High Temperature Deformation and Microstructure Evolution Behaviours of 7075 Cast Aluminum Alloy under Multi-pass Loading

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Abstract. To analyse the effects of loading pass and heating temperature on the deformation behaviour and microstructure evolution of 7075 cast aluminium alloy, multi-pass high temperature loading experiments on Gleeble-3500 thermal simulation compressor were carried out. The results indicated that under each loading, all the true stress-strain curves are typical dynamic recrystallization curves. As strain increases, the stress increases sharply and then basically remains unchanged when it reaches a maximum value. As temperature rise, the peak value of flow stress slightly decreases when the temperature is less than 350°C, whereas it increases slightly when the temperature is larger than 350°C. The grain was elongated perpendicular to the axis. Only a small amount of fine recrystallized grains were found to nucleate and grow at grain boundaries at a lower temperature (250°C). As temperature increased, the recrystallized grain gradually increases, and its proportion gradually also increases until the recrystallization is basically completed. The achievements can provide a guideline to select processing parameters for the processes of metal forming of 7075 cast aluminium alloy, such as ingot blooming, spinning and extrusion.

Keywords: flow stress; hot compress deformation; 7075 cast aluminium alloy; multi-pass loading; microstructure.

1. Introduction

7075 high-strength aluminium alloy (HSA) thin-walled parts have been widely used in high-tech fields such as aviation, aerospace and weaponry because of their light weight, high strength and good corrosion resistance[1,2]. The forming process that the thin-walled parts can be directly produced by the plastic forming from a cast blank can overcome the shortcomings of the traditional manufacturing method of such parts, such as long cycle, low material utilization and high-cost [3]. However, this process of cast HSA is a complex process of multi-field and multi-factor coupling, which lead material to undergo a particularly complex process of inhomogeneous plastic deformation and microstructure evolution. Thus, various macro and micro defects, such as coarse grain, inhomogeneous structure, cracking and peeling, are easily produced during the process if the forming process is not properly controlled.

In the multi-pass loading thermal compression test process of cast HSA, hardening and softening processes, for example, dynamic recovery and dynamic recrystallization are carried out at the same time, which affect the final properties of the material [4]. As a result, how to predict the deformation
and microstructural evolution behaviours of 7075 cast HSA rapidly and accurately has become urgent for the development of the process. Researches on the prediction of deformation and microstructural evolution behaviours of 7075 cast HSA during a hot compression test process have been made for a long time. However, most of them are focused on forging HSA [5,6], and the research on cast HSA has been still scarce. For this reason, the deformation behavior and microstructural evolution of 7075 cast HSA at the high temperature are analysed by the multi-pass hot compression test. The achievements can provide a guideline to select processing parameters for the processes of metal forming of 7075 cast aluminium alloy, such as ingot blooming, spinning and extrusion.

2. Material and Method
The raw material used in the experiment is a semi-continuous cast tube of 7075 aluminium alloy. The size of the tube is $\phi 170\text{mm} \times 10\text{mm} \times 180\text{mm}$. The original microstructure is shown in Figure 1. And the grain size was measured by linear intercept method.

![Figure 1. Original cast structure of 7075 cast aluminum alloy](image1)

The cylindrical compression specimen with the size of $\phi 10\text{mm} \times 15\text{mm}$ was cut out from the 7075 cast aluminium alloy tube by the ire-electrode cutting.

![Figure 2. Gleeble-3500 thermal simulator](image2)

The quasi-static isothermal compression tests under multi-pass loading were carried out on the Gleeble-3500(see figure 2) thermal simulator at the temperatures of 250, 300, 350, 400 and 450°C and the compression deformation 20%, 40%, 60% and 80%, respectively. And the strain rate is 0.01s$^{-1}$. 


3. Result and Discussion

3.1. High Temperature Deformation Behavior of 7075 Cast Aluminum Alloy under Multi-pass Loading

3.1.1. Stress-strain Characteristics under Multi-pass Loading. Multi-pass hot compression experiments of 7075 cast HSA were carried out with a Gleeble 3500 thermal simulator. The multi-pass hot deformation behavior of 7075 cast aluminium alloy was obtained, as shown in Figure 3. From the figure, we can find that the stress raises fast as strain increased in the initial stage of each pass, in addition the increasing rate increases with the increase of loading passes. Moreover, when the stress reaches a maximum value, it does not change with the increase of strain. When the temperature is low (250°C) at pass 1, the true stress-strain curve does not show obvious softening characteristics. As the loading pass and temperature increased, the softening characteristics of the true stress-strain curves are becoming more and more obvious. The reason is that at higher heating temperature and loading pass, the dynamic recrystallization of the material is obvious, and the trend of dynamic recrystallization becomes more and more obvious with the increase of temperature and the deformation.

![Figure 3. True stress-strain curves of 7075 cast HSA under multi-pass loading](image)

3.1.2. Variation of Peak Stress with Loading Passes. The change regularity of peak stress with loading passes under different temperature is shown in figure 4. As can be seen from the figure, the peak stress slightly decreases as loading passes increased at relatively low temperature (<300°C), and the decreasing trend of it is gradually weakening with the increase of temperature. However, the peak stress slightly increase along with loading passes increasing at relatively high temperature (300°C<).

![Figure 4. Variation of peak stress with loading passes](image)
3.1.3. Variation of Peak Stress with Heating Temperature. The change law of peak stress with the heating temperature under different loading passes is shown in figure 5. From the figure, it can be seen that with deformation temperature increasing, the value of peak stress decreases gradually with heating temperature increasing, while the effect of loading passes on it can be neglected.

![Curves of peak stress with preheating temperature](image)

Figure 5. Curves of peak stress with preheating temperature

3.2. Microstructure Evolution Behavior of 7075 Cast HSA under Multi-pass Loading

3.2.1. Effect of Heating Temperature on Microstructure Morphology. Figure 1 shows the initial microstructures of 7075 cast HSA before uncompressing. It can be seen from the figure that the initial microstructures of 7075 cast HSA are coarse equiaxed dendrites; the average grain size measured is about 108.6μm.

Figure 6 shows the microstructures of the 7075 cast HSA at different deformation temperatures. It can be seen from the figure that the grains are elongated perpendicular to the axial direction of the compression specimen. When the heating temperature is below 250 °C, the original grains are deformed and elongated, and only a small number of fine recrystallized grains nucleate and grow at grain boundaries (see Fig.6a). With temperature increasing, the elongated grains decreased, while the recrystallized grains and their proportion increased (see Figs.6 b and c). When the temperature reaches 400 °C, the recrystallization has been basically completed. And the grains grow up gradually with the increase of the temperature (see Figs. 6 d and e).
3.2.2. Effect of Preheating Temperature on Grain Size. The change curve of grain size with temperature after deformation under the multi-pass loading is shown in Figure 7. From the figure, the grain size decreases firstly and then increase with the increase of deformation temperature. The reason is that during high temperature multi-pass loading compression of 7075 cast HSA, the large plastic deformation and dynamic recovery recrystallization coexist. Large plastic deformation and appropriate dynamic recrystallization can refine grain size. However, with deformation temperature increasing, the grain size growth trend caused by recrystallization is larger than that caused by large deformation. Therefore, the grain size becomes coarser.

Figure 6. Microstructure of 7075 cast HSA at different deformation temperatures

Figure 7. The variation curve of grain size with temperature after deformation under the multi-pass loading
4. Conclusions
1) The stress increases rapidly with strain increasing in the initial stage of each pass, and the increasing rate increases with the increase of loading passes. As loading pass and deformation temperature increase, the softening characteristic of the true stress-strain curve become more and more obvious.
2) As heating temperature increased, the value of peak stress deceases gradually, while the effect of loading passes on it can be neglected.
3) The grain size decreases firstly, and then increases with deformation temperature increasing.
4) During the multi-loading compression process of 7075 cast HSA, large plastic deformation and appropriate dynamic recrystallization can refine grain size.

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