The Spark Plasma Sintering Method using Laminated Titanium Powder Sheet for Fabricating Porous Biocompatible Implants

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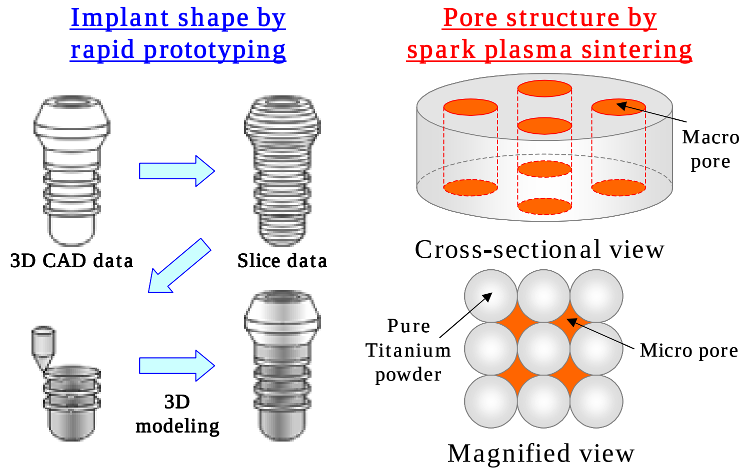
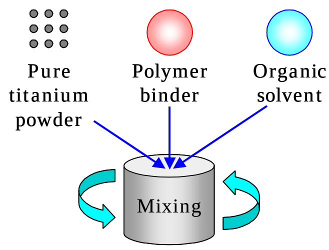
Introduction

There are potential increases in patients having masticatory dysfunction along with a coming aging society, so that attention is paid to the development of dental implants with superior properties of biocompatibility as well as mechanical strength. The purpose of the present study is to establish a process of fabricating porous biocompatible implants by employing the spark plasma sintering (SPS) method. The novelty lies in the use of a thin sheet made of a pure titanium powder with organic binders and its lamination to form three-dimensional sophisticated internal as well as external structures without conventional machining.

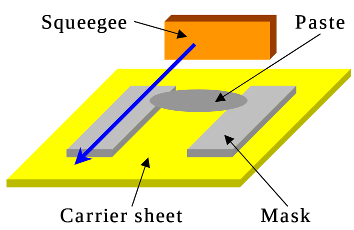


Schematic diagram of implant proposed by this research

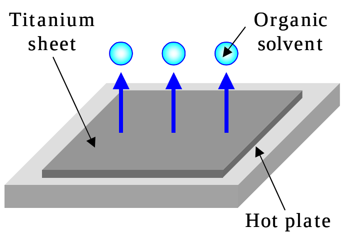
Three-dimensional modeling process



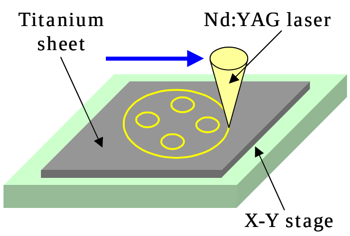
(a) Preparation of paste



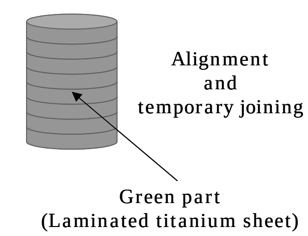
(b) Titanium-sheet forming



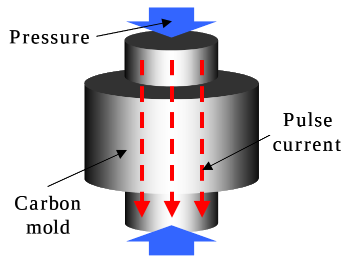
(c) Drying



(d) Laser cutting



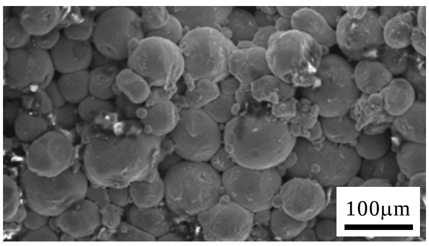
(e) Lamination of sheet



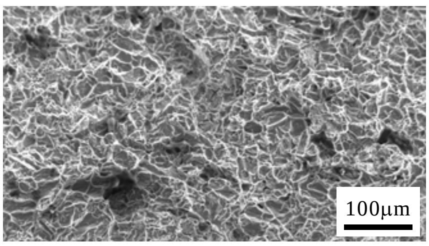
(f) Spark plasma sintering

The proposed method is a combined technology of SPS with rapid prototyping or layered manufacturing. A sheet of titanium powder is formed as thick as about 150 μm by the mask printing method. The sheet is processed to form a two-dimensional shape by laser cutting, and then laminated to build a three-dimensional object. Finally, a stack of the titanium layers is packed into a carbon mold and sintered by the SPS process.

Basic properties of sintered part by SPS



(a) 650℃



(b) 700℃

Cross-sectional SEM micrograph of sintered titanium sheet

☆Rate of shrinkage
- 46-52 % (Total of SPS process)
- 5-11 % (By sintering)

☆Rate of expansion
- 4.7-5.0 % (ϕ14.31±0.02→ϕ15 mm)
- Sintering temperature-independent

☆Porosity
- 14 % (Sintering temperature: 650℃)
- 8 % (Sintering temperature: 700℃)

Fabrication of interconnected pores

In order to investigate the feasibility of generating interconnected pores, experiments were carried out under the sintering conditions listed in the table. As a result, the use of NaCl powder is essential for producing macro pores, playing a role of a spacer during sintering. Dimensional accuracy of pores was evaluated by using a stack of 10 piece titanium-sheet with a changing pore size of 0.5-4.0 mm. It is found that pores with set values can be realized, and the size of pores is adjustable by taking shrinkage into consideration.

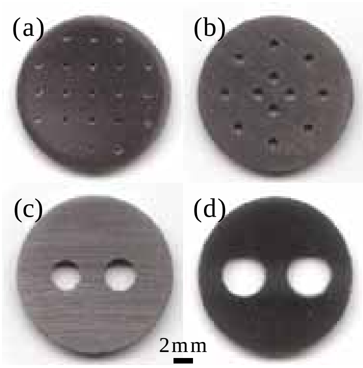
Sintering conditions

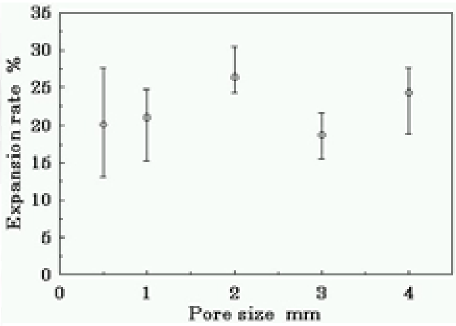
Condition A	Pressure with no sintering
Condition B	Normal sintering
Condition C	Use of space-holding particles (NaCl powder)

Green part Condition A Condition B Condition C

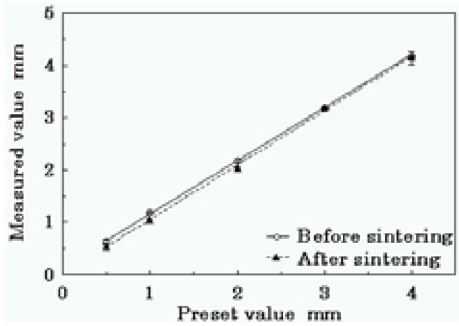
Pore size [mm]

(a) 0.5
(b) 1.0
(c) 3.0
(d) 4.0





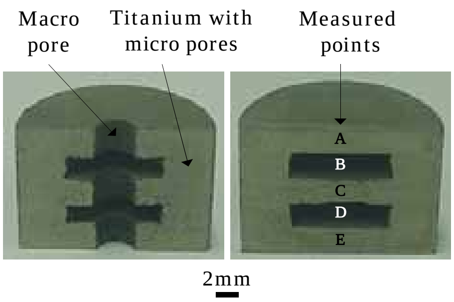
Variation of distance between pores



Variation of pore size

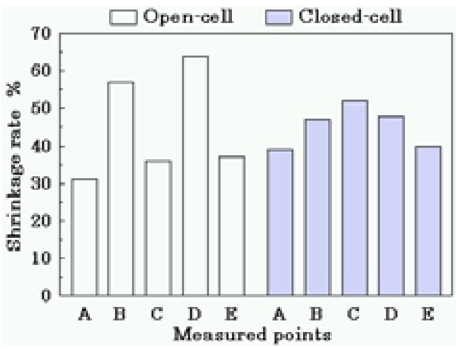
Fabrication of open-cell and closed-cell structures

The models shown below were sintered using 100 pieces of titanium sheet and NaCl powder. Each green sheet was cut by laser, so as to have designed porous structures. Both open-cell and closed-cell structures are retained after sintering. The size of pores can be controlled by setting preset values in the green sheet to compensate shrinkage during sintering. There is a tendency that the rate of shrinkage becomes large at the layers with large pores in the case of fabricating the open-cell structure.

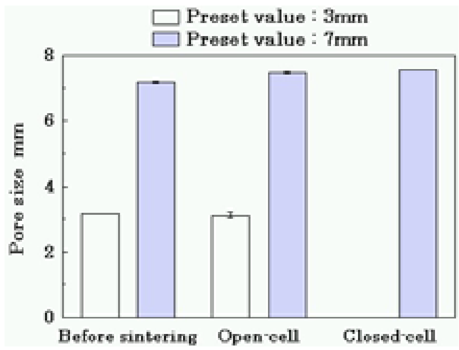


(a) Open-cell (b) Closed-cell

Cross-sectional view



Variation of thickness



Variation of pore size

Conclusions

(1) For the purpose of fabricating porous biocompatible implants, a combined technology of spark plasma sintering with rapid prototyping or layered manufacturing has been proposed. The novelty lies in the laser cutting of pre-formed titanium powder-sheet and the use of NaCl powder during sintering.
(2) Micro pores of around 20 μm can be produced under a sintering temperature of below 650℃.
(3) Interconnected pores or macro pores of around 2 mm are successfully fabricated using the NaCl spacer.
(4) Both open-cell and closed-cell structures can be designed and assembled with the proposed method.

Future work

☆Produce three-dimensional implant shape
☆Evaluate mechanical properties and biocompatibility

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