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Selective laser sintering of bio-metal scaffold

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Abstract

This study presents a fabrication process of bone scaffold model with titanium biomedical materials by rapid prototyping (RP) technique. A RP machine with Nd:YAG laser (120W) was developed to produce bone scaffolds using a selective laser sintering (SLS) technology. The slurry state of biomedical material consists of titanium powder and silica sol mixed at 2g : 1g weight ratio was used in the proposed process. This biomedical titanium slurry was solidified after scanning by a laser beam. The process parameters of laser were tuned at a laser power of 15W, a frequency of 16KHz and a scanning speed of 100mm/s to build the titanium biomedical bone model within 3hrs. Experimental results show that the compressive strength was 142 MPa after post treatment at 900°C. The mechanical strength of these titanium biomedical material specimens by post sintering process is enhanced. Using this RP machine of layer additive processing, a bone scaffold with complex shape structure can be constructed. Therefore, this process has a greater potential for fabrication bio-metal bone scaffold in tissue engineering.

1. Introduction

Biomaterials can generally be classified into four categories: polymers, ceramics, metals and composites. Polymers are deemed to be ductile and not stiff enough and ceramics are too rigid and brittle [1,2]. Biomedical metals are commonly used in joint replacement, bone plates and screws, and dental root implants due to good mechanical properties. Nowadays titanium is popular in biomedical metal due to its low density, good biocompatibility – biological and chemical inertness and mechanical properties – toughness andfatigues strength [3–4].

Rapid prototyping (RP) technique is a non-conventional fabrication process for biomedical engineering field based on the advanced manufacturing and information technology [5]. The outstanding advantage of RP techniques is to fabricate complex artifact directly from computer model rapidly. This computer model can be constructed according to the data of magnetic resonance imaging (MRI) or computerized tomography (CT) of patient. Thus, RP techniques have been utilized in biomedical engineering increasing tremendously [6,7].

Although, many RP processes can be used to fabricate bio-polymer scaffolds due to suitable bioactivity, but their mechanical properties is insufficient. Indirect RP technologies can product metal scaffolds after casting, coating or lost mold process [8-10]. Furthermore, a direct metal rapid prototyping technique was utilized to fabricate porous Ti6Al4V parts with internal pore architecture [11]. Because fewer RP techniques are used to produce metal scaffolds directly [12].

Therefore, this study presents a layer additive process for fabricating a hollow bone scaffold model with titanium-silica composite material, which is solidified by laser gelling.
2. Methods and materials

2.1 Material preparation

The biomedical material for rapid prototyping was prepared in slurry type which can be paved conveniently layer by layer [2]. The ingredients of this RP biomedical material slurry are titanium powder with average particle size of 10 µm and silica sol as binder provided good bond after laser sintering process. If the viscosity of this slurry is too low to provide enough suspension, the overhanging structure of bone scaffold results a large deflection. On the contrary, the viscosity of this slurry is too high, the un-bonded slurry is removed difficulty after radiating by a laser beam. Thus, the slurry was mixed titanium powder and silica sol at a ratio of 68:32 wt% for a suitable viscosity of 3000 cp.

2.2 Experimental of process

In this study, a home-made rapid prototyping machine was designed and developed for fabricating the scaffold based on a selective laser sintering (SLS) technology. The fabricating process of biomedical titanium bone scaffolds is illustrated as Fig. 1 and described as follows [14,15].

(a) A layer of biomedical titanium slurry is paved on the layer elevating platform and scraped to control layer thickness and flatness by the layer scraper.
(b) The paved layer of biomedical titanium slurry is selectively radiated by Nd:YAG laser beam and bonded to form a solidified layer.
(c) The layer elevating platform is moved down in a layer thickness of 0.1 mm.
(d) Repeating steps (a) to (c). A number of solidified layers are stacked to build biomedical titanium part.
(e) The un-bonded slurry is removed by water and a green part of biomedical titanium bone scaffold can be constructed.

Fig. 1. SLG process for fabricating a green part of biomedical titanium bone scaffold.

3. Results and discussion

3.1 Experimental conditions

For this complex biomedical titanium bone scaffold can be fabricated successfully by selective laser sintering. There are a number of process conditions must be carefully controlled. These process conditions are the viscosity of this slurry, the thickness of each paved layer, and the laser power, laser scanning speed and laser hatch spacing [2]. Although, the thickness of each paved layer can be varied from 0.05 to 0.20 mm. For well fabricating these bone scaffolds, the constant layer thickness of 0.10 mm is determined in this study.

In this work, sintering the metal-ceramic slurry needs only low laser power below 28 W. The laser power was adjusted from 12 to 28 W to radiate a specimen. The relationship between laser power and laser scanning speed in laser sintering processes is indicated in Figure 2. When the laser power was less than 12 W, the sintered structures in the slurries were difficult to form due to insufficient laser power density for sintering silica. As laser power was increased from 12 to 28 W, the laser scan speed increased from 90 to 130 mm/min. That is the laser power increased with scan speed. When the laser power exceed 28 W, the sintered layer could not be formed because the laser power density was too large for building layer.
3.2 Bone scaffold fabrication

According to suitable SLS process parameters found by constructing pilot-run sample experiments, the titanium biomedical bone scaffold with hollow shell structure can be built within 3hrs. Fig. 3 presents a titanium biomedical bone scaffold created with appropriate SLS process parameters under layer thickness of 100 μm, laser power of 15 W, scan velocity of 100 mm/s, hatching space of 0.1mm, energy density of 1.5 J/mm², laser beam size of 0.2mm, and a laser frequency of 16 KHz.

For assessing the strength of the titanium biomedical bone model, a round type sample with a dimension of φ 5× 6mm is used in compression testing instrument (HT-9102, Hung Ta Instrument Co, Taiwan). The compression strength is estimated through the formula: 
\[ \sigma = \frac{P}{A} \] (where \( \sigma \) is the compression strength in MPa, \( P \) is the loading force in N, and \( A \) is the section area in mm²).

Some samples were kept in green part condition in ambient and others were taken for post heat treatment process at 700°C, 800°C and 900°C. Fig. 4 displays the results for compression test of these samples. As the results can be observed, the compressive strengths are proportion to the temperature of post heat treatment. In addition, the mechanical strength of this titanium biomedical material is reinforced significantly by post heat treatment due to the silica sol is melted and fused with titanium powder.

3.3 Mechanical properties

The biomedical titanium green parts built by SLS are usually weak and fragile. A post-curing process, high temperature heat treatment is applied for extreme strength reinforcement and this post heat treatment part is so-called brown part. The temperature 700°C, 800°C and 900°C with 120 minutes duration are chosen for sintering these biomedical titanium parts.

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3.4 Cell culture

The cell cultures were implemented on the green part and biomedical titanium bone scaffolds after post heat treatment at 800 °C to prove its suitable biocompatibility. The human osteogenic sarcoma (MG63) was adopted in a microculture tetrazolium test (MTT) assay to analyze the cell activity. The results of cell culturing are shown in Figure 6. The value of optical density (OD) means the number of live cells. As can be seen, the OD values increases with the cell culture time. In addition, the OD values of a sintered scaffold are larger than that of green part. This indicates that a sintered scaffold can be more contributive to the cell growth.

Fig.6. MTT assay for osteoblast-like cell.

4. Conclusions

In this study, the process parameters of laser were tuned at a laser power of 15W, a frequency of 16KHz and a scanning speed of 100mm/s to build the titanium biomedical bone model within 3hrs. Testing results of the titanium biomedical material show that the compressive strength is 142 MPa after post heat treatment process. It is confirmed that a bio-metal bone scaffold with complex shape structure can be constructed by this layer additive processing. Therefore, this process has a greater potential for fabrication bio-metal bone scaffold in tissue engineering.

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