# A Study on the Effect of Powder Forging for Cup-shaped Product

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## ABSTRACT

The purpose of this paper is comparing the forging effect according to the shape of preforms of cup shaped powder forging product, and extending the application of powder forging technology to more complicated cup-shaped products like pistons. In order to achieve this, preforms are provided by compacting, sintering, and machining to 5 different shapes, then forged to the final shape of products. The workability for sintered aluminium powder material was examined and confirmed its slope was 0.5 as known. Density and strain loci of forged products are also evaluated and compared. On the basis of the results, the most effective shape of preform was proposed. The preform for the piston which is 50mm in diameter was prepared and hot forged successfully to the final product.

**Keywords :** Powder forging, Cup-shaped product, Workability, Aluminum alloy piston

## 1. Introduction

Powder forging process is a new technology combining the merits of powder metallurgy and precision forging technology. The precious forging process is used for overcoming the limits of mechanical characteristics in sintered products and for unifying the composition and the characteristics of alloys. In the powder forging process, the manufacturing costs can be reduced by making without flash products, and reducing the additional manufacturing by using of closed die forging. Moreover, products having holes or complicated shape can be manufactured with none or without material loss.[1]

Power forging process is divided into three steps, which are hot repressing, closed die forging without flash, and forging with flash. The first kind, the hot repressing process, requires the exact control of weight. In this process, the wear of the tool and die is increased by friction between the die and preform. The second kind, the closed die forging process without flash, is a conventional powder forging process, in which, the weight and shape have to be controlled preciously. The third kind, the forging with flash, this technology approaches conventional forging technology but is not net shape forming compared to those technologies above and places less importance on the control of weight and shape.[2]

The application of powder forging to manufacture engine pistons for vehicles[3], gears[4], parts for oil pumps[5], and parts for shock absorbers has been actively achieved. The purpose of this paper is to compare the forging effects according to the shape of preforms, finding the optimal shape, and extending the application of powder forging technology to cup-shaped products such as a piston.

In order to achieve this purpose, 5 types of preforms which have different shapes were prepared by powder metallurgy and forged by a closed die. The variation of density and the strain loci during the forging process in the specimen were evaluated and compared. On the basis of the results of this experiment, the preform for the final product, a piston which is 50mm in diameter, was prepared. With the preform, a piston, a final product which has a more complicated shape was successfully formed.

## 2. Powder forging process

The powder forging process consists of 4 steps: mixing of the powder, compacting it, sintering it, and forging it. The determination of optimal parameters on the powder forging process is very important. Moreover those parameters are various.

### 2.1 Compacting

The aluminum alloy powder used in the experiment was Alumix 123 (Al-4.5Cu-0.5Mg-0.7Si) produced by ECKART, co. ltd. in Germany and 200mesh (less than 150㎛ in diameter) in size. The powder included 1.5% (mass) of lubricant. Floating die set was designed to provide a uniform distribution of density along the top and bottom of a circular cylinder part as shown in Fig. 1. Generally, the compacting of aluminum alloy powder is performed within 2~5ton/cm$^2$; within the scope of 92~95% with respect to forming density.[6]

In order to estimate how efficiently the forging process affects a density increase, the punch pressure was set at 2ton/cm$^2$, which is the minimum value. This value is around 92% of theoretical density, which means that the compaction of Al powder needs a comparatively lower forming load than Fe or Cu series powders.

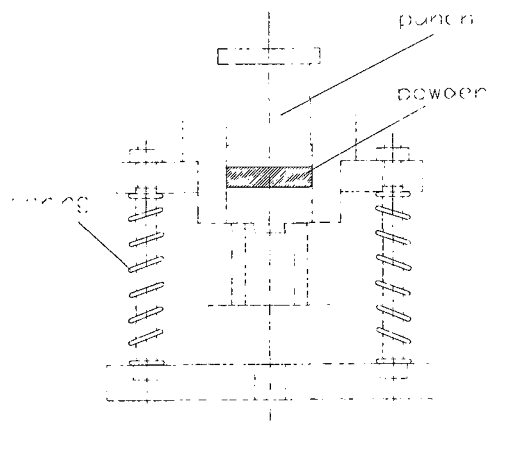


Fig. 1 Description of floating die set.

### 2.2 Sintering

The sintering process consists of 3 steps which are dewaxing, heating, and cooling. The purpose of dewaxing is to remove wax contained in the compact. This is required for perfect sintering. Usually the sintering furnace used for mass production has three continuous zones with different temperatures. Compacts are moved by a conveyer belt system through these zones and the sintering process can be performed continuously. In this paper, those sintering processes were performed in a one-chambered furnace. Sintering conditions in the experiment are shown in Table 1.

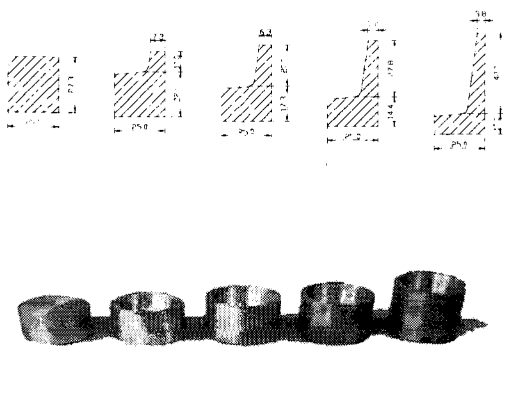
Table 1 Sintering conditions

| process / condition | Dewaxing | Sintering | Cooling |
|---|---|---|---|
| Temperature (℃) | 400 | 590 | 150 |
| Holding Time (min) | 25 ~ 30 | 25 | 30 |
| Atmosphere | $N_2$ | | |

### 2.3 Preform design

The shape of the product is a simple cup-shape as shown in Fig. 2(d) having 50mm in diameter, 30mm in height, and 5 ~ 8mm in the thickness of its wall. In order to forge the cup-shaped product, several shapes of the preform, as shown in Fig. 2, can be considered. Fig. 2(a) is a cylindrical preform which has the merits of easy compaction and sintering. However, it has the problem of die filling when it is backwardly extruded by a closed die. Fig. 2(b) and (c), which show preforms having wall-shaped parts in them, are considered in order to achieve perfect die filling. Fig. 2(d) has the same shape and dimensions with those of the final product. Therefore, forging with this preform is done with a hot repressing process in which the bottom and the wall of the preform are pressed at the same time. In this case, it is not important if the degree of densification of both the bottom and the wall become different because there is much difference in the height of the bottom and the wall of the preform.

Fig. 2(e) was prepared to solve such problems by causing the pressing at the wall of the preform to happen first. During the forging process, the upper punch contacts with the wall firstly. After pressing for a while, the upper punch contacts with the bottom and both parts of the preform become pressed at the same time. The shape of the preform determined in this present study consist of a closed die forging type as shown in Fig.2(a) ~ (c) and a hot repressing type in Fig. 2(d), and (e). The preforms were machined for dimensions as shown in Fig. 2 after compacting and sintering into a cylindrical shape. Each dimension of the preforms was calculated on the assumption of the same density and weight.



(a) (b) (c) (d) (e)

Fig. 2 Shape and dimension of preforms

### 2.4 An experiment to form product.

The preforms were forged by a closed die shown in Fig. 3 using a 200ton hydraulic press. The material temperature was 450℃ and the die temperature was maintained at 250℃ by a die heating system. Graphite was used as a lubricant. Each strain in the regions of the preform was measured after forging by steps of 3 ~ 5mm. Then, those preforms were reheated in a bath to maintain the temperature. The forming load at the final step of the forging did not exceed 90ton. After forging, the products were T6 heat treated.

## 3. Results and Discussion

### 3.1 Material workability estimation

An upsetting test was performed to estimate the forgeability of sintered material. The temperature of the specimen in this test was 450℃, which is the same value start here with the cup-shaped forging experiment.

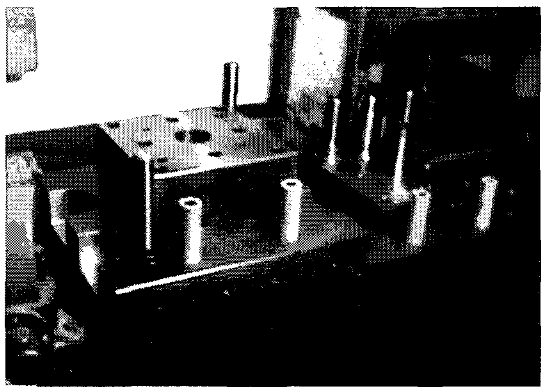


Fig. 3 Forging die set

The graphite was used to reduce friction between the die and the specimen. Three types of specimen were prepared: H/D = 1.0, 1.2, and 1.5. Compressive and tensile strain at the final step were measured after a crack appeared on the free surface of the specimen. As shown in Fig. 4, the fracture line of the porous material is a straight line and the slope of the line is 0.5, which is the same with those of solid material[7,8]. It was observed that the slope of the fracture line in present test was also 0.5.

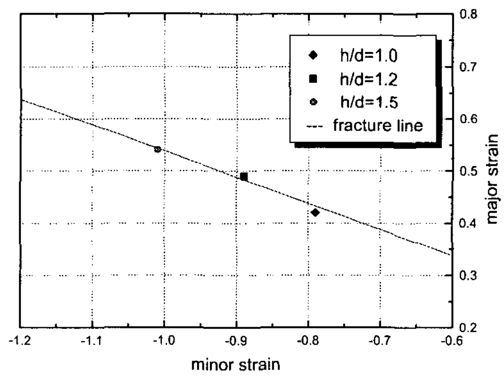



Fig. 4 Workability of the material

### 3.2 Density variation

The result of the evaluation for density of the forging product by the Archimedes[8] method is shown in Fig. 5. The average density of the preform before forging was 2.5. Fig. 5 shows the variation of density and its distribution according to each shape of the preform. With preform (a), a uniform density distribution on the bottom and the wall region of the product was achieved. For stable mechanical properties of the forging product, the density of the product should be uniform. Another merit of preform (a) is that compacting is relatively easier due to the simple cylindrical shape. However, in this case, die filling at the top of wall region was not achieved completely. This could cause a problem when a product has a thin wall. In order to achieve a perfect die filling, it needs a higher forming load an or additional process of machining. With preform (b), uniform density distribution and perfect die filling were achieved at the bottom and the wall region of the product. Preform (c) and (d) show great differences in density at both regions. In particular, preform (d) shows the greatest difference due to the simultaneous pressing at both regions of the product. Because the height of the bottom is much lower than that of the wall, the density at the bottom region became solidified first. In order to prevent such a phenomenon, preform (e) could be prepared. In this type of preform the punch presses the wall first because it needs to be pressed more than the bottom. In the result, the difference in density at bottom and wall region decreased and it became similar with that of preform (b). However, in this case, a folding happened at the boundary of the bottom and the wall region inside of the product because the wall was too high. In addition, in this case, it should be noticed that it becomes hard to get uniform density distribution at the compaction process.

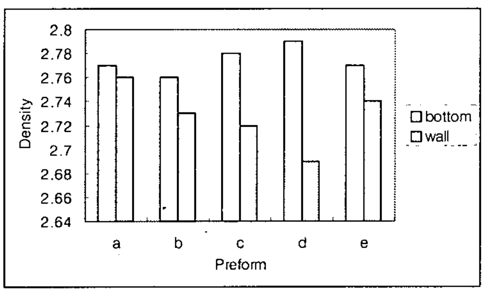
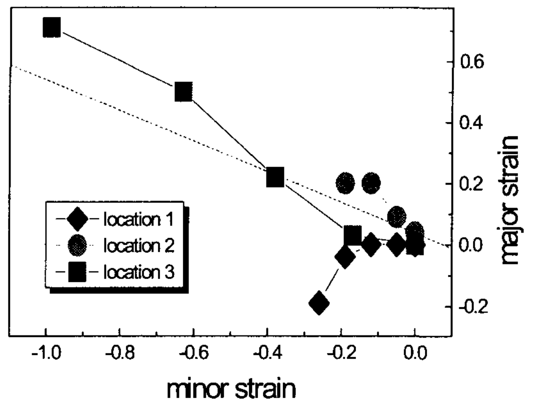


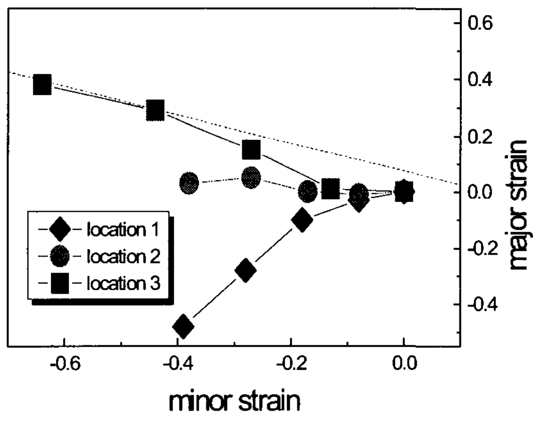

Fig. 5 Density distribution of the products

### 3.3 Transformation ration path

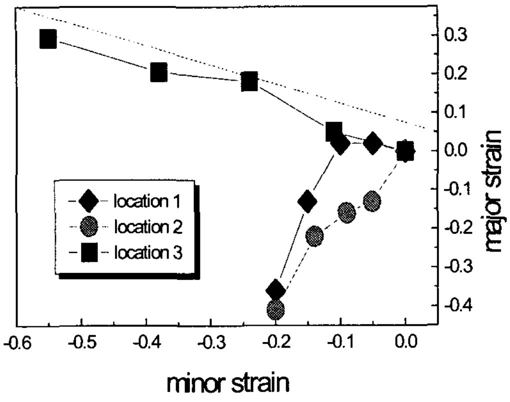
The strain loci during the forging process for each region of the final product is shown in Fig. 6. The measured strain at the end of the wall, outside of the wall, and outside of the bottom are marked on the graph as locations 1, 2, and 3 respectively. A dotted line indicates the fracture line. Although a strain locus exceeds the fracture line, a cracking might not always happen because it is a closed die forging. However, such conditions should be considered and in order to increase the strength of the material a preform with a long strain locus should be used. From this point of view the preform (b) in Fig. 6 becomes the most effective one.



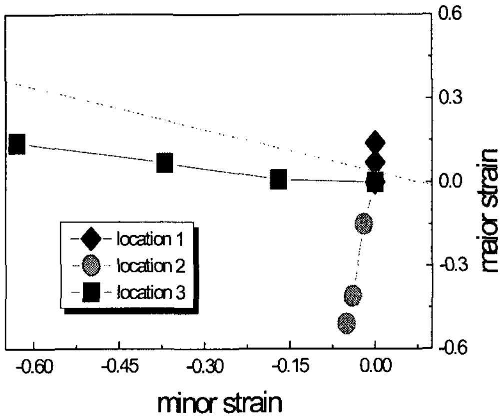

preform (a)



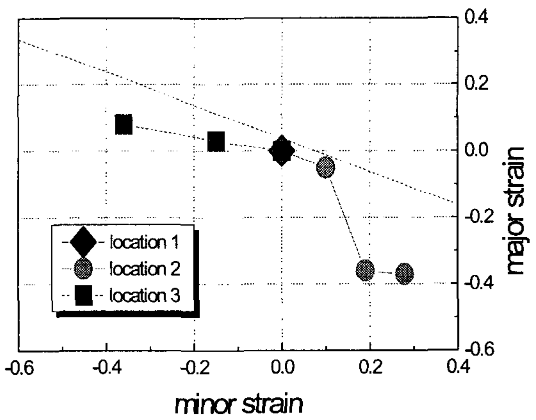

preform (b)




preform (c)



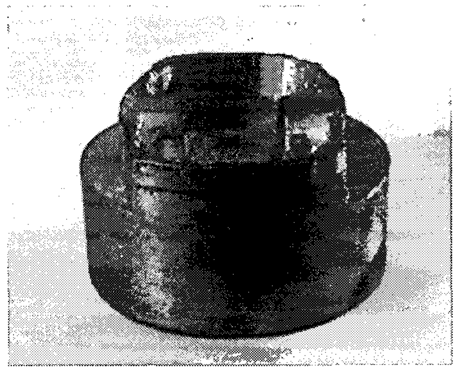

preform (d)



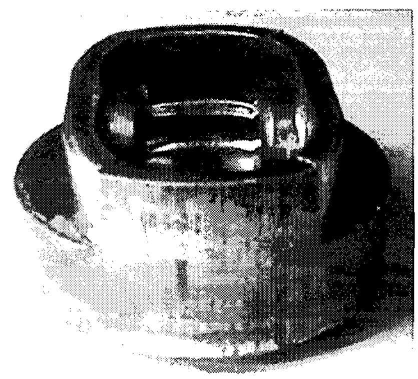

preform (e)

Fig. 6 Strain loci during forging process

The shape of the preform and the final forging product designed by the evaluation of the density and strain loci are shown in Fig. 7.



(a) Preform



(b) Powder forged piston

Fig. 7 Preform and powder forged piston

## 4. Conclusions

In this present study, in order to compare and investigate the effect of forging according to the shape of the preform for cup-shaped powder forging products, the density variation after forging and the strain loci at each region of product were evaluated. In addition, on the basis of the results, a piston which was 50mm in diameter was formed by a powder forging process. The results of the study are as follows.

1. A forging product from the cylindrical preform as

shown in Fig. 2(a) increases density and its uniform distribution. However, die filling is hardly achieved at the end of the wall and a fracture might easily happen at the outside of the bottom of the product.

2. A forging product from the preform which has proper wall height is able to achieve perfect die filling at the end of the wall, increase density, and achieve uniform density distribution.

3. With the preform of a wall too high, a product which has uniform density distribution can hardly be forged because the density at the wall region does not increase enough.

4. With the preform refered to Fig. 2(b), a piston which is 50mm in diameter was formed successfully.

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