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ADVANCED MICROMANUFACTURING FOR HIGH-PRECISION MICRO BEARING BY NANOPOWDER METALLURGY AND LIGA PROCESSING

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Abstract. The micromanufacturing based on nanopowder metallurgy and LIGA process was investigated. The micro-bearing metallic mold with high aspect ratio, for powder injection molding process, was fabricated by deep X-ray lithography and nickel electroplating process (LIGA process). The feedstock was prepared by mixing the metal alloy nanopowder and the wax-based binders. The process conditions were carefully controlled and optimized to produce the sound bearings. The maximum density of the sintered gas bearing with 80% powder fraction in volume was 94% of theoretical density. The dimensional tolerance of micro-structures in the sintered bearing was within 1% error limit.

1. INTRODUCTION

The various products, including information technology equipment are getting smaller with the development of electro-mechanical technology in industry. The miniaturization of micro machinery is being gathered speed by technical development. The importance of micro motor as core driving devices is being magnified with the increase of complexity and multifunction in the industry. Thus, the demand of micro bearing which is a critical component of the micro motor is on the increase with the significant growth of micro motor industry. It has been focused on a study of process technology for the fabrication of complex-shaped micro components.

Nanopowder metallurgy is considered to be one of key approaches. Nano-sized particles show a wide difference in characteristics in comparison with conventional powder having micron sizes [1,2]. A bulk material of nanopowders can produce completely different properties from that of micro powders. The small particles provide some advantages: a) smaller structural details, higher aspect ratio and better shape retention of microstructure, b) isotropic behavior, and c) better surface finish. In the sintering process aspect, the use of nano-powder also has an advantage of energy saving because of low temperature sintering. Meanwhile, typical techniques to produce metal micro components with 3D shapes are LIGA (Lithographie, Galvano-formung, and Abformung), electroforming, micro investment casting, and micro powder injection molding (PIM: Powder Injection Molding). Recently micro-metal injection molding technique among these is widely used to produce micro-component due to its versatility on manufacturing geometrically complex component [3-5].

In this work, we attempted to combine the metal-molding system by LIGA process with the nanopowder metallurgy. From a fabrication point of view, the use of LIGA metal-mold has a great advantage in the size accuracy. In this study, the nanopowder micro gas bearing was prepared using

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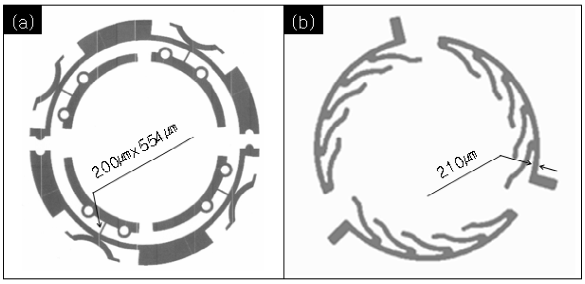


Fig. 1. Design of gas bearing for micro motor; (a) Tilting pad gas bearing (b) Foil gas bearing.

LIGA metal-molding process. The applicability of the new fabrication process for micro components and effect of manufacturing conditions in each step of the process were investigated. The accuracy in size and stability in pattern of the sintered bearing were also examined.

2. EXPERIMENTAL METHODS

Fig. 1 shows the overall design of the micro gas bearing considering the rotor growth, manufacturing, and assembly issues [6]. The bearing design consisting of the complex-shaped microstructure was provided for the manufacturing of Ni-mold by LIGA process. The sequence of fabrication processes to produce the gas bearings shown in Fig. 2 include: (a) Mixing for the homogeneous feedstock consisted of nanopowder and binder; (b) Compacting for the high-accuracy micro bearing using LIGA metal-mold; (c) Debinding and Sintering for the final sound bearing. Details of procedures were described as following.

Fe-45wt.%Ni nanopowder (>97% purity, Sigma-Aldrich chemistry.) with an average diameter of 30~50nm size was used as the starting material. Fe-45wt.%Ni nanopowder and the wax-based binder system were mixed using kneading machine, and the amount of powder was controlled to obtain the certain mixing ratio. The binder system in injection molding consists of major binder, minor binder, and various processing aids such as surface modifier and plasticizer. The specific components of binder system are paraffin waxes 25 wt.%, bees waxes 20 wt.%, carnauba waxes 20 wt.%, ethylene vinyl acetate (EVA) 25 wt.%, polypropylene 5 wt.% and stearic acid as surface modifier 5 wt.% [7,8]. The mixing process was held at temperature below 100 °C in order to prevent burning of nanopowder. In the compacting process, green parts with shape of gas bearing were prepared using 2-mold consisted of positive and negative mold type by LIGA process as shown in Fig. 2b. To avoid damage during the de-molding, the compacted green parts on the positive mold were carefully demolded from the metal-

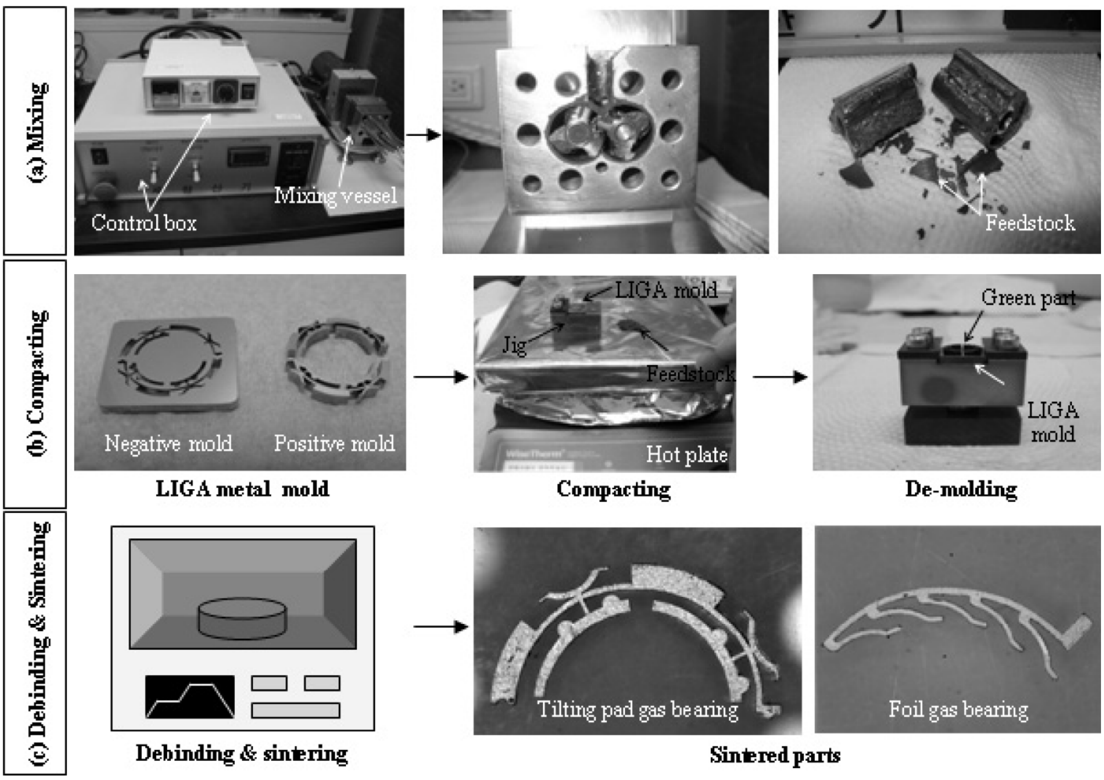
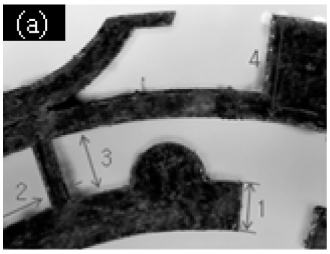


Fig. 2. Process for manufacturing of nanopowder gas bearing using LIGA mold.



(μm)

(b)	1	2	3	4
Pattern Design	459.0	200.0	554.0	973.0
LIGA Mold	459.0	198.0	553.0	972.0
Green Part	456.3	198.0	552.6	968.6

(by digital microscope)

Fig. 3. Size tolerance of the micro-bearing green parts fabricated using LIGA metal mold.

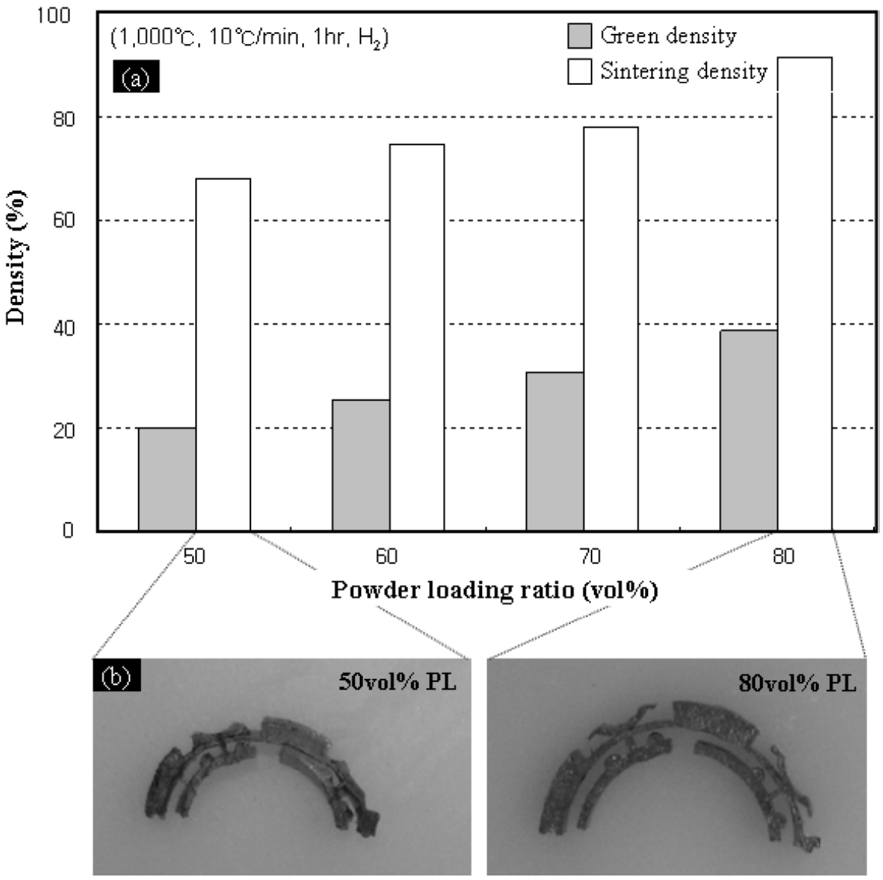


Fig. 4. Density change as a function of the powder loading rate; (a) Density of compacted and sintered parts (b) Sintered bearing patterns.

mold. A process for debinding and sintering of the compacted bearing was performed consecutively in the tube furnace under a controlled atmosphere. Before the sintering, binder debinding for removing the multi-binders was done in 120 °C for 1 hour; 290 °C for 2 hours; 480 °C for 2 hours. The sintering was done in 600~1000 °C for 1 hr under hydrogen atmosphere.

The bearing properties as a function of processing conditions were investigated. The green density and the density of sintered samples were measured using the M-xylene method. The dimensional change on specimens before and after sintering step was measured using the digital microscope for the evaluation of the size tolerance and shrinkage properties. Also, the stability of bearing pattern in each processing step was observed.

3. RESULTS AND DISCUSSION

3.1. Dimensional stability of the green parts compacted by LIGA molding process

The gas bearing requires the high dimensional accuracy due to the very complicated and minute structures. Thus, the control on the dimensional change

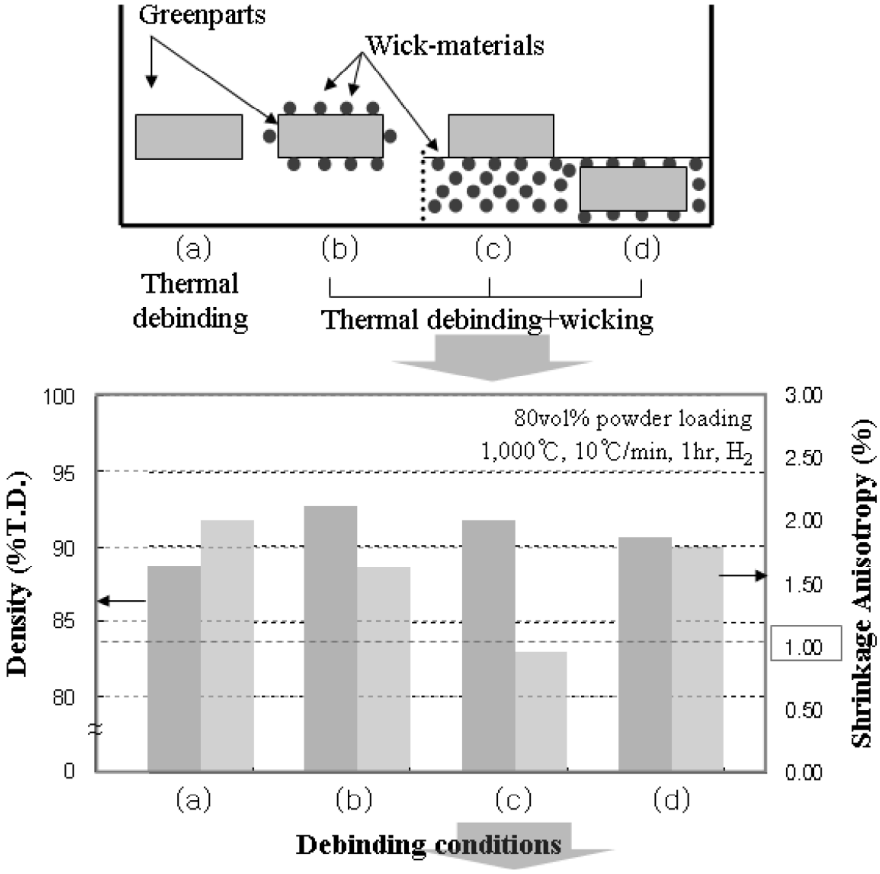
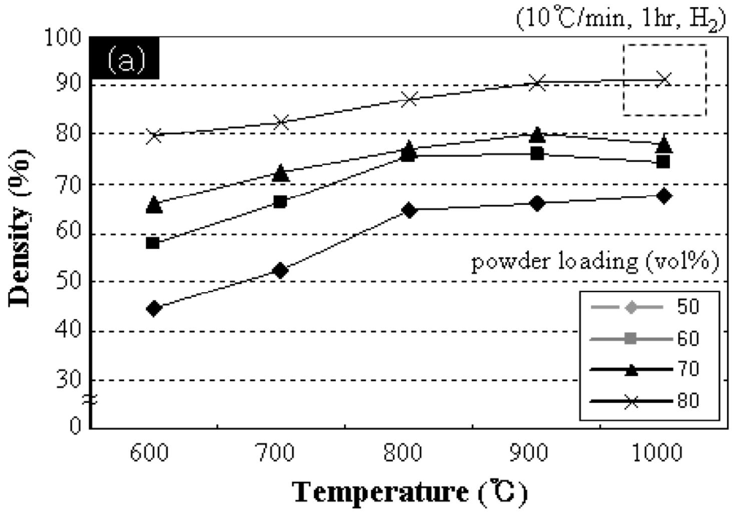
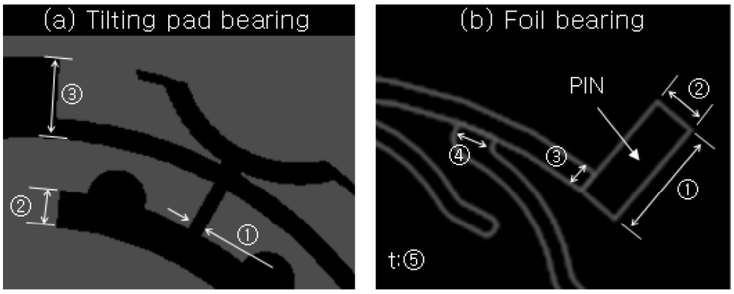


Fig. 5. Schematic diagrams of various debinding conditions and sintering properties.



(b) conditions	① 1000℃ 10℃/min 1hr	② 1000℃ 10℃/min **2hrs**	③ 1000℃ **5℃/min** 1hr
Sintered Density (%T.D.)	91.67	93.76	94.12
Shrinkage Anisotropy (%)	1.32	1.27	1.20

Fig. 6. Sintering properties of the samples as a function of the sintering conditions.



(a)	Mold (㎛)	Green compacts Aver.± Err. (㎛)	Sintered parts Aver.± Err. (㎛)
①	149.83	148.74 ± 0.3	108.46 ± 0.2
②	415.78	408.99 ± 0.5	282.75 ± 0.4
③	1026.72	1008.94 ± 2.4	627.60 ± 1.5

(b)	Mold (㎛)	Green compacts Aver.± Err. (㎛)	Sintered parts Aver.± Err. (㎛)	Shrinkage rate (%)
①	1121	1124 ± 3	786 ± 1.2	30.04
②	420	420 ± 0.3	292 ± 1.8	30.45
③	210	210 ± 0.6	146 ± 1.2	30.40
④	386	385 ± 0.5	268 ± 1.4	30.41
⑤	525	521 ± 5.5	365 ± 2.7	29.73

Fig. 7. Dimensional tolerance before and after sintering of micro bearing.

of parts needs to be considered from the first step of the compacting process. In the green parts using LIGA molding process as seen in Fig. 3a, almost all of the structures were clearly embodied, and the dimension of major part of bearing structure was measured to evaluate the dimensional accuracy. Fig. 3b shows the size tolerance of the compacted micro bearing. That of the green parts from the original design pattern is within 1% error limit. The new fabrication process using metal mold by LIGA process shows the possibility of a closer control in the size dimension of green parts than that using polymer mold like PDMS [9].

3.2. Optimization of the process conditions

In the raw materials preparation as the first step of the fabrication process, it is important to determine the optimum mixture rate between a nanopowder and a binder. Fig. 4 shows the change of green density, sintering density and bearing pattern as a function of powder loading ratio. The feedstock with the lower powder loading ratio leads the sintered bearing into the pattern with deformation such as a structural loss, and a dimensional tolerance. On the contrary, the feedstock with the higher volumetric powder loading provides the higher density and the sound sintered body, and causes the compatibility-degradation at the same time. Thus, in this experiment, the optimum critical batch of mixed powder was 80% powder fraction in volume.

The various debinding and sintering conditions were investigated. Fig. 5 shows the difference of density, shrinkage anisotropy and bearing pattern as a function of debinding method. The multi-debinding method relatively shows the superior sintering properties. Especially, as seen in Figs. 5b and 5d, the deformation of patterns was observed in the bearing components surrounded by the wick-materials (used as binder absorbent materials) on all of sides. This is due to the volume of wick-materials located between structures of bearing. Therefore, the optimum debinding condition for the sound bearing pattern is as shown in Fig. 5c.

In Fig. 6a, the density of the sintered bearings is on the increase with increasing of the sintering temperature. The change of densities as a function of the powder loading (PL) ratio shows the similar behaviors. It was found that the sintered density reached saturated value at the sintering temperature at 900 °C. The maximum sintered density was found to be 91% of the theoretical one when the sample with 80 vol.% PL was sintered at 1000 °C.

The sintering properties on the extended sintering conditions were investigated as seen in Fig. 6b. The sintered density and shrinkage anisotropy were improved at the condition of the slow heating rate.

3.3. High accuracy of the sintered bearings

Fig. 7 shows the size tolerance of micro bearing parts with the optimum processing conditions. The dimensional tolerance of micro-structure in bearing parts is within 0.8%, and shrinkage rate on each part of that is nearly the same. By this new process, the high-accuracy size control on each micro-structure in pattern is possible. But, when installing the bearing in a sleeve, the size tolerance of overall bearing pattern is within 3%. Therefore, the sintered micro bearing still needs much more improvement in terms of the size tolerance for an accurate assembly.

4. CONCLUSIONS

The fabrication of micro gas bearings was performed by the nanopowder metallurgy using LIGA molding process as the new manufacturing method. The applicability of the new process and the effect of manufacturing conditions on micro component were investigated. The optimum process conditions were determined. The critical batch of mixed powder is 80% powder fraction in volume, and the maximum density of the sintered bearing reaches 94.1% of theoretical density. The shape of sintered bearings is very clean and the dimensional tolerance of the micro-structure is within 0.8%.

In this study, the new process is expected to be very applicable to the fabrication of small micro machinery parts with very complicate shapes. In order to apply complex structures fabricated by the nanopowder metallurgy process to the industries, more advanced investigation for mechanical and physical properties is necessary.

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