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EFFECT OF FORGING CONDITIONS ON THE SURFACE PORES OF POWDER FORGED PRODUCTS

粉末鍛造品の表層残留空孔に及ぼす鍛造条件の影響

by Takeo NAKAGAWA*, Toyoharu TAKANO*, C.S. SHARMA** and Tomio AMANO*

中川威雄・高野豊晴・シー・エス・シャルマ・天野富男

1. Introduction

Although much of research work has been done on powder forging, but a few of them deal with the actual forging condition which could successfully be applied in practice. This is one of the most important reason that the powder forging system or process is not clearly understood. The system's know-how is still unpublished and therefore the effect of forging conditions on the quality of product seems to be worthwhile for study. The present study mainly deals with the influences of forging temperature, die-preheating, cooling of preform during handling time, sintering sequence, preform shape and size on the extent of the surface pores.

2. Experimental Procedure

2.1 Metal Powder

Atomized iron powder (Atomel 4600, Composition C=0.006; Si=0.01; Mn=0.23; P=0.011; S=0.10; Ni=1.96; Mo=0.49) was used with addition of 0.5% C and 0.8% Zinc stearate, after mixing them thoroughly.

2.2 Preform Preparation

Preforms of two different diameters such as 20ϕ and 29ϕ, having heights 44 mm and 21 mm respectively, were made of the same weight. The dimensions after forging, when the real density was achieved, were 30.6$\phi \times$15 mm weighing 86.8 gm. The preform density obtained by using a compacting pressure of 4 ton/cm^2 was 6.5 g/cm^3.

2.3 Sintering

Sintering was performed at 1150°C for 30 minutes in H_2 gas atmosphere. In the present experiment the conventional forging condition had been changed by changing the sequence of sintering and forging of the preform. Accordingly, the preform was first hot coined and then sintered (denoted by F→S) while in conventional method, the preform is first sintered and then hot-coined (denoted by S→F)

2.4 Heating Equipment for the Preform

An induction heating equipment of about 3 KW power, as shown schematically in Fig. 1 of powder forging process, was used for heating the preform up to the forging temperature. The preform rests on a ceramic cylinderical bar fixed to a long metal bar and is surrounded by a heat-proof glass tube around which the induction coil comes in. From the base of the tube, N_2 gas is passed at constant rate to keep the atmosphere inside the tube free from oxygen to prevent oxidation of the hot preform. The metal bar, on which the preform finally rests, is moved up and down within the upper and lower end of the coil to provide uniform distribution of temperature to the preform. The preform temperature was measured by a radiation thermometer. The preforms of diameter 29ϕ and 20ϕ were heated to 870°C

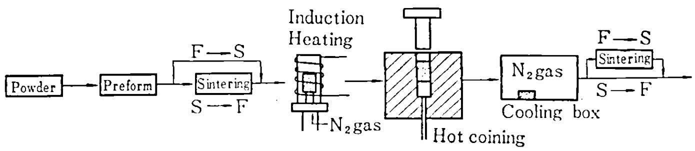


Fig. 1 Powder forging process

* Department of Mechanical Engineering and Naval Architecture, Institute of Industrial Science, University of Tokyo.

** Visiting Research Fellow, Institute of Industrial Science University of Tokyo, from Bihar Institute of Technology, India.

−760°C and 760°C−600°C respectively for forging.

2.5 Forging Process:

The hot preform was taken out of the induction coil by a tong and put into the cavity of die fitted on an 80 ton C-frame mechanical crank press. In fact, the hot preform after taking out from the induction heater was forged 3 seconds latter because this was the total time, spent in bringing the hot preform from the heater to the die and in the die itself before the punch reached the surface of the preform. Out of this total time, about 1.5 seconds were spent in the die. To see the effect of cooling during this time, the hot preforms were kept in die for extra time such as 0, 5 & 10 seconds before forging. Therefore, the actual cooling time before forging became 3, 8 and 13 seconds respectively. The lubricant, graghite with oil was painted on the wall of the die cavity and punch surface. The forging load was measured by strain gauge method with strain-gauge cemented on the punch itself. The heating and cooling curve with respect to time (time-temperature) for the preforms are shown in Fig. 2. The temperatures indicated under the bracket in Fig. 2 represent the fall in temperatures of different preforms after 13 secs from the period when they were taken out of the induction coil.

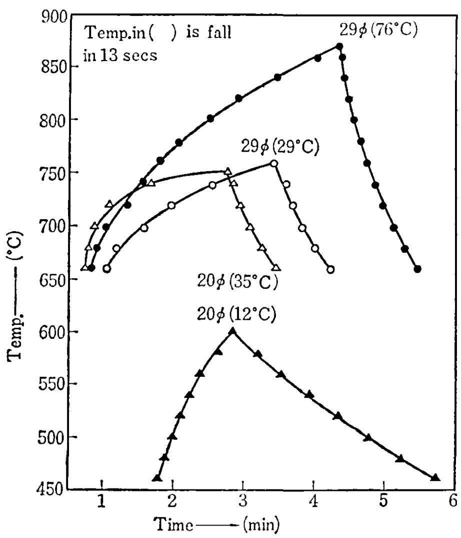


Fig. 2 Cooling curves

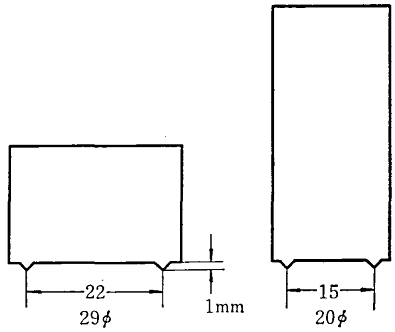


Fig. 3 Preform with circular ridge at the bottom surface

In addition to the above mentioned changes in the forging condition, the die was heated to 250°C before the preform was forged and another change was made by producing a circular ridge at the bottom of the preform as shown in Fig. 3. This ridge was made by machining off other portion of the material.

3. Results and Discussions

3.1 Density

The density vs coining pressure curves for different sizes and temperatures of preforms are shown in Fig. 4. These curves indicate the influence of preform diameters viz. 29 φ and 20 φ

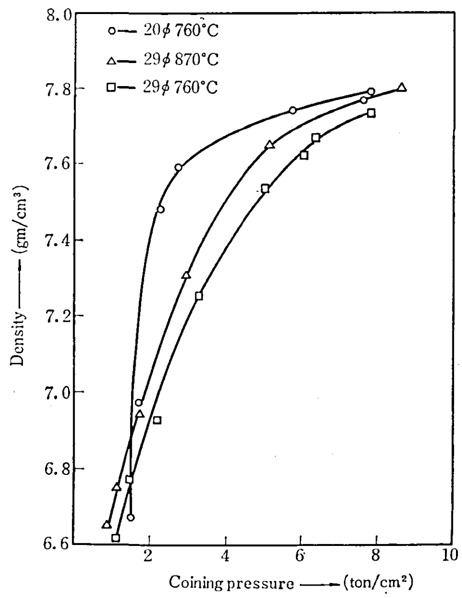


Fig. 4 Relation between coining pressure and density for different diameter of preforms and their temperature

and of forging temperatures on the density of the product. It is obvious from this Fig. that the same density could be obtained at lower forging pressure by hot forging of 20 ϕ preform which is much less than the diameter of the die cavity and hence presenting a case of up-setting. But the forged product takes the shape of barrel with no sharp corners. On the other hand at lower forging temperature of 600°C, cracks appear on the surface and the density gain is 7.72 g/cm^3 at forging pressure of 9 ton/cm^2. Moreover, at forging temp. of 760°C, cracks are only on the corners where the elongation exceeds its limit. Fig. 5 shows the effect of cooling time

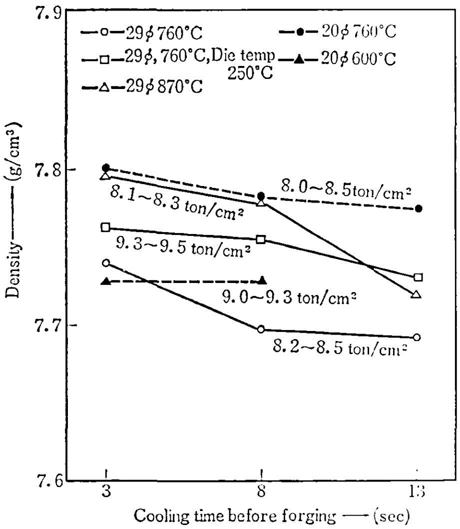


Fig. 5 Effect of cooling time on density

during handling on the density of the product. The density decreases with the increase of cooling time. Though the forging load increases with the cooling time, this increase was not so high because of rather low rigidity of the press used. Though the effect of die preheating does not give a concrete idea, where the forging load increases due to thermal expansion of die, the results shown in Fig. 5 give a reduced effect of cooling time during handling. In general the decrease in density is more apparent at higher forging temperatures of preform.

Under the same forging condition while the forging load is found to be almost same, F→S sequence gives a lower density than S→F because the resistance to densification is higher. Tensile strength and elongation values of S→F products as shown in Fig. 6 are of course higher than the

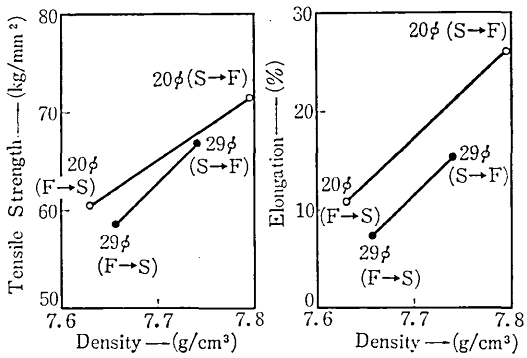


Fig. 6 Mechanical properties of forged product

F→S products. These differences are supposed to be mainly due to different densities, but there is some effect of rate of cooling because S→F products are cooled faster after forging than that of F→S products after sintering.

3.2 Surface Pores

In Fig. 7 the effect of preform diameter, forging

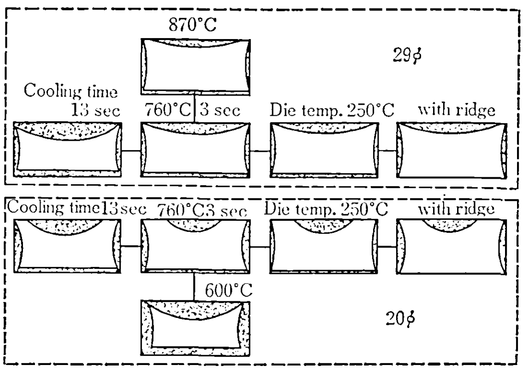


Fig. 7 Exaggerated model representation of surface pores

temperature, cooling time during handling, die pre-heating and the circular ridge at the bottom of the preform, on the extent of the surface pores of the product has been illustrated exaggerately after microscopic observation of the section to be discussed next. Forging conditions which may be main reasons for such surface pores are also

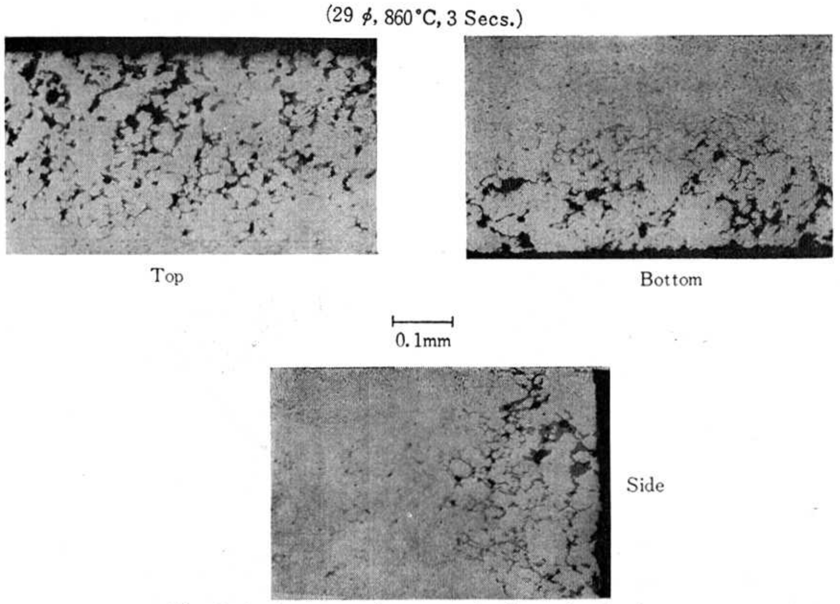


Fig. 8 Surface pores in conventional powder forging

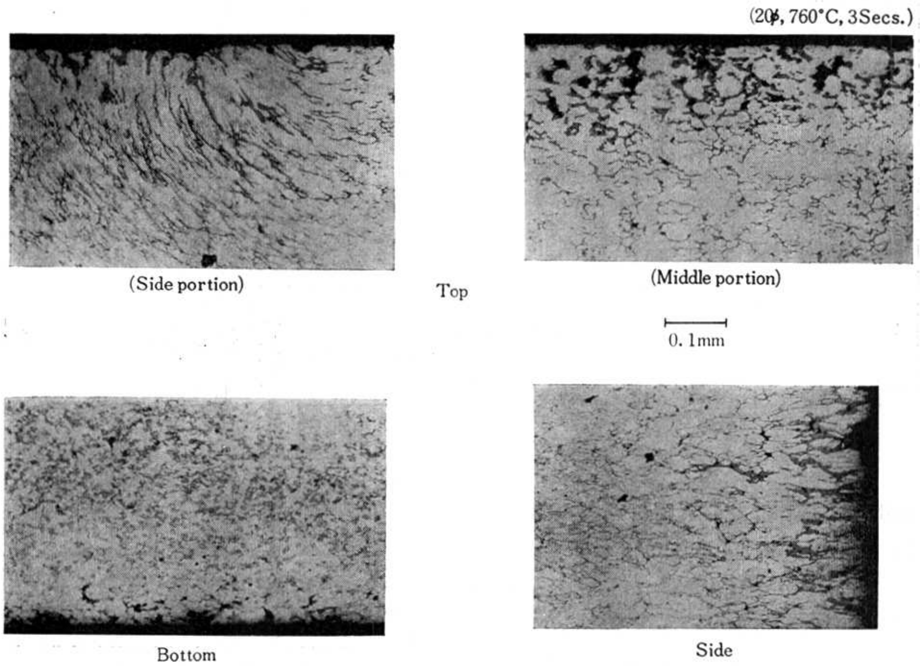
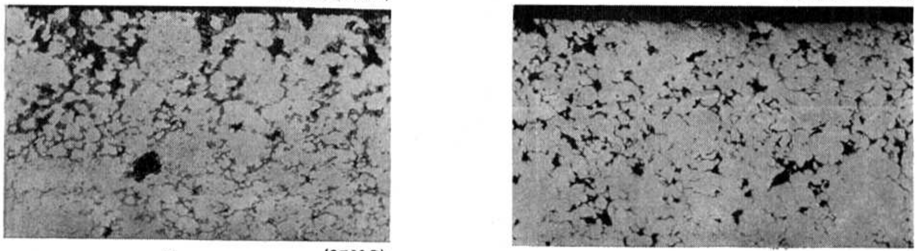


Fig. 9 Effect of preform shape

shown in this Fig. More pores are seen on the upper surface than both on the side and base as shown in Fig. 8. In fact, this tendency may be seen from the very beginning at a very low density before the true density is reached. This is not because of the differences in temperatures of the top, bottom and side surfaces of the preform, but due to more oxidation of top surface than others. Although the real reason of this phenomenon are still unknown but the spring back, after rease of load, may be supposed as one of these reasons. The preform size has also some effect on the upper surface-pores as shown in Fig. 9 in case of 20 ϕ preform where the fibre

(29 ϕ, 3 Secs.) (20 ϕ, 3 Secs.)



Top (870°C) Top (600°C)

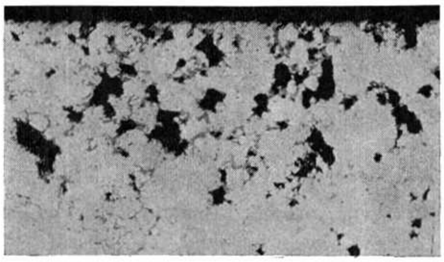
0. 1mm

Fig. 10 Effect of temperature

flow takes place from centre to the side of the product. By this fibre flow the surface pores are decreased on the top side surface. From this observation, some relationship may be found between the resultant pores and the dead metal zone.

On comparison of Figs. 8, 9 and 10 (29 ϕ; 870°C, 20 ϕ; 600°C) it is observed that many differences exist among the forged products due to thermal effect. Fig. 11 shows the existence

(29 ϕ, 760°C, 13 Secs.)



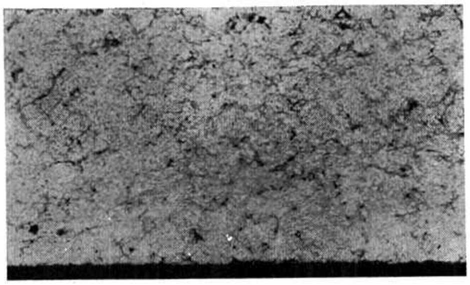
Top

0. 1mm

Fig. 11 Effect of cooling time

of more pores which result due to further oxidation if the hot preform is kept for more time

(29 ϕ, 760°C, 3 Secs.)



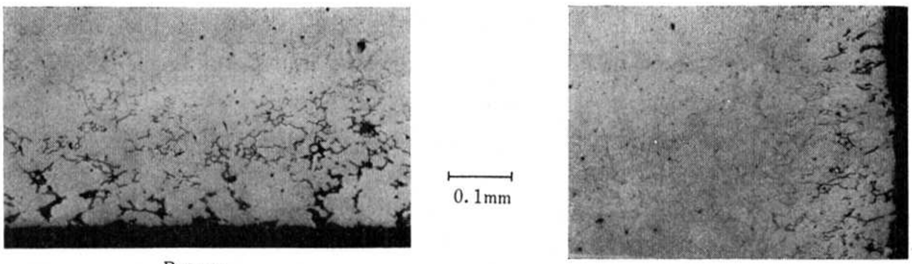
Bottom

0. 1mm

Fig. 13 Surface pores in case of specimen made from coined billet with circular ridge at the bottom

viz 13 secs before forging. On the other hand the pre-heating of die before forging decreases the pores on the sides and bottom surfaces of the product as shown in Fig. 12. The surface pores on the bottom disappear as shown in Fig. 13 in the case of preform having circular ridge at the bottom. These results are due to the change in the resistance to deformation caused by the drop in the surface temperature of the preform in contact with the tool surface and atmosphere.

(29 ϕ, Die temp., 250°C, 3 Secs.)



0. 1mm

Bottom Side

Fig. 12 Effect of preheating of die

(29 ϕ, 760°C, 3 Secs.)

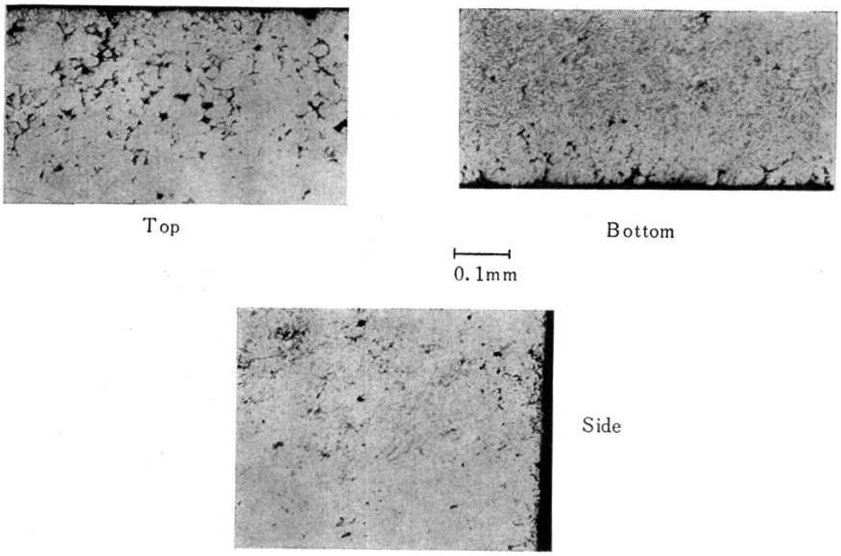


Fig. 14 Surface pores obtained in case of F→S specimen

However, even in ordinary powder compaction and cold coining, similar pores are found and hence this tendency is not due to thermal effect only.

The depths of surface pores in the case of F→S are small on the top surface and almost nil on the side and bottom as shown in Fig. 14 in spite of its low average density. From this fact it is obvious that these surface pores decrease during sintering. So, re-heating of the product possessing surface pores is effective in decreasing pores.

4. Conclusion

The surface pores of the product are affected by preform temperature and its cooling during handling which results in the oxidation of surface in contact with air. In this experiment, particularly the differences in the depth of surface pores on the top and bottom are given more importance whereas many factors still left for explanation.

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A little difference can be found between the exponents to D. However, the result of error analysis revealed that there did not exist any significant difference between the values of these two exponents provided the confidence limits of 95% were assumed.

In Fig. 6 the data from Figs. 4 and 5 are plotted together and, simultaneously, the data obtained for the inclined surfaces(2) are added. For these whole points the relation between h and D becomes

$$h=0.21\times10^{6}D^{-0.31} \qquad (5)$$

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