Studies on Compacting of Spherical Cast Iron Powders.*

By Masanori YOSHIMAWA**, Toshio ASAEDA***,
Katuji OKUYAMA****

The purpose of this study is to examine a new powder compacting method which will be described later and to investigate the properties of the compact produced.

The process is as follows. A mixture of the spherical cast iron powders of about 0.2mm in diameter and water glass is poured into a plaster mold, compacted under a low pressure, solidified by carbon dioxide gas and sintered. Then the pores of the sintered product are filled with liquid copper.

The results are as follows. The sintered products containing water glass 2% compacted under 50kg/mm² sintered for 3 hours at 1,250°C, indicate a shrinkage of 1.6% in the direction of compaction after sintering, a porosity of 40% and a compressive strength of 2.0kg/mm². The specimens made by injecting copper into 75% of all the pores of the products sintered compact for 3 hours at 1,150°C indicate a dimensional change of 0.2%, a porosity of 2%, a tensile strength of 20kg/mm² and a compressive strength of 72kg/mm² with 40% elongation.

1. Introduction

In manufacturing of strong sintered products, it is necessary to use sponge powders or dendritic powders in order to take a product out of the mold without damage. It is also necessary to use powders which have comparatively large specific surface because sinterings of metallic powders start from points of contact between powder grains. But these shapes of powders make it difficult to compact them densely, so very large compacting pressure is needed to get high density compacts. Thus this method is suitable for making small products but cannot be adopted to make large ones. Moreover, because of great friction between powders, the density distribution can be hardly uniform, so dimensional changes in sintering vary from part to part. This irregular dimensional change makes processing of uneven products difficult.

On the other hand, spherical powders are easy to compact densely, so dimensional changes in sintering are relatively small even when the compacting pressure is small. Moreover, because of small friction between powders, the density distribution can be easily unified. But with spherical powders it is difficult not only to make strong sintered products but also to take a product out of the mold without damage, because points of contact between spherical powders are few. This is the reason why spherical powders have been used only for such products as the sintered bearing and the sintered filter, and not used for sintered mechanical parts.

No report could be found on the suitability of spherical powders for mechanical parts which need sufficient mechanical properties.

If any powder compacting method through which strong sintered products can be made with spherical powders is established, large sintered products with high dimensional accuracy will be obtained.

In this investigation, a new powder compacting method with spherical iron powders was devised using a binding material and various characteristics of the products were examined.

2. Processing of specimens

The chemical compositions of spherical powders are shown in Table 1 and their photograph in Figure 1. Those powders are about perfectly spherical cast iron powders with diameter of about 0.2mm.

After necessary amount of water glass is put into cast iron powders, the mixture is poured into a plaster mold and compacted under a pressure low enough not to break the mold. The reason why the mold

* Received 24th January, 1974.
** Associate Professor, Tokyo Institute of Technology, Meguroku, Tokyo
*** Professor. Tokyo Institute of Technology,
**** Instructor. Tokyo Institute of Technology,
is made of plaster is that plaster is easy to mold into a complicated, irregular form for practical use. One of the plaster molds is shown in Figure 2 which can form a cylindrical product with diameter of 30mm. After compacted, the upper and the lower punches are taken off from the mold and carbon dioxide gas passes through the product both from the upper surface and from the bottom surface. The spherical cast iron and sodium silicate are solidified and connected. After the solidified product is taken out from the mold, it is sintered in the atmosphere of hydrogen gas for prescribed time at prescribed temperature. The photograph of this sintered product is shown in Figure 3 and the processing requirements are shown in Table 2. This photograph shows that the corner of the sintered product remains intact.

In order to obtain an impregnated product, copper boards are put on the upper surface of the sintered product and kept in the atmosphere of hydrogen gas for prescribed time at prescribed temperature. The processing requirements are shown in Table 3.

3. Examinations of the specimen

The shapes of specimens are shown in Figure 4 (a) and (b). (a) is a specimen to measure the density ratio, dimensional change, porosity, compressive strength and density distribution and to observe impregnation and machinability. (b) is a specimen to measure the tensile strength.

In order to examine if water glass is useful as lubricant, the relations between density ratio and compacting pressure in a product containing water glass 2% and product without water glass were examined. In this experiment, a metal mold was adopted instead of a plaster mold. If water glass is useful as lubricant, products with same density ratio may be obtained under smaller pressure.

Table 2 Processing Requirements of the Sintered Products.

<table>
<thead>
<tr>
<th>Water glass content</th>
<th>3, 7, 11.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compacting pressure</td>
<td>30, 60, 90, 120, 150, 180 kgt/cm²</td>
</tr>
<tr>
<td>Sintering time</td>
<td>2 sec</td>
</tr>
<tr>
<td>Sintering temperature</td>
<td>900, 1,000, 1,150, 1,200°C</td>
</tr>
</tbody>
</table>

Table 3 Processing Requirements of the Impregnated Compacts.

<table>
<thead>
<tr>
<th>Impregnation ratio</th>
<th>6, 12.5, 25, 37.5, 50, 62.5, 75, 87.5, 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impregnation time</td>
<td>0.5, 1, 2, 3, 6, 4 hours</td>
</tr>
<tr>
<td>Impregnation ratio</td>
<td>6, 12.5, 25, 37.5, 50, 62.5, 75, 87.5, 100%</td>
</tr>
<tr>
<td>Impregnation time</td>
<td>0.5, 1, 2, 3, 6, 4 hours</td>
</tr>
</tbody>
</table>

* Impregnation ratio: Value content against piece of the sintered compact.

In order to find the suitable water glass content for solidification, the compressive strength of the green compact was measured. In order to see the suitable water glass content, the compacting pressure, sintering temperature and sintering time, dimensional change by sintering, porosity and compressive strength were measured.

Dimensional changes on every part of a green compact ought to be equal in order to improve the dimensional accuracy of a sintered product. Therefore, the density distribution of a green compact must be uniform. But it is impossible to measure the density distribution by dividing the green compact into several pieces and measuring the density of each piece, because mechanical properties are not uniform.

![Fig. 1 Shape of cast iron powders used.](image1)

![Shape of the plaster mold.](image2)

![Fig. 3 The sintered product.](image3)

![Fig. 4 Shapes and dimensions of specimens.](image4)
enough. So, instead of the green compact, the density of the sintered product was measured and herefrom the density distribution of the green compact was estimated. Pieces of 5 x 5 x 5 cm were cut off from the sintered product by a grinding wheel of 0.4 mm in thickness as shown in Figure 5, and the density of each piece was measured. Then the relation between the density distribution of the sintered product and the compacting pressure was examined.

Experiments of impregnation were performed in order to find the best impregnation requirements and to investigate the effects of impregnation ratio and impregnation time on the characteristics of an impregnated product.

For the good practical use of the impregnated product in mechanical parts, mechanical properties of every part must be uniform and its machinability must be equally good. In this study, from the idea that mechanical properties of each part and its density are in close connection, the density of each part was measured instead of mechanical properties, and the relation between the density distribution, and impregnation ratio and impregnation time was measured. Machinability test was carried out with a lathe at a cutting speed of 434 m/min, a feed of 0.16 mm/rev and a depth of cut of 0.1 mm. The material of a single point tool used was sintered carbide, and the shape of the cutting edge was as follows; a nose angle of 90°, a nose radius of 1.5 mm, a rake angle of 5° and a relief angle of 5°.

Fig. 5 Measured points of density.

4. Results

4.1. Green Compact

Figure 6 shows the relation between density ratio and compacting pressure of the green compact. In order to get the green compact with necessary density ratio, the green compact containing water glass needs a higher compacting pressure than the green compact without water glass if the density ratio is less than 54%, and the green compact without water glass needs a high compacting pressure if density ratio is more than 54%.

It was impossible to take out the solidified product from the plaster mold without damage when water glass content was less than 12%. Therefore, all the experiments were performed using compacts containing water glass of more than 12%. Figure 7 shows the relation between the compressive strength and the water glass content. The maximum compressive strength is 0.75 kg/mm² at 2 - 3%.

4.2. Sintered Product

Figure 8 shows the influence of water glass content on dimensional change in sintering, porosity and compressive strength. (compacting pressure: 50kg/cm²)

Fig. 6 The influence of water glass on density ratio of the green compacts.

Fig. 7 The relation between compressive strength of the green compacts and water glass content. (compacting pressure: 50kg/cm²)

Fig. 8 The influence of water glass content on dimensional change, porosity and compressive strength of the sintered products. (compacting pressure: 50kg/cm², sintering temperature: 1,250°C, sintering time: 3 hours)
strength. Shrinkage in sintering varies with the direction and shrinkage in the horizontal direction of compaction is larger than that in the vertical direction of compaction. Shrinkage in the horizontal direction of compaction increases as water glass increases, but shrinkage in the vertical direction of compaction does not. Porosity slightly decreases and compressive strength slightly increases with an increase of water glass. These values are remarkably large comparing to those of the green compact before sintering shown in Figure 7.

Water glass reacts to carbon dioxide gas and produces hydrate silica and sodium carbonate. Sodium carbonate is resolved into sodium dioxide and carbon dioxide by heating and at the same time, sodium carbonate reacts to hydrated silica and produces sodium silicate glass. But in the observation of a cutting surface of the sintered product by the microscope, what looked like sodium silicate glass was not found, because sodium silicate glass was melted at high temperature and flowed out of the sintered product. Therefore, the reason why the sintered product has a higher compressive strength than the green compact seems not to depend on the existence or non-existence of sodium silicate glass but on the procedure of sintering taking place between cast iron powders.

In subsequent experiments, water glass content was fixed at 2% at which the green compact had large compressive strength and small shrinkage in sintering. Figure 9 shows the influence of compacting pressure on dimensional change, porosity and compressive strength. Shrinkages both in the horizontal direction of compaction and in the vertical direction slightly decrease with an increase of compacting pressure. With this decrease of shrinkage, porosity decreases and compressive strength increases. But none of compressive strengths is enough for mechanical parts.

In subsequent experiments, compacting pressure was fixed at 50 kg/cm² at which the plaster mold could endure.

Figure 10 shows the influence of sintering temperature on dimensional change, porosity and compressive strength. Shrinkage increases straightly with an increase of sintering temperature and shrinkage in the horizontal direction of compaction is larger than in the vertical direction at any sintering temperature. Porosity decreases straightly with an increase of sintering temperature. Compressive strength increases with an increase of sintering temperature and the increase ratio becomes large as sintering temperature becomes high. The increase ratio of compressive strength with an increase of sintering temperature is higher than the increase ratio of shrinkage.

In subsequent experiments, sintering temperature was fixed at 1,250°C at which the maximum compressive strength was obtained within the limit of this experiment, because it was impossible to obtain a desirable impregnated product if compressive strength of the sintered compact was less than 1.8 kg/cm² at which a crack occurred during impregnation or cooling after impregnation.

Figure 11 shows the influence of sintering time on dimensional change,
porosity and compressive strength. Shrinkage increases with an increase of sintering time and the increase ratio is a little larger within the first three hours than after the three hours. Porosity decreases with an increase of sintering time and the decrease ratio within the first three hours is a little larger than after the three hours. Compressive strength increases with an increase of sintering time and the increase ratio within the first three hours is remarkably larger than after the three hours. Therefore, it becomes clear that sintering remarkably proceeds within the first three hours comparing to sintering after that.

In subsequent experiments, sintering time was fixed at three hours, that is, the possible shortest time for large compressive strength.

Figure 12 shows the density distribution of the sintered product. The specimen compacted at 30 kg/cm² is almost uniform indensity with density of 3.9 g/cm³ around the bottom circumference and 4.0 g/cm³ in the other parts. The specimen compacted at 150 kg/cm² has a wide density distribution with the minimum density of 4.3 g/cm³ around the bottom circumference and the maximum density of 4.7 g/cm³ at upper parts and the middle part of axis. In every specimen, the maximum density exists in upper parts and the middle part of axis and the minimum density exists on bottom circumference. The difference between the maximum density and the minimum density increases with an increase of compacting pressure and densities are 0.1, 0.2 and 0.4 g/cm³ under compacting pressures of 30, 50 and 150 kg/cm².

4.3. Impregnated Product

As is stated above, this sintered product does not have enough compressive strength for mechanical parts. In order to improve the mechanical properties, pores of the sintered product were impregnated with copper. The sintered products used in experiments of impregnation were produced under the following conditions.

- Water glass content: 2%
- Compacting pressure: 50 kg/cm²

![Impregnation ratio 12.5%](image1)

(a) The case when copper does not impregnate all the pores.

![Impregnation ratio 50%](image2)

(b) The case when copper impregnates all the pores.

![Impregnation ratio 87.5%](image3)

(c) The case when extra copper flows out of the sintered product.

Fig. 12 Density distribution of the sintered products. (water glass content; 2%, sintering temperature; 1,250°C, sintering time; 3 hours, unit of density; g/cm³)

- Sintering temperature: 1,250°C
- Sintering time: 3 hours
- The characteristics of this sintered product are as follows:
  - Shrinkage by sintering: 16% (the horizontal direction of compaction), 0.9% (the vertical direction of compaction)
  - Porosity: 46%
  - Compressive strength: 2.05 kg/mm²
  - The difference between the maximum density and the minimum density: 0.2 g/cm³

Figure 13 (a) - (c) show photographs of sectional plane and appearance of the impregnated products which are impregnated for an hour with various impregnation ratios. (a) is an axial sectional photograph of specimens with impregnation ratio of 12.5%, 25% and 37.5%. In a specimen with impregnation ratio of 12.5%, copper (white part in photos) reaches to upper parts and the middle part of axis. In the specimen with 25%, copper does not reach some parts around the bottom circumference. In the specimen with 37.5%, copper infiltrates everywhere except very small
part on the bottom circumference. (b) is an axial sectional photograph of the specimen with impregnation ratio of 50%. All the pores of the sintered product are uniformly infiltrated and no copper flows out, and the best impregnation ratio is 50% for an hour at 1,150°C.

In order to obtain the best impregnated product as is stated above, various impregnated products were obtained under various impregnation ratios and times. Figure 14 shows the results obtained from the observation of their impregnation. Mark o indicates the cases when copper impregnates all the pores and does not flow out of the sintered compact and mark x indicates the case when copper does not infiltrate all the pores or extra copper flows out of the sintered product. The desirable impregnation ratio exists in the range between the two dotted lines and it varies with impregnation time.

Figure 15 shows the surface roughness of the impregnated products, which is recorded by the light cross section method. The convex part is made of perfect spherical cast iron powder and the concave part is made of impregnated copper. Copper plugs pores satisfactorily and attaches itself to cast iron powders. It is 0.05 mm from the top to the bottom. These observations hold almost true in all the other products.

Figure 16 is microphotographs of the impregnated products with impregnation ratios of 75 and 50% for two hours. (a) shows that sintering occurs only at points of contact among cast iron powders which have hardly changed the distances between themselves. This might be the reason why the impregnated product is must better than the sintered product in its compressive strength. (b) shows that spherical pores can be seen almost in the center of copper filling the gaps between cast iron powders. These pores might be caused by lack of copper for filling all the gaps of the sintered product and the capacity of these pores might be almost equal to the shortage of copper. The reason why the pores exist mostly at the center of copper impregnated may be that copper is drawn towards the cast iron powder surface during impregnation.

Figure 17 shows the influence of impregnation ratio on dimensional change and porosity of the impregnated products.

(b) impregnation ratio; 50%, impregnation time; 2 hours

(a) impregnation ratio; 75%, impregnation time; 2 hours

Fig. 16 The microphotographs of the impregnated products. (x150)

Fig. 17 The influence of impregnation ratio on dimensional change and porosity of the impregnated products. (impregnation time; 3 hours)
porosity of the impregnated product. In every case, dimension does not change and porosity decreases in inverse proportion to the increase of impregnation ratio.

Figures 18 and 19 show the compressive stress-strain diagram and the tensile stress-strain diagram of the impregnated products. In Fig. 18, every specimen follows almost the same diagram. But compressive strength with which equal elongation is brought becomes higher as impregnation ratio increases. In other words the impregnated products with high impregnation ratio are hard to elongate. None of the specimens were cracked with elongation of 40%.

In Fig. 19, there is not any clear proportional limit nor yield point in any specimens and all of them show quite a same curve in the range of less than 3.5% elongation and tensile strength by which equal elongation is caused becomes larger as impregnation ratio increases in the range of more than 3.5%.

Figure 20 shows the density distributions of the impregnated products under various impregnation ratios and infiltrating times. (a) shows the cases with impregnation ratios of 50, 62.5 and 75% for an hour. In a specimen with impregnation ratio of 50%, the maximum density is 6.5 g/cm³ which exists in the center of axis, and the minimum density is 5.7 g/cm³ which exists around the bottom circumference. In specimens with impregnation ratios of 62.5 and 75%, the same density distribution patterns are seen and the maximum densities are 7.0 and 7.8 g/cm³ and the minimum densities are 6.1 and 6.4 g/cm³. Therefore, for every impregnation ratio, the maximum density exists in the center of axis and the minimum density exists around the bottom circumference. Each difference between the maximum density and the minimum density is 0.8, 0.9 and 1.4 g/cm³ with impregnation ratios of 50, 62.5 and 75% and it increases with an increase of impregnation ratio. (b) shows the cases under infiltrating times of 0.5, 2 and 6 hours and infiltration ratio of 62.5%. In specimens with infiltrating times of 0.5 and 2 hours, the maximum densities are 7.4 and 6.8 g/cm³ which exist in the center of axis and the minimum densities are 5.7 and 6.3 g/cm³ which exist around the bottom circumference. In a specimen with impregnation time of 6 hours, the maximum density is 6.8 g/cm³ at the bottom of axis and the minimum density is 6.2 g/cm³ around the top circumference. Each difference between the maximum density and the minimum density is 1.7, 0.5 and 0.6 g/cm³ with impregnation times of 0.5, 2 and 6 hours. There must be an impregnation time for which the difference between the maximum density and the minimum density shows the minimum value and it is two hours under the processing requirements of this experiment.

Figure 21 shows the shape of the chips of the impregnated product with impregnation ratio of 50% for two hours.

![Fig. 18 The compressive stress-strain diagrams of the impregnated products. (Impregnation time; 3 hours)](image)

![Fig. 19 The tensile stress-strain diagrams of the impregnated products. (Impregnation time; 3 hours)](image)

![Fig. 20 Density distribution of the impregnated products (unit of density; g/cm³)](image)

(a) The influence of impregnation ratio (Impregnation time; an hour)

(b) The influence of impregnation time (Impregnation ratio; 62.5%)

NII-Electronic Library Service
The chips are long, helical and of small curvature, which proves good machinability.

5. Conclusions

The results obtained are as follows. The sintered products containing water glass 2% which have been compacted under 30 kg/mm² and heated for three hours at 1,250°C, indicate a shrinkage of 1.6% in the direction of compaction by sintering, a porosity of 46% and a compressive strength of 2.05 kg/mm². These specimens made by impregnating copper into 75% of all the pores of the above sintered product for three hours at 1,150°C, indicate a dimensional change of 0%, a porosity of 2%, a tensile strength of 20 kg/mm² and a compressive strength of 72 kg/mm² with 40% elongation.

Fig. 21 The chips of the impregnated product. (Impregnation ratio; 50%, impregnation time; 2 hours)