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MICROSTRUCTURAL CHARACTERISTICS OF HOT FORGED AL 6061 ALLOY

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Abstract

Many researches have been already done on the issues of high temperature deformation and the microstructural evolution. The information has been very useful for the plasticity industry, especially successful for the extrusion. However, the parts made with forging usually have a complex shape. It is difficult to control the distribution of the variables like strain, strain rate and temperature rise due to the working heat during a hot-forging process. Consequently, the microstructural variation could be occurred depending on the plastic deformation history that the forged part would get during a hot forging. In the present study, the microstructural characteristic of a hot-forged 6061 aluminum alloy has been discussed on the aspect of grain size evolution. A forging of 6061 aluminum alloy has been carried out for a complex shape with a dimensional variation. Also, finite element analysis has been done to understand how the deformation variables such as strain, strain rate give an influence on the microstructure of a hot forged aluminum product.

Keywords : Hot Forging, 6061 Al, Microstructure, Finite Element Analysis

1. Introduction

Most automakers started to develop the aluminum parts from car body and closure to chassis components since the early 1990s. One of the most remarkable examples is the concept model "Prodigy" made by Ford, which belongs to the North American mid-size class, so-called PNGV(Partnership for a New Generation of Vehicles) grade, but just weighs 1,085 kgf. Usually, suspension parts take 25% of the total weight for a mid-size car. Specifically, Al counterpart could weigh just around 2.5~3kgf in the most retail cars, while the conventional steel control arm consisting of several parts ranges over 5 kgf.

These aluminum control arms are made from a hot forging process. Since most control arms have the complex shape, it is difficult to get the uniform distribution of strain, strain rate and temperature rise due to heating over a part, which could bring a variation of microstructure and mechanical properties. It has been well agreed that aluminum and its alloys have a recovered microstructure after a warm deformation. If the above explanation still works in the case of a hot forging with a high-speed press, it is easy to control a microstructure even after uneven distribution of strain on the hot forged parts.

In the present study, we have investigated the microstructural characteristics of a hot forged 6061 aluminum alloy. Finite element analysis has been done to understand how the deformation variables such as strain, strain rate give an influence on the microstructure of a hot forged aluminum product. The calculated results were discussed with the conventional metallographic observations.

2. Hot Forging of 6061 Aluminum Alloy

Model geometry has been designed to investigate the various factors encountered during forging. The sections circled in Fig. 1 were chosen for microstructural observation with the finite element analysis. Hot forging was carried out with 6061 aluminum alloy at the temperature of 400°C.

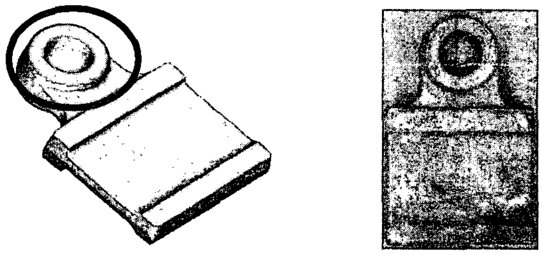

Fig. 1. Model geometry for a hot forging experiment and forged part.

Fig. 2 represents the distribution of strain and strain rate over the mentioned section in model I. Fig 2(a), (b) and (c) shows the distribution of strain, strain rate and temperature just at the final step of a hot forging. It is quite astonishing from Fig. 2(d) that the grain size of a forged sample differs from region to region greatly. The left part of section in Fig. 2(d) shows the large elongated grains with the size of tens of mm, which is likely to be originated from a deformation assisted grain growth. On the other hand, the thinner center section has the small grains with the size of less than 100μm. Feathery grain boundaries are observed at the right lower section, which is a familiar example of recovered structures. Since forging operation was conducted at the same temperature(400°C), those microstructural differences are closely related with the variation of strain, strain rate and temperature, etc. over the different region. From FE analysis, all of above mentioned variables were calculated. Fig. 3 shows the respective microstructures taken three different regions as marked in Fig. 2(d).

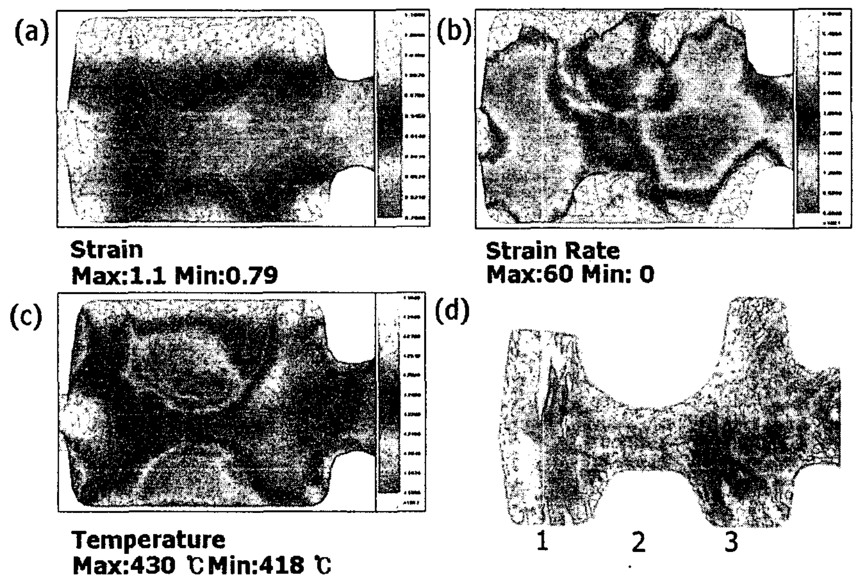

Fig. 2. Finite element analysis results and section view of a hot forged model mentioned in Fig. 1 (a) strain distribution, (b) strain rate distribution, (c) temperature distribution and (d) macrostructure showing a wide range of microstructural differences.

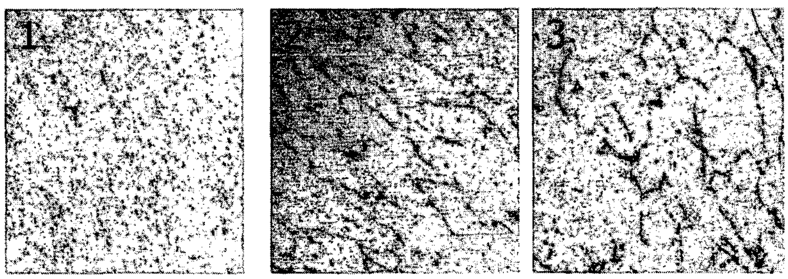

Fig. 3. The microstructure of the respective regions in Fig. 2 showing the recovered structure.

When the macrostructure and strain distribution were compared(Fig. 2(a) and (d)), it is possible to observe that grains coarsen with the increment of strain amount(ε>0.95). Grains could agglomerate due to dislocation rearrangement along a special direction with the strain. Texture and particle characteristics with grain boundaries could also be related with this abnormal grain growth. The small grains in the middle section are not clear whether they are the recrystallized grains or not. There is a chance for the material with a high amount of hard particles to accumulate enough energy for recrystallization. From FE result, the small-grained region gets the strain rate of about 60/s, much higher than the rest of regions (10~20/s). As strain rate gets higher, a recrystallization process could substitute climb-controlled recovery.

Fig. 4(a) represents the recovered structures after the deformation at the temperature of 400°C. The subgrains with the size of 3~5μm were well developed after deformation. From the TEM micrograph, it was possible to confirm that the controlling mechanism is a climb-controlled deformation again. It is worthwhile to note that the precipitation behavior founds to differ from the original material after a hot-forging in the present study. Fig. 4(b) shows the uneven distribution of precipitates in a hot-forged 6061 aluminum alloy for example. More detailed explanation on this phenomenon would be reported in the other paper soon.

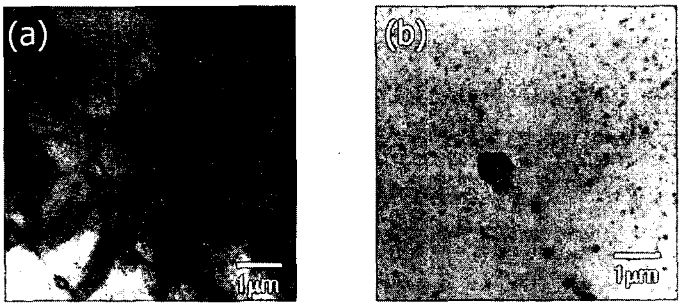

Fig. 4. TEM micrograph of (a) after forging and (b) T6 heat treatment.

3. Conclusion

A hot forging of 6061 aluminum alloy should be carefully controlled to ensure an uniform microstructure and mechanical properties. For that purpose, a forged component should be designed with the concern of the microstructural evolution during a hot forging step.

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