Research paper

Application of explosive compaction technology to fabrication of medical porous–surfaced implants

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Abstract

Medical porous–surfaced implants have been shown to lead to higher bone/metal shear strength than other types of fixation. A problem that has been identified with porous surface implants is the loss of physical properties.

Porous–surfaced titanium implants were fabricated by cylindrical explosive compaction method by using various pressure transmitting media, i.e. water, grease or paraffin. The shear strengths between a Ti rod and Ti particles, surface pore sizes and porosity ratios for the obtained Ti implants were measured. On the effect of transmitting media, the order of value of surface pore size is as follows grease > paraffin > water. The diameter of pore size is in the range between 180 μm and 361μm when using T6 powders and between 265μm and 514 μm when using T10 particle, respectively and these ranges are almost the same as the result of the pore size range of 50 to 400 μm by Bobyn et al.[7]. The obtained shear strength between a Ti rod and Ti particles in implants were in the range of 130~230MPa and were higher than that of bone itself (60MPa). On pressure transmitting media, the order of value on surface pore size for the shear strength was grease ≧ paraffin > water. The surface of the implants showed the porous shape for favorable to bone tissue growth.

Keywords : Explosive compaction, Porous–surfaced implants, Titanium particle, Pressure transmitting medium, Plasma rotating electrode process

1. Introduction

Medical porous–surfaced implants have been shown to lead to higher bone/metal shear strength than other types of fixation [1),2)]. Titanium and titanium–base alloys have been recognized as desirable materials for implantation into bone because of their good mechanical properties and tissue compatibility[3)]. A problem that has been identified with porous surface implants is the loss of physical properties (i.e. fatigue strength) resulting from the particle sintering process and, therefore, satisfied bonding strengths were not yet obtained[3)]. This reduction of fatigue strength is attributed to stress concentrations at the porous interface.

Recent our studies indicated that explosive compaction could produce a porous titanium implants with high strength properties[4)–6)]. In the present work, the explosive compaction was performed by using various pressure transmitting media, i.e. water, paraffin or grease, and the implants produced by this research showed good shear strength and porous structure for favorable for bone tissue growth[7)].

The advantage of present work is that Ti particles can be easily bonded with each other and with Ti rod, without using the organic binder which is used in commercial powder metallurgy process[8)]. The purpose of this research was to get strong bonding between the particles, and between the particle and Ti rod, suppressing the deformation as much as possible.

2. Experimental procedure

2.1 Materials and explosive assembly

Porous–surfaced Ti implants were fabricated using spherical Ti particles having two particle size ranges i.e. 610μm (T_6) and1mm (T_{10}) in average diameters, which are produced by Fukuda Powder and Foils Co. Ltd. (Kyoto, Japan) from the plasma rotating electrode process as shown in Fig.1 and spherical shaped Mg particle with diameter 500 μm. Ti rods with 5mm diameter were used as core ma-

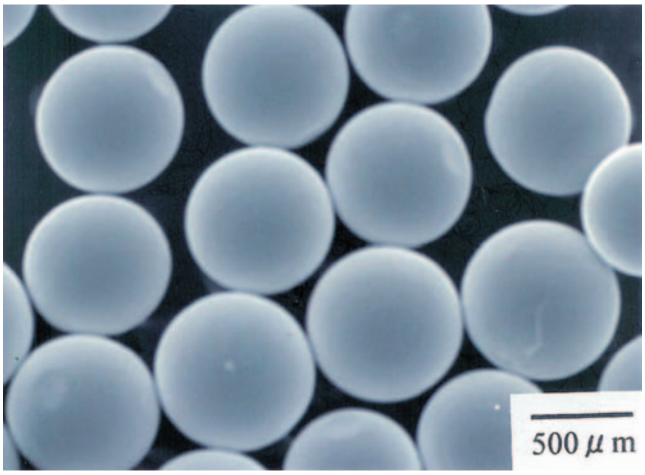

Fig. 1 SEM micrograph of titanium particles with diameter of T 6 (610μm).

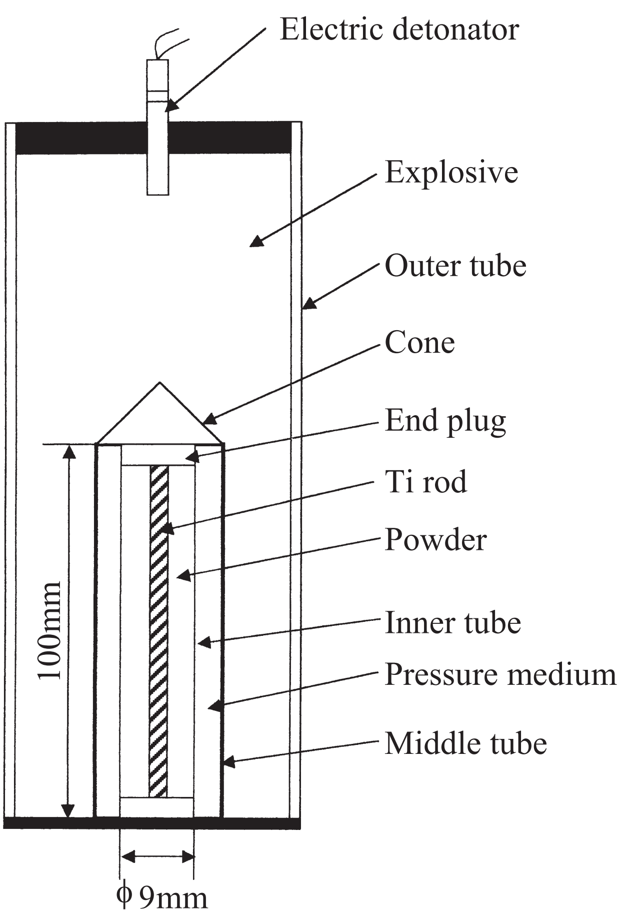

Fig. 2 Assembly for cylindrical explosive compaction.

terials.

The cylindrical explosive assembly used in this experiment is shown in Fig. 2. The assembly was constructed with three tubes. In the inner tube, Ti particles were set around a Ti rod. The pressure transmitting medium, i.e. water, grease or paraffin, was set between the middle tube and inner tube. By using the pressure medium, the particles were compacted quasi−statistically and long pressure loading duration was obtained by the multi−refraction and converging of shock wave. Explosive was set between the outer tube and middle tube. The explosive used in the present investigation is granular explosive consisting mainly of ammonium nitrate compound and its detonation velocity is $2.4x10^3$ m/s produced by Asahi Kasei Co. Ltd. After ignition of detonator, the detonation proceeds down along the wall of tubes, leading to bond Ti particles and Ti rod tightly. Porous titanium implants coated with Ti particles and/or (Ti+Mg) mixed particles with various ratios were fabricated. Notation for the specimens using (Ti+Mg) mixed particles, i.e. T10M73 means that T10 is1mm diameter of Ti particle and M73 means Ti : Mg ratio to be7 : 3. The influence of Mg contents was investigated for (Ti : Mg) ratios for8 : 2, 7 : 3 and 6 : 4. After explosive compaction of the specimens containing (Ti+Mg) particles, Mg metal was evaporated by heating the specimen at 1173K for 2h under $5.0x10^{-5}$ Torr. After the evaporation treatment, the implants were sintered at 1273K for 2h under $2.0 x10^{-5}$ Torr.

2.2 Measurement of porosity, surface pore size and shear strength of porous surfaced implants

Porosity of the implants was measured by point counting method[9] using SEM micrograph of the specimen surface.

The surface pore size was measured as follows ; Ti particles are assumed to be the sphere shape with uniform, the neck size was calculated from the SEM micrographs and the surface pore size was estimated by geometric analysis. Schematic particle configuration was shown in Fig.3. We assumed that the surface pore is a sphere surrounded by three Ti particles. Surface pore size (d_0) is estimated using the diameter of Ti particle (d_p) and necking size (x), i.e.

$$d_0=(d_p^2-x^2)/3d_p.$$

The shear strength between a Ti rod and Ti particles of the porous−surfaced implant was measured by push−out test[1] using Instron−type tensile instrument at room temperature.

3. Experimental Results

3.1 Microstructure of Ti porous−surfaced implants

Figure 4 shows SEM micrographs of Ti porous−surfaced implants using T6 powder. Ti particles are bonded well and with small deformation. The SEM micrographs of the Ti implant using (Ti+Mg) mixed particles shows higher porosity ratio than the implant with Ti particle alone. Figure 5 shows the relationship between surface pore size and Mg content in (Ti+Mg) content, Fig. 5 (a) for the case using T6 particle and (b) for the case using T10 particle, respectively. In general, surface pore size increases with a increase of Mg content in (Ti+Mg) content. After vaporization treatment of Mg atom in specimen, it is easily understand that specimen with larger content of Mg has the larger pores. On the effect of transmitting media, the order of value of surface pore size is as follows grease > paraffin > water. The detail is not clear at now stage, but the viscosity of the medium will be related for surface pore size. The diameter of pore size is in the range between 180 μm and 361 μm when using T6 powders and between 265 μm and 514 μm when using T10 powder, re-

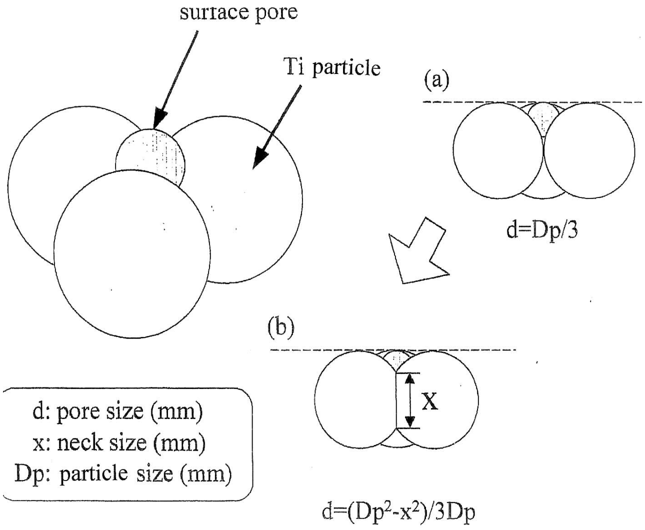

Fig. 3 Concept of surface pore size in this study.

spectively and these ranges are almost the same as the result of the pore size range of 50 to 400 μm by Bobyn et al.[7], who studied the suitable pore sizes for bone ingrowth in the canine femurs.

3.2 Bonding strength of Ti porous-surfaced implants

We have already reported[6] that shear strength of implant with Ti particle alone is 250 MPa, independent of particle size of Ti particle and the shear strength of the implants with (Ti +Mg) mixed particles decreases with increasing Ti particle sizes or increasing Mg content using water as a pressure medium.

Figure 6 shows the relationships between shear strength and porosity ratio in implants for various transmitting media i.e. Fig. 6(a) is the case when using T6particle and (b) is the case when using T10 particle. Increasing Mg content in (Ti+Mg) mixed particles, higher porosity ratios were gained in both cases. On the effect of pressure transmitting media, the order of value on the porosity ratio for shear strength was grease≧paraffin > water shown in Fig.6. The obtained bonding strength was higher than the shear strength of bone itself (60MPa)[7].

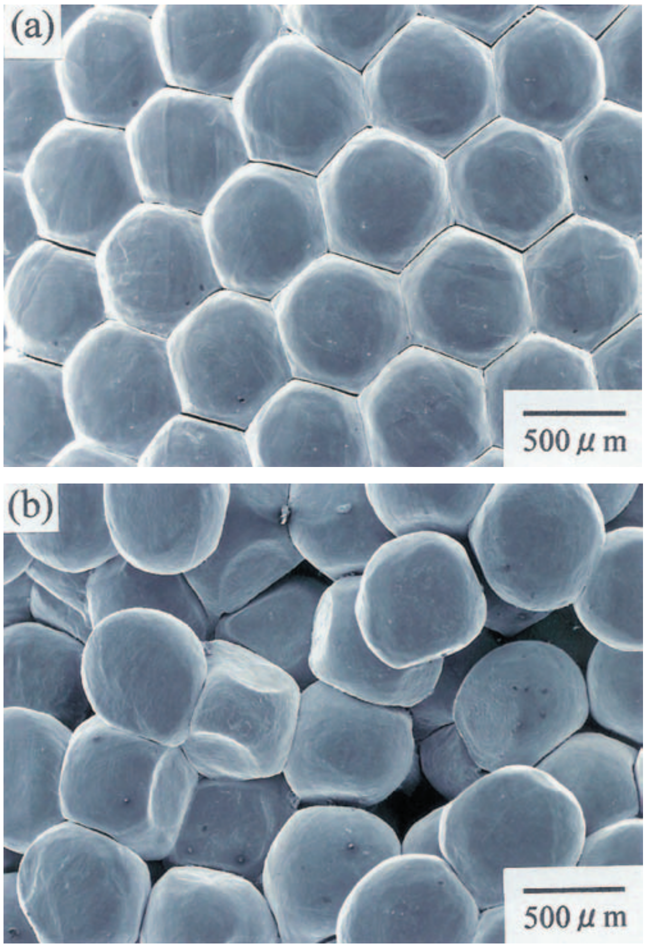

Fig. 4 SEM micrographs of Ti porous−surfaced implants, (a) T 6 and (b) T 6 M73.

Conclusions

By using explosive particle compaction technique, we established the optimal conditions to fabricate medical porous−surfaced titanium implants coated with Ti particles and/or (Ti+Mg) mixed particles with various ratios by using various pressure transmitting media, i.e. water, grease or paraffin. The advantage of the present experiment is that Ti particles can be strongly bonded with Ti rod, with-

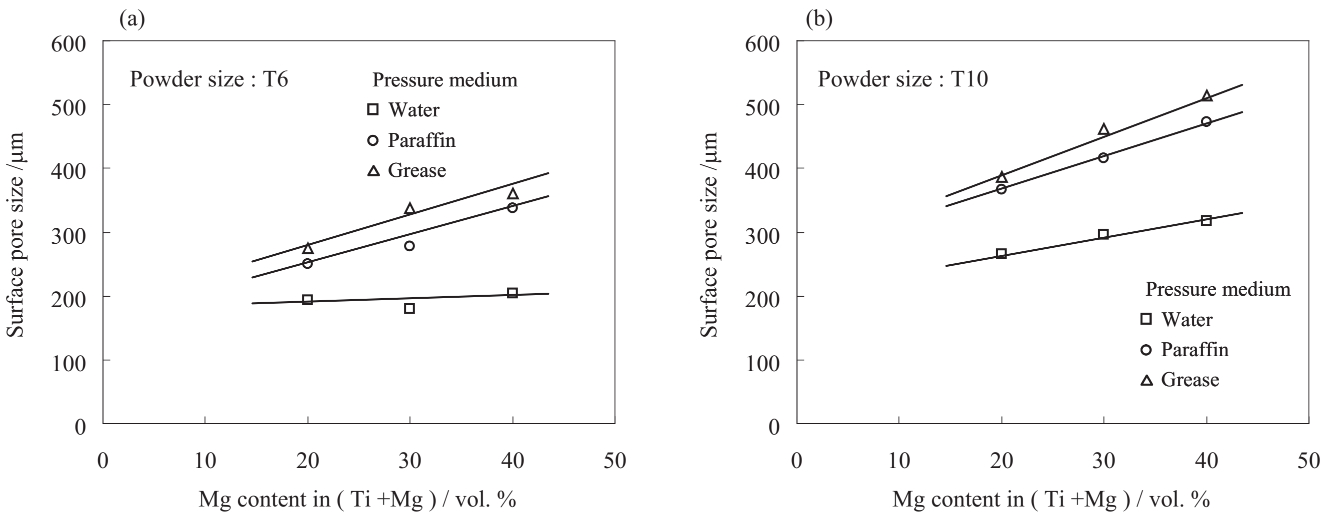

Fig. 5 The relationship between surface pore size and Mg content in (Ti+Mg) content using various transmitting pressure media, (a) T 6 particle and (b) T10 particle.

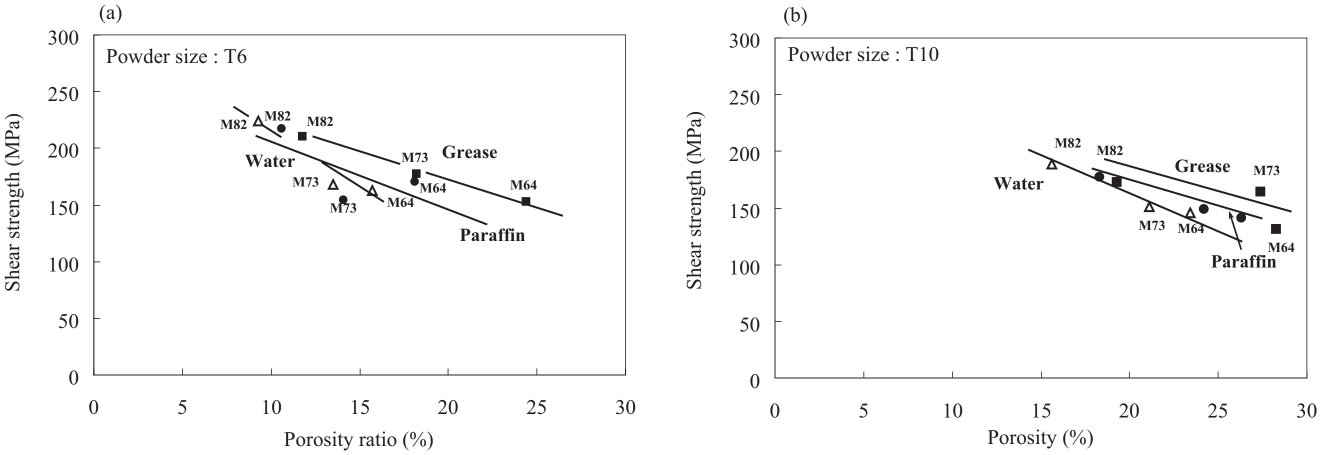

Fig. 6 The relationship between shear strength and porosity ratio using various transmitting media, (a)T 6 particle and (b) T10 particle.

out using the organic binder. After explosive compaction, Mg particles in implants with (Ti+Mg) mixed particles were evaporated by post−heating in vacuum.

In summary, obtained results are as follows ; (1) Increasing Mg content in (Ti+Mg) mixed particles, we could get the high porosity ratio and large surface pore size.

(2) On pressure transmitting medium used in this experiment, the order of value on the porosity ratio for the shear strength was grease≧paraffin> water.

(3) The obtained bonding strength between Ti rod and Ti particles was high enough and the surface−porous structure in this study was favorable to bone tissue growth.

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医療用表面多孔質インプラント材作製への爆発圧縮技術の応用

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これまで，医療用表面多孔質インプラント材は骨との接合性に優れることが知られているが，インプラント材の多孔質部の接合強度が低いことが問題点となっている。本研究はインプラント材の多孔質部の接合強が高く，かつ多孔性に優れるインプラント材の開発を目指し，爆発圧縮技術の応用する表面多孔質インプラント材の作製について検討したものである。特に衝撃圧力伝播媒体として，水，パラフィン，グリースについて，その効果を検討した。その結果，３種の圧力伝播媒体について，インプラント材のTiロッドとTi粉末粒子とのせん断強度は140~240MPaで，骨自身のせん断強度（60MPa）より十分強く，かつ，表面空隙サイズも150~500μmと広範囲に変化させることができ，骨組織を有効に成長させうることが知られた。

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