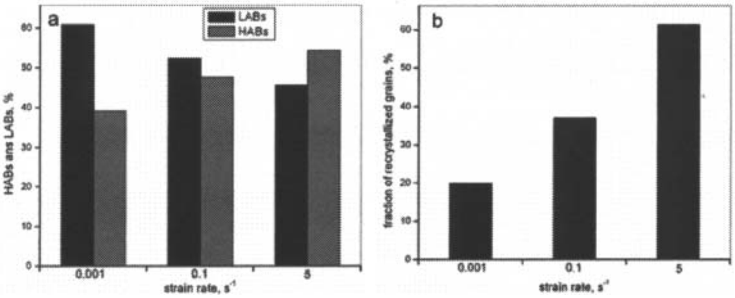

Fig. 6 The effect of strain rate on the percentage of HABs and LABs (a) and fraction of recrystallized grains (b) in hot compression specimen up to 0.912 at 573K.

Conclusion

Hot compression tests were performed on a DC cast Al-15% Si alloy under different strain rates at 573K. The effect of strain rate on the microstructure development was investigated. The following conclusions could be drawn:

Hot deformation under different strain rate up to strain of 0.92, the α-Al dendrites is almost disappeared and the Si particles distribute reasonably homogeneously throughout the material. The morphology and size of the Si particles is nearly the same as prior to deformation with less of them crack. The strain rate has a significant influence on the flow behavior of the present alloy and the microstructure of Al matrix. The size of CDRXed grains decreases and the volume fraction of these grains increases with the strain rate increases. The fraction of HABs is increased gradually and that of LABs is decreased considerably as strain rate increases. The large fraction of Si particles stimulated CDRX.

Acknowledgements

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