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Development of Porous Aluminium by Metal Injection Moulding

K. Nishiyabu[1], S. Matsuzaki[2], M. Ishida[2], S. Tanaka[2], H. Nagai[3]

[1]Osaka Prefectural College of Technology, 26-12 Saiwai, Neyagawa 572-8572, Osaka, Japan
[2]Taisei-Kogyo Co., Ltd.
[3]Japan Aerospace Exploration Agency (JAXA)

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Abstract

This study describes the net-shape manufacturing of porous aluminium components by the metal injection moulding (MIM) process, which is a manufacturing method combining the traditional powder metallurgy process with plastic injection moulding. The powder space holder method was applied to the MIM process. In addition to aluminium powder and thermoplastic binders, coarse spherical materials made of thermoplastics were used as lost material for formation of fine opened porous structures in MIM components. The compact-ability, density of green compacts, or sintered body and shrinkage percentage of ISO dumbbell specimens fabricated by the MIM process were also investigated in comparison to high densified aluminium MIM specimens with variable fraction of aluminium powder. The effects of fraction of space hold particle on the pore size and mechanical properties of porous sintered body were also investigated. From these experimental results, it was concluded that the micro-scale fine opened aluminium porous materials can be fabricated with optimizing the fraction of spherical materials for spaces and sintering conditions.

1. Introduction

Metal injection moulding (MIM) is a manufacturing method combining the traditional powder metallurgy (PM) process and plastic injection moulding. It has over the past decade established itself as a comparative manufacturing process for small precision components which would be costly to produce by alternative methods. It is capable of producing in both large and small volumes complex shapes from almost all types of materials including metals, ceramics, inter-metallic compounds, and composites [1-3]. Recently MIM has not been studied only for hard metals, but also for materials such as titanium, copper and aluminium [4], etc. These metals have a low quality problem in strengths of high densified MIM products because the adherent oxide film that is always present on the surface of powder particles inhibits sintering. Metal Foam and cellular metals, on the other hand, have been widely studied [e.g. 5], and the fabrication technique of lotus-type porous metals were also successfully developed by unidirectional pore formation in casting process [6]. These do not deal with fine opened porous structured and complicated shaped metal components, which are strongly desired in higher performance applications for filter, catalyst electrode, heat shield and dental implant, etc. The aim of this study is to develop the net-shape manufacturing method for micro-scale porous aluminium components.

2. Concept of Micro-porous Al MIM

Our concept of micro-porous MIM developed in this study is illustrated in Figure 1. In a conventional MIM process, the feedstock materials are composed of metal powder and binders, and a higher densification after debinding and sintering processes is most significant for high quality of MIM products. In highly porous structured MIM products, on the other hand, many spaces require retention after sintering. We have therefore applied the powder space holder method into MIM process. In addition to aluminium powder and thermoplastic binders, coarse spherical materials made of thermoplastics were used as lost material for formation of fine opened porous structures in MIM components. The fraction of space holder particle and processing parameters were used to form either closed or opened porous structure. Our method is characterized by possessing multi-scale structure in porous MIM components as shown in Figure 2, and by the precision net-shape production.

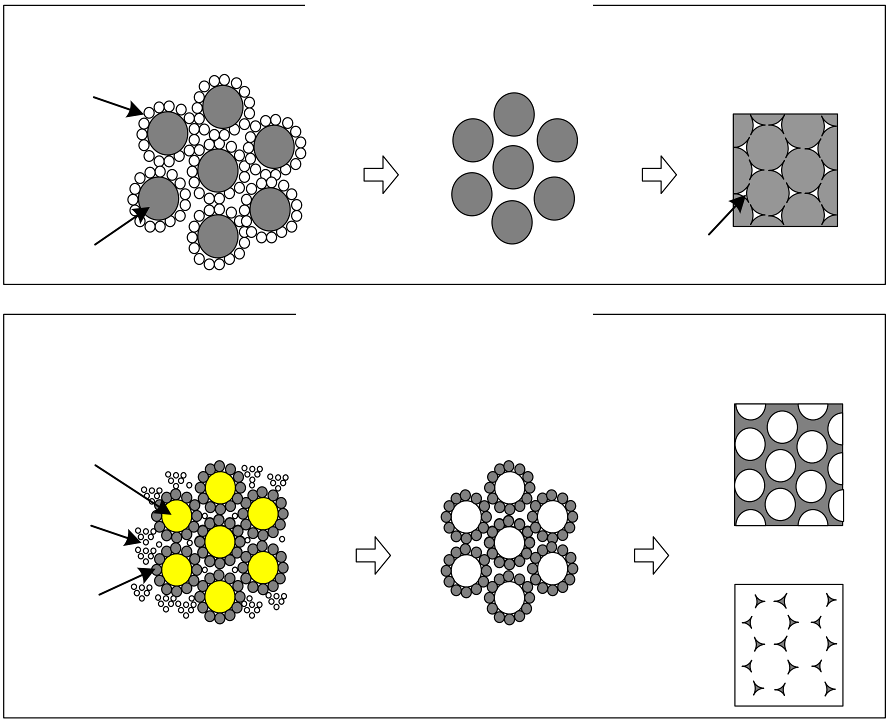


Figure1: Conception of micro-porous MIM process with powder space holder method.

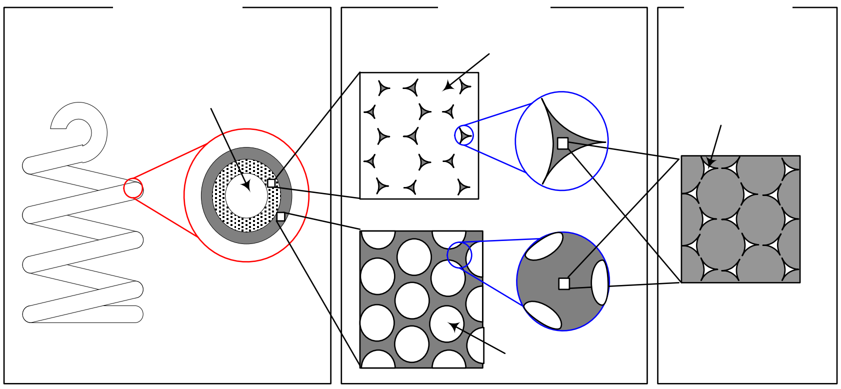


Figure 2: Multi-scale structure in porous MIM components.

3. Experimental Details

3.1 Experimental Materials

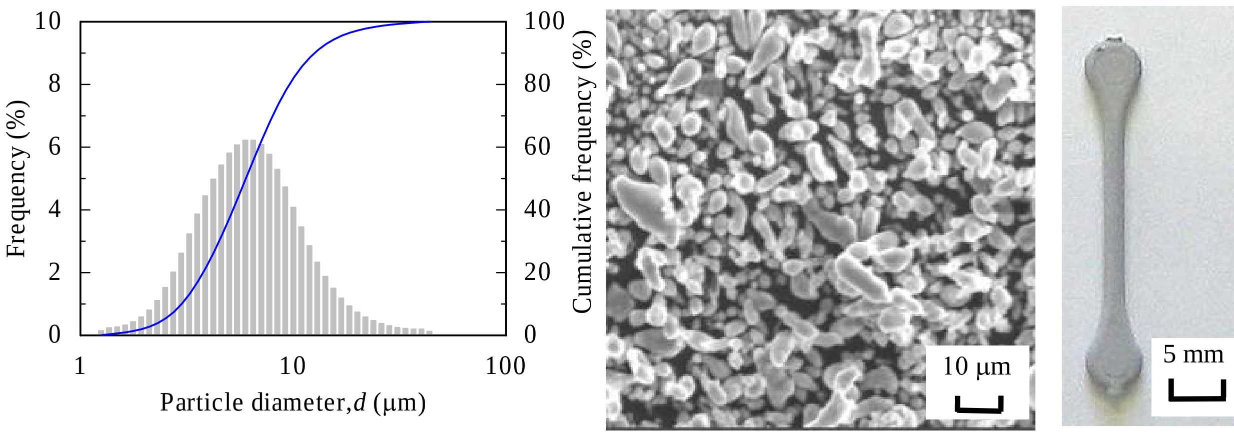
Table 1 shows the characteristics of Al MIM and porous Al MIM feedstock materials used for the experiments. The characteristics of the fine aluminium water atomized powder used as cellular members are shown in Table 2 and Figure 3(a), (b), and was widely varied the volume fraction as experimental parameter. The space holder material used was PMMA particles which are formed in a spherical shape of 15 μm in mean diameter. These materials were co-mixed and pelletized with high-pressure kneader (Toshin Co. Ltd., TD1-3M) and plunger-type extruder (Toshin Co. Ltd., TP80-2).

Table 1: Characteristics of Al MIM and porous Al MIM feedstock materials used for experiments.

Type of metal powder	Aluminium water-atomized powder, 5.98 μm in mean diameter (Minalco Co., Ltd., 600F)
Binder constituents	Polypropylene, Poly-acetyl, Paraffin wax, etc
Fraction of metal powder	25 - 65 vol.%
Space holder material	PMMA particle, 13.5~16.5μm in diameter (The Soken Chemical & Eng. Co., Ltd., Chemisnow, MX1500H) Decomposition temperature: from 270 to 400 deg.C

Table 2: Compositions of aluminium water-atomized powders.

Chemical composition [mass%]							Mean particle [μm]
Al	Si	Fe	Cu	Mn	Ti	Other	
99.81	0.04	0.13	tr.	tr.	0.01	0.01	5.98



(a) Distribution of particle size (b) SEM image (c) Specimen

Figure 3: Aluminium powder used in this experiment and geometry of ISO dumbbell specimen.

3.2 Injection Moulding and Debinding-sintering Conditions

Table 3 shows the injection moulding conditions, and Table 4 shows the debinding-sintering conditions used for experiments. Holding pressure, injection and holding time were optimized independently for Al MIM and porous Al MIM. The specimens adopted by ISO 2740 standard defining tensile test samples in powder metallurgy (Figure 4(c)), were produced using Al MIM and porous Al MIM feedstock with variable content of Al powder and PMMA particles, respectively. The debinding and sintering were sequentially processed in an Argon gas atmosphere in the vacuum furnace to avoid oxidation.

Table 3: Injection moulding conditions used for experiments.

Types of injection machine	Nissei Plastic Industrial Co., Ltd. PS10E1ASE, Screw diameter=16mm
Holding pressure (MPa)	78.99 (Al MIM), 59.24 (Porous Al MIM)
Injection speed (mm/s)	105
Injection and holding time (s)	2.5 – 4
Material temperature (deg.C)	170
Mould temperature (deg.C)	50 - 70

Table 4: Debinding and sintering conditions used for experiments.

Types of vacuum furnace	Shimadzu Mectem Inc. VHSgr, 40/40/100-M
Debinding and sintering temperature (deg.C)	650
Debinding and sintering time (hr.)	4 or 6
Debinding and sintering atmosphere	Argon gas

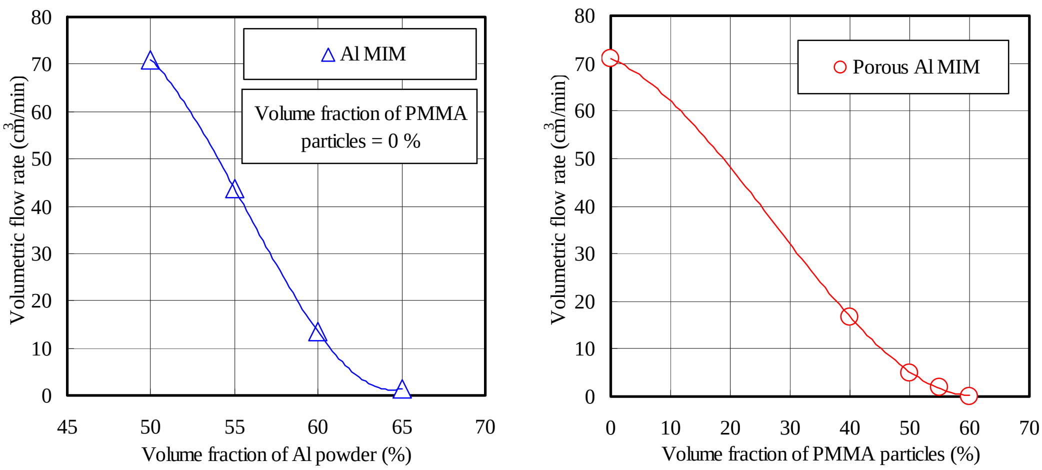
4. Results and Discussion

4.1 Compactability

Compactability of MIM feedstock materials in the injection moulding process was simply evaluated by melt viscosity, which was measured with melt indexer (Toyo Seiki Seisaku-sho, Ltd., P101) for Al MIM and porous Al MIM feedstock materials. Figure 4 shows the volumetric flow rate as a function of volume fraction of Al powder or PMMA particles. Melt viscosity of Al MIM feedstock remarkably decreases with increasing the volume fraction of Al powder, meanwhile with porous Al MIM feedstock, it also significantly decreases with increasing the volume fraction of PMMA particles. Therefore, for MIM feedstock with higher content of metal powder and PMMA particles, the full filling in an injection moulding become more difficult. Binder content is also considered, and three material parameters principally exist and are optimized for demands on fluid-ability and porosity.

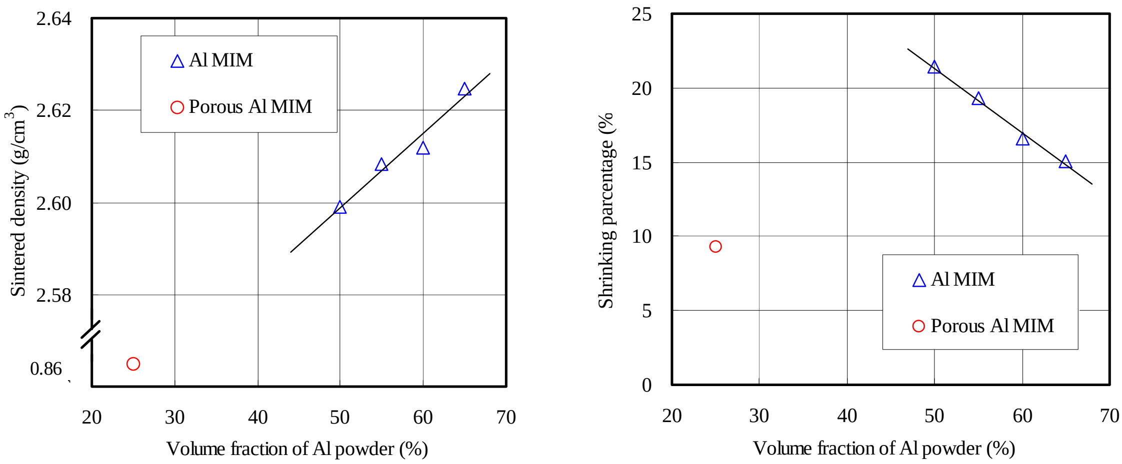
4.2 Sintered Density and Shrinkage

Figure 5 shows the sintered density and shrinkage percentage in Al MIM and porous Al MIM dumbbell specimens with variable volume fraction of Al powder. Sintered density and shrinkage percentage of porous Al MIM specimens are much lower than any other Al MIM ones. The sintered density of Al MIM specimens linearly increases as the volume fraction of Al powder. The specific strength of porous increases, while shrinkage percentage shows the opposite tendency.



(a) Al MIM (b) Porous Al MIM

Figure 4: Melt viscosities (MFR) of MIM feedstock materials.



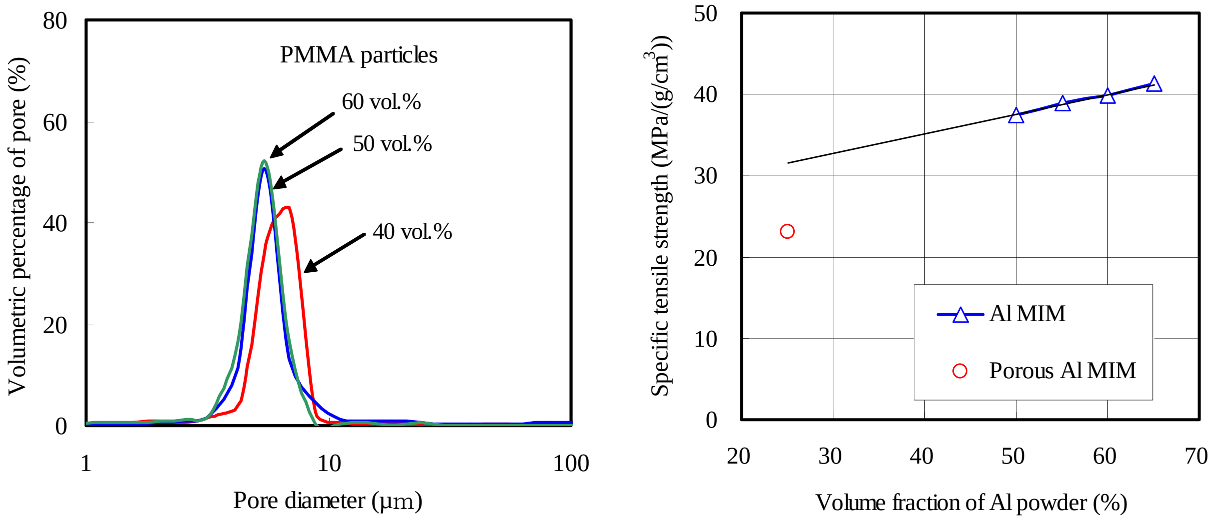
(a) Sintered density (b) Shrinkage

Figure 5: Sintered density and shrinkage percentage in Al MIM and porous Al MIM dumbbell specimens with variable volume fraction of Al powder.

4.3 Pore Size and Tensile Properties

Figure 6 shows the pore size distribution with variable volume fraction of PMMA particles, and specific tensile strength of Al MIM and porous Al MIM dumbbell specimens as function of volume fraction of Al powder. As the volume fraction of PMMA particles increase, the pore size tends to decrease because of shrinkage of more open spaces in sintering process. With Al MIM specimens, the specific tensile strength linearly increases with increasing volume fraction of Al powder. While specific strength of porous Al MIM is lower than that of Al MIM.

This might be due to an insufficient sintering because many surfaces in opened porous structures were subjected to oxidation. It is then necessary to strengthen the Al cellular parts by modifying the sintering conditions or by heat treatment.

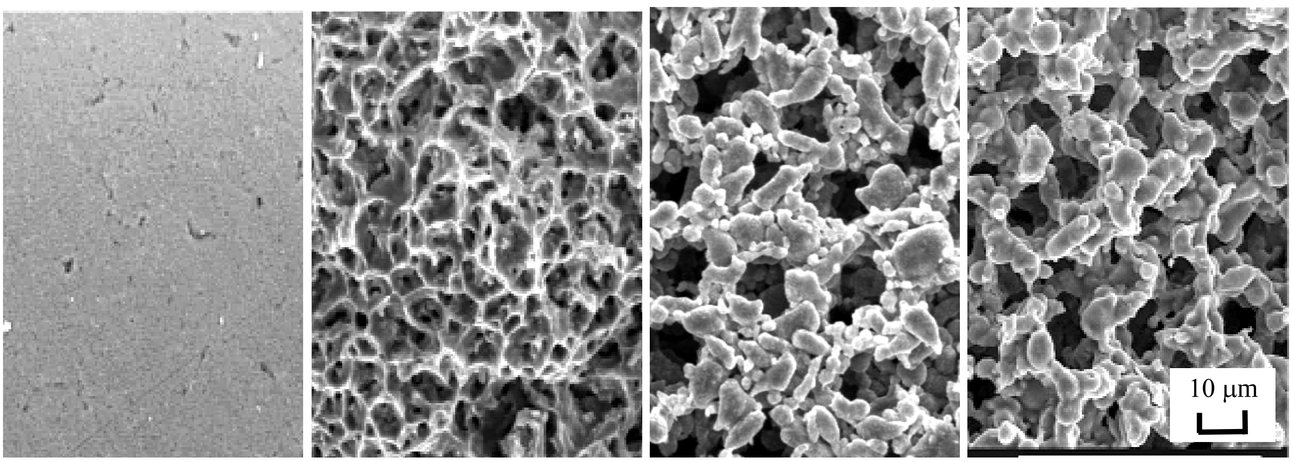


(a) Pore size distribution (b) Specific tensile strength

Figure 6: Pore size distribution, and specific tensile strength of Al MIM and porous Al MIM as function of volume fraction of Al powder.

4.4 Microstructures

Figure 7 shows the SEM images on cross-section of Al MIM and the surface of porous Al MIM. With Al MIM, only a few pores on the cross section and dimple patterns on the fracture surface appear. Therefore the Al MIM specimens are recognized to have the tensile strength of molten materials. With the porous Al MIM, aluminium powders surrounding the openings and an opened porous structure in formed. More surface area could be created because of insufficient diffusion between aluminium particles in sintering process. Higher rates of sintering makes the openings reduce in size and tend to cause densification.



(i) Cross-section (ii) Fractured surface (i) Surface (ii) Fractured surface

(a) Al MIM (60% Al) (b) Porous Al MIM

Figure 7: Microstructures of Al MIM and porous Al MIM.

5. Conclusions

The net-shape manufacturing methodology of porous aluminium components by applying a powder space holder method to metal injection molding process was proposed in this study. From these experimental results, it was concluded that the micro-scale fine opened aluminium porous materials can be fabricated with optimizing the fraction of spherical materials for spaces and sintering conditions.

Acknowledgements

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