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Superplastic Behavior of Al5083 Alloy during Microforming Process

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Abstract

Microformability and superplastic behavior of Al5083 alloy was investigated by finite element analysis and the simulation result was compared with the previously reported experimental result. Micro V-groove die was modeled to analyze the effects of forming time, load, temperature, and interface friction on the microformability of the Al5083 alloy. Geometrical transferability was used to represent the formed surface topology and the area of material flow into the die groove. The microformability of the Al5083 alloy was estimated by R_f values ($=A_f/A_g$), where A_f is the filled area of microformed sample, and A_g is cross sectional area of V-groove. The simulation result suggests that the temperature and the interface friction have significant effects on the accuracy of the hot microforming model. Also, high strain rate detected during microforming simulation is suspected to be another important parameter affecting microformability.

Keywords

Microformability, Superplasticity, High strain rate, Al5083 alloy.

1. Introduction

Microforming is a manufacturing process to produce miniature parts for various engineering applications. The parts manufactured by the microforming technology are commonly used in everyday life, such as consumer electronics, mobile phone, and etc.[1]. Also, the microforming technology is receiving increasing interest from micro system technology (MST) or medical sectors [2]. Although some of the parts are currently being produced by microforming technology, but still now the major numbers of these parts are produced using conventional manufacturing process. For small quantities conventional process may be applicable, if asked for large quantities, microforming technology seems to be appropriated due to its well known advantages [2].

Superplastic forming of aluminum alloys is under increasing interest from industries due to high demands for lightweight materials in various engineering application. In general, superplastic deformation of metals is achieved with a very small grain size less than 10 to 15 µm [3]. The 5XXX aluminum alloys, especially Al5083 alloy have useful material properties including good corrosion resistance, weldability, low density, and relatively high strength [4], and they generally exhibit good superplasticity [4,5]. In this regard, various researches have been conducted on the superplastic deformation of Al5083 alloy, which superplastic condition obtained via grain refinement by static recrystallization prior to deformation [6]. According to Cleveland et al. [6] the slightly difference strain rate sensitivities and variations in alloy composition have significant effects on superplastic elongation. Patankar and Jen [7] investigated the effect of strain rate on Al5083 alloy. The result of Patankar and Jen [7] suggested that dynamic recrystallization is responsible for the superplastic behavior of Al5083 alloy. Park et al. [8] have investigated the high strain rate superplasticity of sub-micrometer grained Al5083 alloy containing dilute amount of scandium (Sc). According to Park et al. [8] tensile tests under high strain rate showed the failure occurred in a brittle manner related to cavitations.

In spite of many works carried out on the superplasticity of Al5083 alloy, not much attention has been directed on the superplastic behavior during microforming of Al5083 alloy. Son et al. [9] investigated the superplastic behavior of Al5083 alloy during microforming by using microforging apparatus. Their experimental result showed that microformability of Al5083 alloy improved as the increasing forming load and time at superplastic temperature range. W.J. Kim, et al. [10] investigated the transition behavior from superplastic flow to non-superplastic flow during microforming of Mg-9Al-1Zn alloy.

In the present study, a numerical model is proposed to describe superplastic microformability of Al5083 alloy. Effect of forming conditions such as strain rate, time, load, temperature, and friction coefficient on microformability will be discussed based on the result of finite element analysis.

2. Constitutive Equation for Al5083 Superplastic Alloy

Superplasticity is the ability of a material to undergo large amounts of tensile deformation prior to fracture. Any material that is able to withstand tensile elongation greater than 200% prior to failure is considered to be superplastic material. Superplasticity is frequently defined in terms of strain rate sensitivity exponent m, which is defined as [11]

$$m = \frac{d \ln \bar{\sigma}}{d \ln \dot{\bar{\varepsilon}}} \qquad (1)$$

where $\bar{\sigma}$ is the effective stress, and $\dot{\bar{\varepsilon}}$ is the effective strain-rate. Equation (1) can be easily rewritten in a different form as:

$$\bar{\sigma} = k \dot{\bar{\varepsilon}}^{m} \qquad (2)$$

where k is the strength coefficient. According to Iwasaki et al. [12], m≈0.5 for the Al5083 superplastic alloy.

3. Numerical Modeling

Microforming simulations of Al5083 alloy were carried out using Deform-2D FEM commercial software. The microforming simulation was set to be identical to the experiments [9] except the friction coefficient, (which was unknown in the experiment). The microforming process with a 16 V-groove die [9] was simulated. Due to the symmetries in geometry and loading condition, only a half of the experimental set-up (8 V-grooves) was modeled as shown in Figure 1. The geometry of the die groove is also shown in Figure 1. The workpiece was meshed with 7000 quadrilateral 4 nodes elements. A higher mesh density was applied to the workpiece-punch interface where the most of the material-flow was expected to occur. The result of a convergence error study in simulation showed that the number of elements used in this study was sufficient to accurately simulate the deformation of the workpiece during the microforming process. The punch and the die were modeled as rigid bodies. The material properties of the Al5083 provided by the manufacturer were adopted in the simulation: Young’s modulus 68.9 GPa, Poisson’s ratio 0.33.

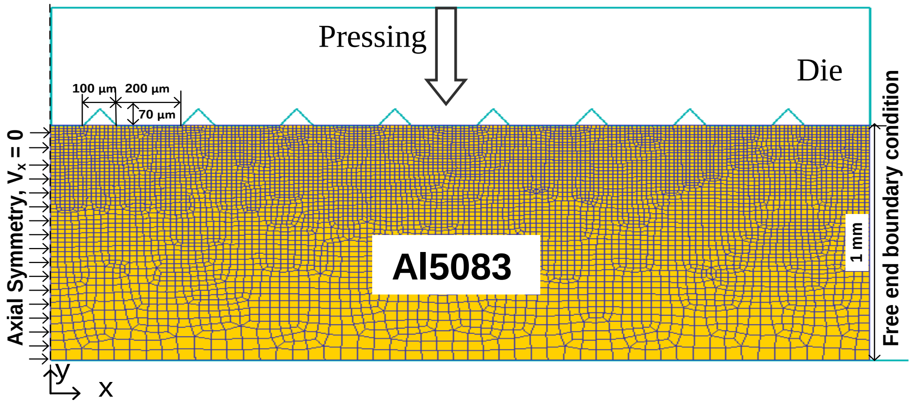

Figure 1: FEM model for microforming process with multiple V-grooves.

The flow stress–strain rate behavior of Al5083 superplastic alloy (Sky Aluminum, Japan) was experimentally evaluated by Iwasaki et al. [12]. Figure 2 showed the flow stress of Al5083 alloy as a function of strain rate and temperature. The flow stress data obtained from the experimental result shown in Figure 2 were then introduced into Deform 2D FEM codes.

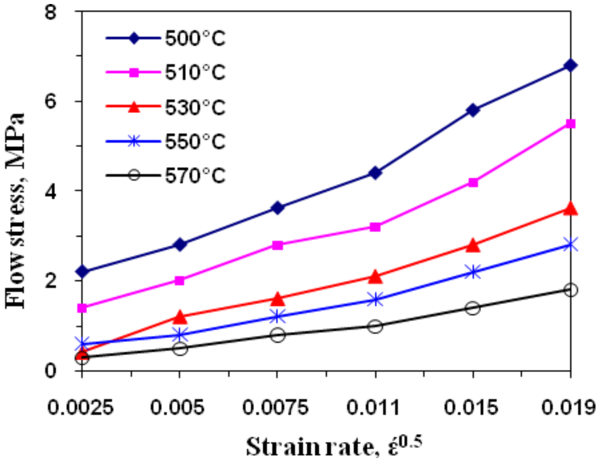

Figure 2: Relationship between flow stress (true stress) and strain rate for various temperatures.

Percentage of flow area R_f (=A_f/A_g) [13] was used as a parameter to evaluate microformability, where A_g is the area of the die groove and A_f is the area of material flow into the die groove, which was calculated in the simulation.

4. Results and Discussion

To investigate the microformability of the Al5083 alloy, the FEM simulation was carried out for microforming with combinations of three different workpiece temperatures, three different forming loads, and three different punch speeds. At 20 min of forming time, R_f was plotted as a function of punch load in Figure 3. Figure 3 shows that the R_f value increased with increasing forming load, and the R_f values reached approximate (~1) at forming load 96 N. At forming load 96 N, the R_f values were very close to each other for the selected workpiece temperatures, but at 37 N of forming load the R_f values decreased as the workpiece temperature decreased. The result suggested that the superplastic microforming strongly depends on temperature.

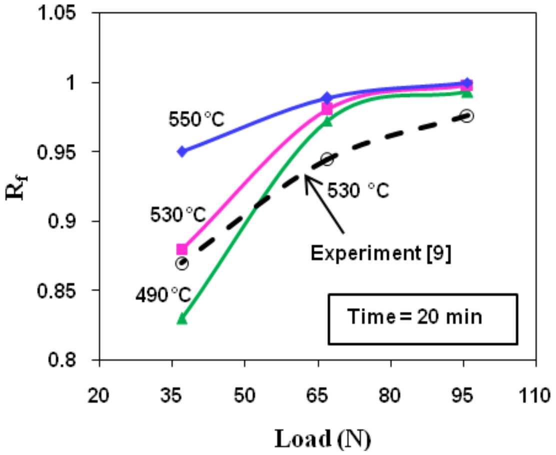

Figure 3: Result of R_f with effect of load

At forming load 96 N, the R_f was plotted as a function of time in Figure 4. Figure 4 shows that the R_f values increased with increasing forming time. Continuous metal flow into the V-groove leads to increased R_f values with increasing forming time. It should be noted that the R_f values were no longer increased as the forming time further increased. It should be the cause of metal flow into the critical depth or the tip of V-groove became harder, where the width is much smaller in comparison with the grain size of Al5083 alloy.

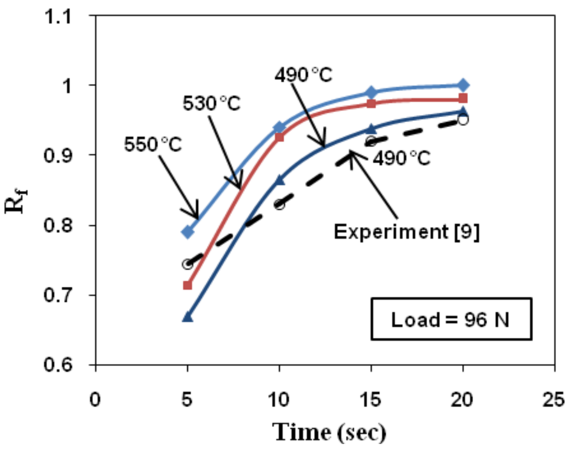

Figure 4: Result of R_f with effect of temperature

Figure 5 shows the calculated R_f with three different punch speeds at the forming temperature 530°C as functions of time. As shown in Figure 5, for all the selected three different punch speeds, the maximum R_f 0.98 could be achieved even though the times to reach R_{fmax} were different. However, the punch loads at R_{fmax} are different for the different punch speeds and the different forming temperatures as shown in Figure 6. Note that the punch load at R_{fmax} corresponds to the maximum load during microforming. The simulation result shows that the load at R_{fmax}, which is the maximum load during microforming, increased as the punch speed increased at the given forming temperature and decreased as the forming temperature increased at the given punch speed.

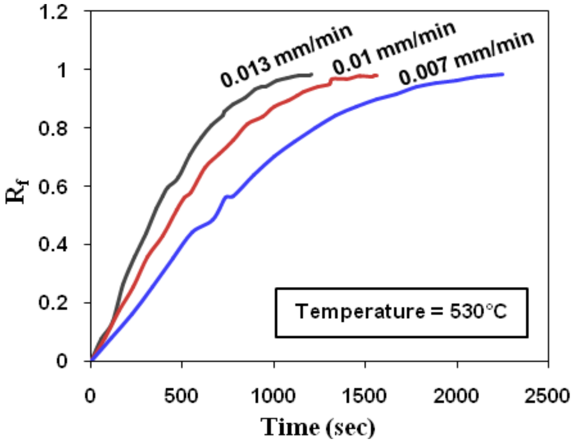

Figure 5: Result of R_f with variation of forming time and punch speed at 530°C

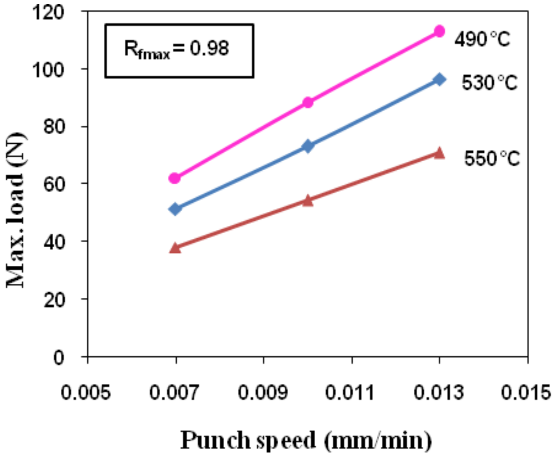

Figure 6: Result of Maximum Load for different punch speed.

Figure 7 shows the FEM result for the microforming on a die with multiple V-grooves after 20 min of forming time. The FEM result showed that die-filling is nearly completed near the center of the die groove, but the degree of die-filling tends to decreased as the groove location moves toward the free end. It might be the cause of material flow in radial direction become higher at free end than center portion. However, if the coefficient of friction increased the degree of die-filling near the free end was increased. The result suggested that the interface friction have significant effect on the material flow during microforming with multiple V-grooves.

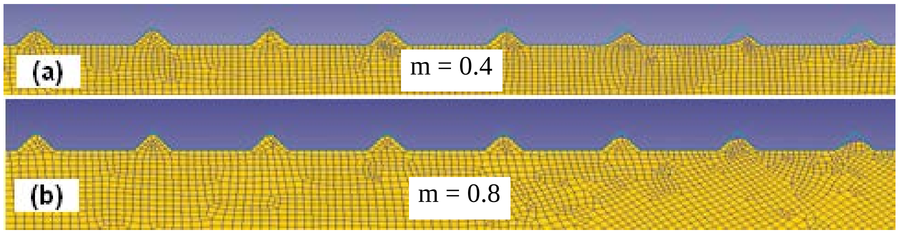

Figure 7: Effect of friction on multiple V-grooves (a) friction coefficient 0.4, and (b) friction coefficient 0.8

Next, to investigate the strain rate effect during microforming, two different test conditions, the constant punch load and the constant punch speed were simulated. The constant punch load, the Al5083 workpiece was subjected to a fixed compressive load 96 N with the microforming time 20 min. Figure 8(a) shows that the material point P1 near the edge of the groove exhibited a significantly higher strain rate than the material point P2 in the early stage of deformation. As the deformation proceeded, the strain rate of the point P1 rapidly decreased while the strain rate of the point P2 became significant as shown in Figure 8(a).

In the case of constant punch speed, the workpiece was subjected to a compressive load at a fixed punch speed 0.013 mm/min until the maximum load 96 N was reached. Figure 8(b) shows that the material point P1 exhibited the high strain rate values up to 720 sec (forming time) then the strain rates became rapidly decreased. On the other hand, the material point P2 showed initially low strain rate but increased sharply at final stage of the deformation. It should be noted that for constant punch speed, the forming load increased with forming time, and the increasing forming load resulted at tip portion of V-groove exhibited the high strain rate deformation. It also observed that the maximum strain rate is exerted at constant punch load.

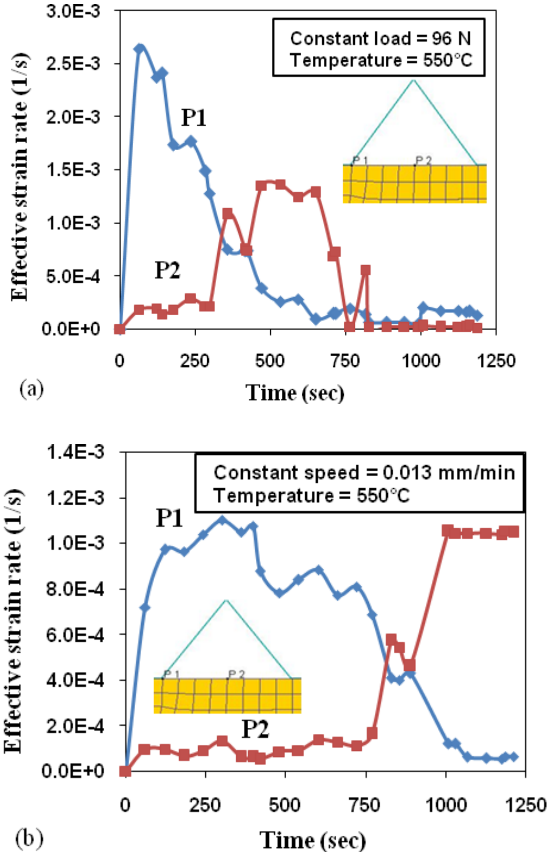

Figure 8: Effective strain rate at the edge and center of a groove: (a) constant punch load; (b) constant punch speed

5. Conclusions

Microformability and superplastic behavior of Al5083 alloy has been investigated by microforming simulation. The results obtained are summarized as follows.

- In microforming simulation on a V-groove die, the degree of die-filling increased with forming load, time, and temperature. For the high friction coefficient result could improve the degree of die-filling during microforming simulation. According to numerical analysis, the microforming simulation results reasonably well agreed with experimental results.
- Microforming on a V-groove die, the constant punch load, and the constant punch speed were two important aspects that affecting strain rate behavior.
- The simulation result suggested that Al5083 alloy not only exhibits good microformability and superplasticity, but also a complex geometric feature could be successfully fabricated via superplastic microforming.

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