Rapid Tooling by Powder Casting Transferred from R/P Model
-Manufacturing Conditions Pursuing Zero Shrinkage-

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SUMMARY

High accuracy is being sought in the rapid manufacturing of long life metal dies and molds by transferring from layer laminated models. Powder casting serves as a promising rapid tooling method as it enables high density filling and thus controls dimensional shrinkage to a considerable extent during sintering and infiltrating. This study aims to study the relation between the tooling conditions and dimensional changes of powder casting and find the conditions at which dimensional changes are minimum. In the experiments performed, a golf ball model was chosen as an example of a small mold and results show that dimensional changes can be controlled to below 0.1%, which will facilitate practical application. By subjecting the cast powder to vibrations after adding the binder to achieve higher density, and adding fine copper powder to a mixture of two different size stainless steel powders for dimensional adjustments, almost zero shrinkage control in rapid tool making was realized.

1. INTRODUCTION

In the recent years, small-lot production of different varieties of products is carried out widely in industry. As the life of products grow shorter and shorter, model changes are carried out in rapid succession, and therefore the reduction of the development time of new products has become a very important task to manufacturing industries. For this reason, the reduction of the production time of prototypes and forming die and mold is drawing widespread interests. With the emergence of the layer laminate manufacturing method which can produce prototypes directly from 3D CAD by the additive process, the production time of prototypes has shortened considerably. Also drawing strong hopes is "rapid tooling" which aims to make tools rapidly using this layer laminate R/P model. However, while the prototype tools made by soft tooling with silicon and metal-polymer composites have been widely received, metallic hard tooling which can be employed in mass production has not yet reached the practical application level. One of the main reasons for this is because it loses to milling methods in terms of accuracy, speed and cost. 3 to 4% shrinkage occurs in powder sintering methods (SLS, 3D-Printing) and warp problems have yet to be resolved for the direct sintering of copper alloy powders.

In methods which transfer from a layer laminated model by the wet-type slurry casting method, mixing of fine cemented carbide powders has been said to successfully hold down shrinkage to 0.8%, although the additional finishing process like milling and drilling is said to be rather difficult.[1] The authors thus developed a method to hold down shrinkage by obtaining the highest possible density by applying the dry powder casting method using stainless steel powder, and demonstrated that shrinkage can be reduced to 0.4% and high density twice the current level can be realized.[2] This study aims to further develop this method and achieve higher density by refining the production conditions.

2. INCREASING DENSITY BY ADDING VIBRATIONS

2-1. Adding Vibrations After Binder Infiltration

In rapid tooling by sintering using metal powders as the tool material, the factor most closely related to dimensional accuracy is the powder density during powder molding. By obtaining the highest density possible, close contact between the powder particles can be achieved and shrinkage in post-processes can be controlled. For this, the authors developed a dry-type powder casting method expected to produce high densities than the wet-type slurry casting by mixing liquid binder. As shown in Fig. 1, the liquid binder is poured for infiltration in the post process after powder casting in this method.

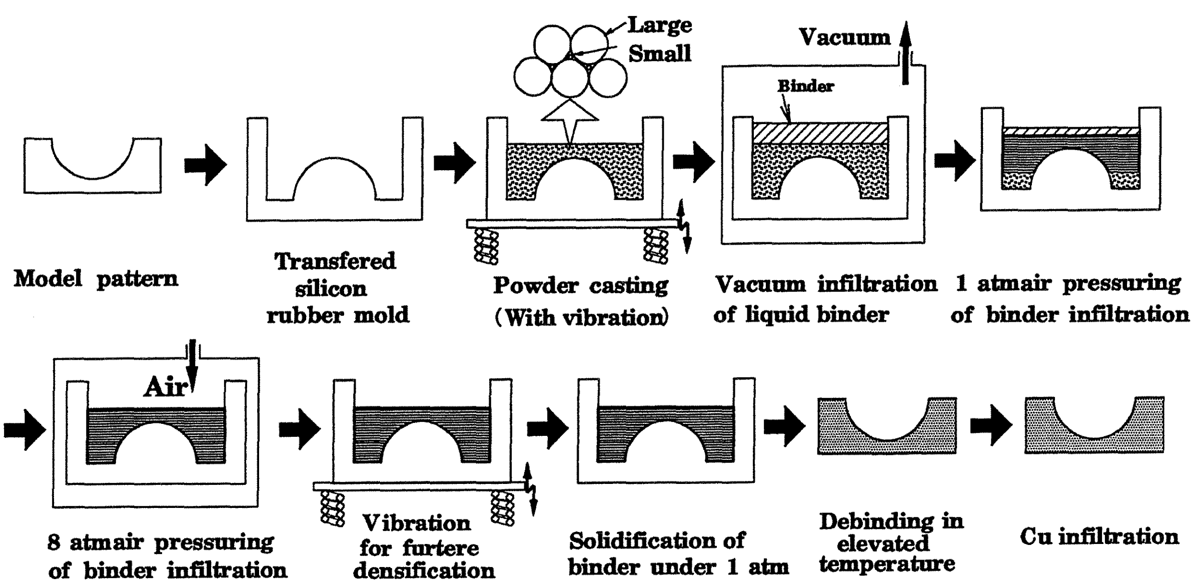


Fig. 1 Manufacturing process of powder casting for making rapid tool

The powders used are stainless steel atomized spherical powder and fine stainless steel powder. Table 1 shows the specifications of stainless steel powder used. Studies were then carried out to investigate if the density can be further increased in rapid tooling process using these powders. Although the powders are already vibrated during the powder dry casting, they were subject to vibration another time after infiltrating the liquid binder. As shown in Fig. 2, it was found that the density increases more than the current methods, because the powder show thixotropic behavior due to the vibration applied after infiltrating the binder. Such a high density of course cannot be obtained by the wet-type slurry method.

Table 1 Stainless steel powder used in experiments

a) Size distributions of nomal size powder

Mesh size	+145	145-200	200-250	250-350	−350
Volume ratio (%)	0.8	25.5	26	40.2	7.5

b) Tap density of powder

	Average diameter (μ m)	Tap density with vibration (vol%)
A: Large size	66	61
B:Small size	5	39
A(82.5%)+B(17.5%)	−	67

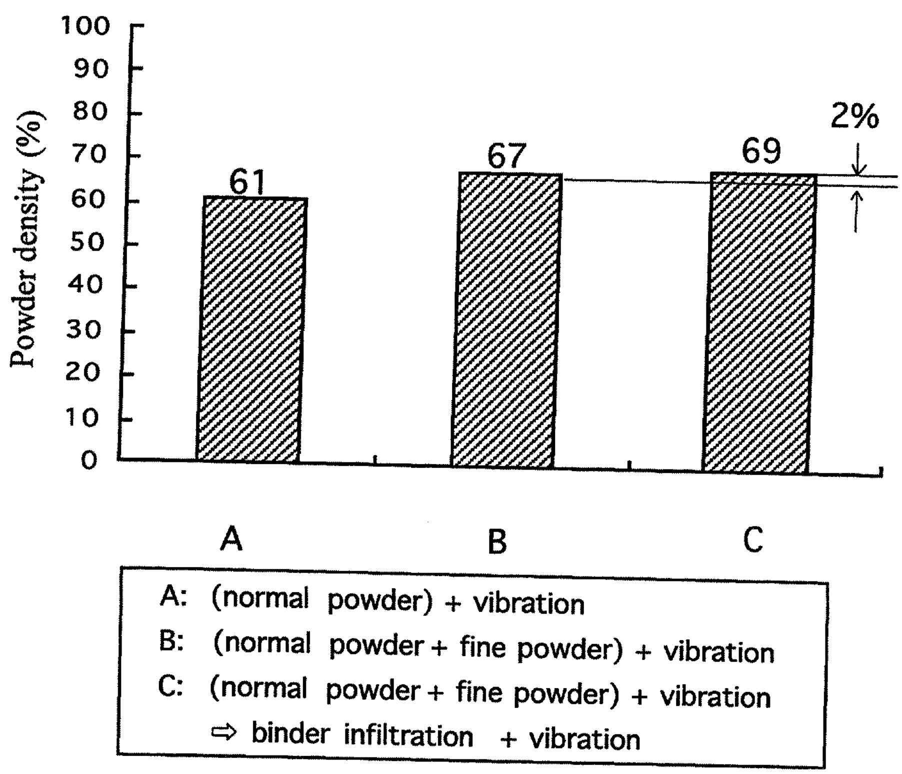


Fig. 2 Powder density by vibrating powder casting

2-2. Dimensional Change of Vibrated High Density Model

Next, effects of density increases by vibration on final dimensional changes were investigated. As shown in Fig. 3, by infiltrating copper in the dried and degreased tool model after vibration, the expansion on the contrary increased to 0.83% as compared to the 0.4% shrinkage when no vibration is applied after infiltrating the binder. The dimensional changes between each process were then measured, and as shown in Fig. 4, it was found that; the original dimensions of the product are maintained more or less in the drying and degreasing processes, and the expansion occurs considerably during the final copper infiltration process. It is assumed that this results because although close direct contact between the stainless powders is achieved during filling, the powders on the contrary tend to separate during copper infiltration through the surface traction phenomenon.

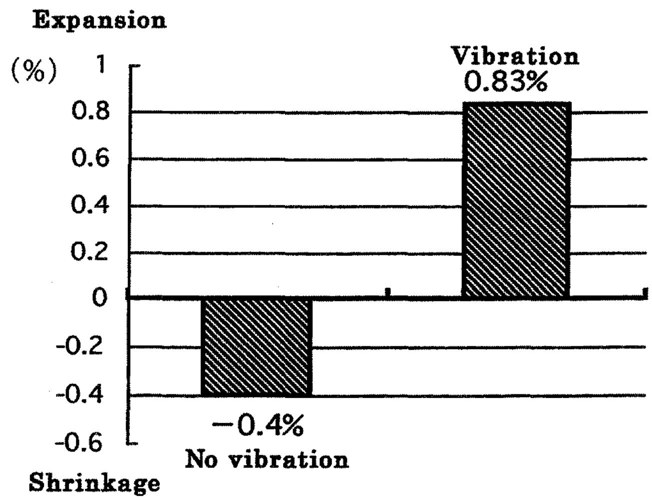


Fig. 3 Dimensional changes of vibrated high density product (after copper infiltration)

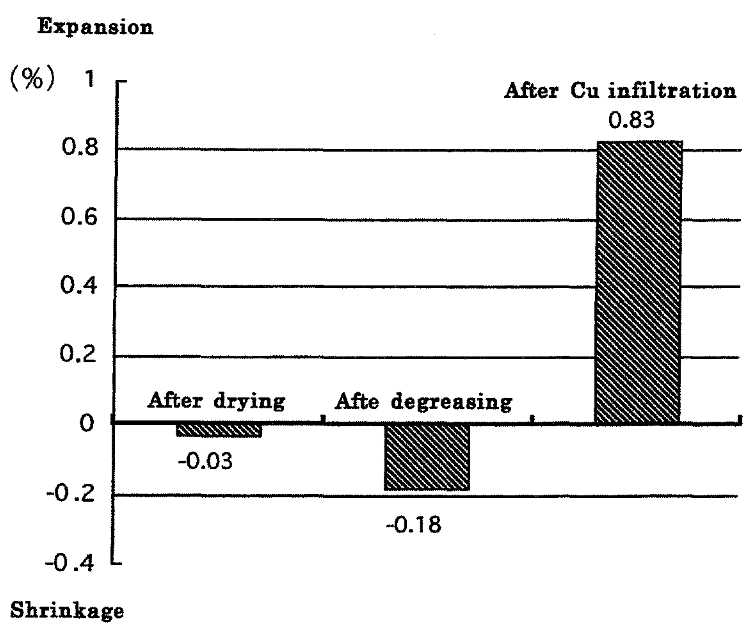


Fig. 4 Dimensional changes between each process of infiltrated high density product

3. CONTROL OF DIMENSIONAL CHANGES BY ADDITION OF COPPER POWDERS

As mentioned earlier, the fact that dimensions increase when copper infiltration is carried out raises the possibility that the overall final dimensional changes can be controlled by adjusting the material and process conditions. Attempts were therefore made to control the dimensional changes after copper infiltration to zero by controlling the powder density of the cast tool model. Various methods were considered for controlling the density of the product, such as adding powder which can be removed during degreasing. In this study, fine copper powders with an average diameter of 10 μ m were added. As for the amount added, half of the 17 vol% fine stainless steel powder proviously added was replaced with copper powder.

Fig. 5 shows the effects of adding copper powders. In this case, the drying and degreasing processes showed shrinkage of 0.22% and 0.53% respectively. In the liquid-phase sintering of the mixed stainless steel powders with copper and copper infiltration (copper powders for infiltration containing 2.7% cobalt) carried out next, 0.42% expansion and 0.26% expansion were recorded, and eventually shrinkage could be controlled to 0.07%. Fig. 6 shows the external view of the metallic rapid tool produced by this process and the cross-section of the tool material under these conditions. Fig. 7 shows the surface roughness of the flat surface which is relatively satisfactory.

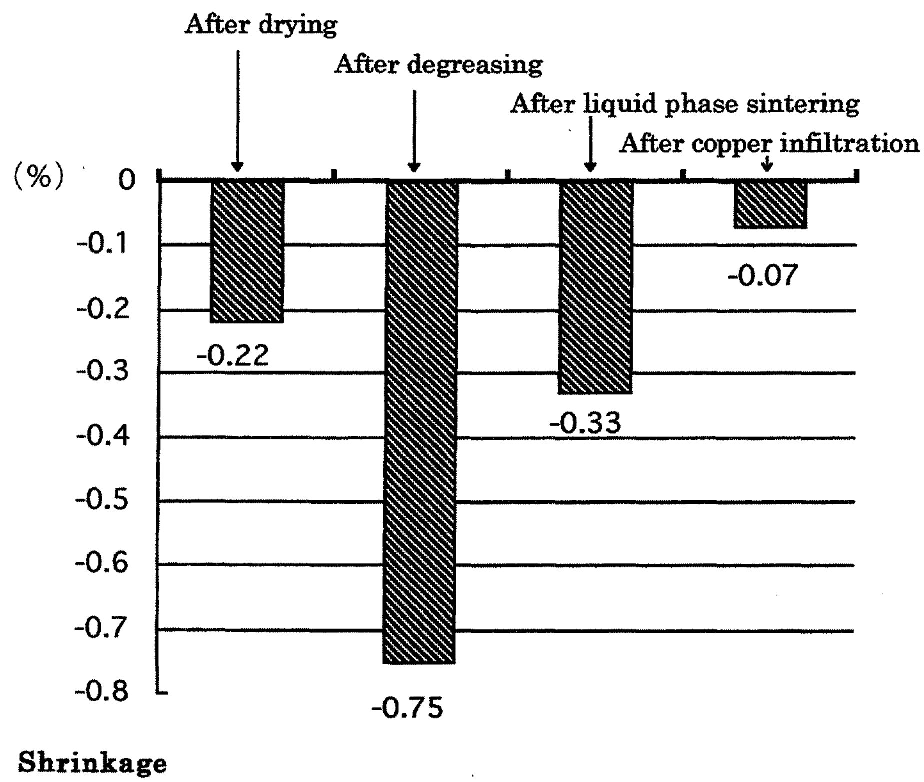
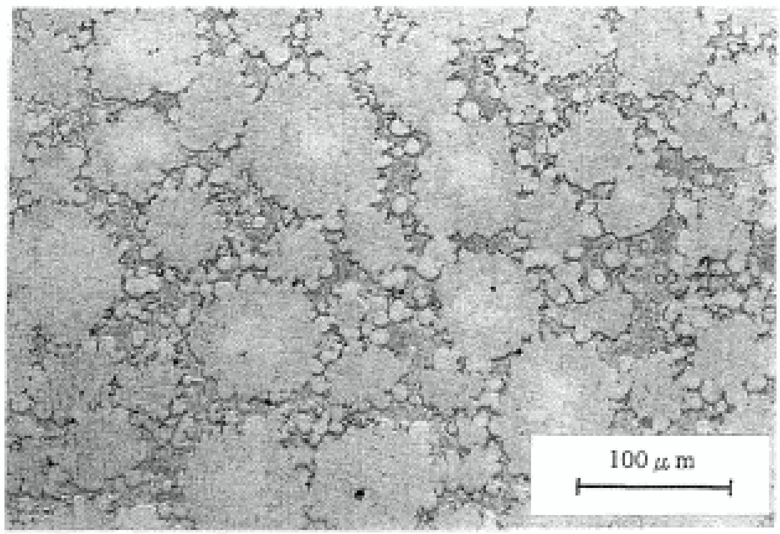


Fig. 5 Control of dimensional changes by adding copper powder

a) Tool made experimentally



b) Section of tool material

Fig. 6 Photograph of stainless steel rapid tool by powder casting

Nomal powder A	Rmax	13 (μ m)
	Rz	9
	Ra	2.2
Added fine powder B (8.5 vol%)	Rmax	6.5 (μ m)
	Rz	4
	Ra	0.9

Fig. 7 Surface roughness of golf ball mold after copper infiltration

4. CONCLUSION

Although much remains unknown on the reasons for the shrinkage in the drying and degreasing processes when copper powder is added, expanding mechanism during sintering and infiltration, and quantification of dimensional changes, the study clarified that the targeted dimensional changes below 0.1% can be achieved successfully. The dimensional accuracy of the layer laminated R/P model may not be high enough like machined one at the moment, and therefore if the accuracy of the transferred rapid tool can be controlled to 0.1%, the accuracy of the product produced by this rapid tool should at least be satisfactory for practical application. Fig. 8 shows an example of the metallic rapid tool for a cellular phone prototyped by this method. No problems were seen in the surface profile nor the post-polishing process. The tool strength, heat-transmission, cooling pipe

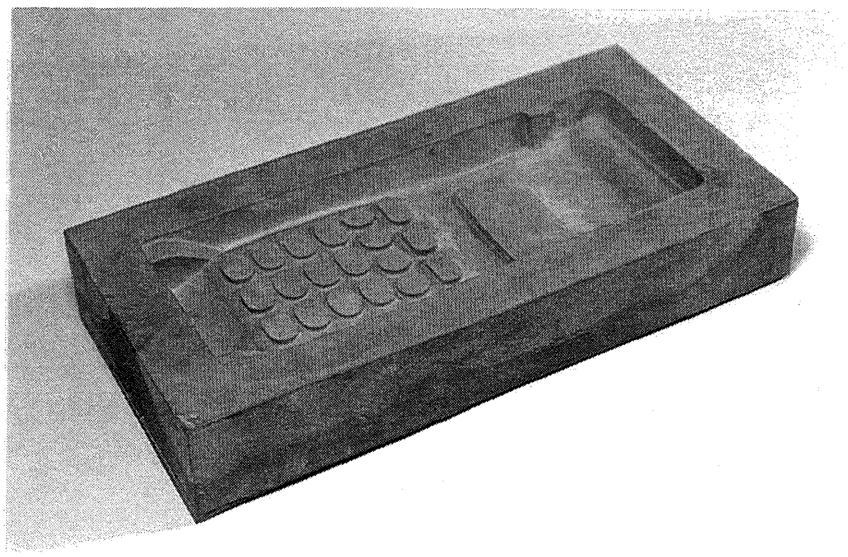


Fig. 8 Metallic rapid tool of cellular phone produced by this process

arrangement, machinability in post-processes, and durability as a tool for injection molding for mass production may be also satisfactory. As expansion characteristics were seen in the procedure of the whole powder casting process, it suggests the possibility of attaining more stable high accuracy through further studies. Next, attempts will therefore be made to manufacture different types of tools, establish the application range, standardize the manufacturing process, and consider the various dies and molds for spreading this method for rapid tooling. Since it requires no mention that this method can be also used to manufacture metallic rapid prototyping products, such applications should also be taken into consideration.

The authors would like to thank NTT CMET and Brother Industries for their cooperation in making the tool model and sintering for the cellular telephone.

References

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