

Bioceramic Scaffolds Fabrication by Rapid Prototyping Technology

F.H. Liu, S.H. Chen, R.T. Lee, W.S. Lin, Y.S. Liao

Abstract—This paper describes a rapid prototyping (RP) technology for forming a hydroxyapatite (HA) bone scaffold model. The HA powder and a silica sol are mixed into bioceramic slurry form under a suitable viscosity. The HA particles are embedded in the solidified silica matrix to form green parts via a wide range of process parameters after processing by selective laser sintering (SLS). The results indicate that the proposed process was possible to fabricate multilayers and hollow shell structure with brittle property but sufficient integrity for handling prior to post-processing. The fabricated bone scaffold models had a surface finish of $25\ \mu\text{m}$, a dimensional shrinkage of 18 %, a maximum bending strength of 4.7 MPa under the laser energy density of $1.5\ \text{J}/\text{mm}^2$. Therefore, this process has a greater potential for fabrication bone scaffold in tissue engineering.

Keywords—bioceramic, bone scaffold, rapid prototyping, selective laser sintering

I. INTRODUCTION

THE commonly implants materials can be categorized into metals, polymers, and ceramics. The implants usually be attached on the bone with screw, which can cause the bone damage due to the stress concentrations [1]. However, bioactive materials can be attached by a more suitable method to form a secure physical bond with tissue surrounding the implantation [2]. In addition, bioceramics have been widely adapted as bone replacement materials due to their high biocompatibility properties [3, 4].

The conventional implant fabrication processes have only a limited sample of implants for surgeons to choose [5]. A significant problem of these restrictions is the degree of skeletal adaptation. Therefore, a new method would be highly desirable to generate a model according to custom designed and to produce suit individual implants.

On the other hand, the traditional processing methods require bone replacement materials to be mould and cut, which lack precise control over the internal architecture, such as pore size and pore shape [6]. In order to overcome these issues, the aim of this article is to generate tissue engineering scaffolds using the rapid prototyping (RP) technique with bioceramic materials because the complex shape is easily to be built in this way.

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II. METHODS AND MATERIALS

A. Selective Laser Sintering

Selective Laser Sintering (SLS) technique sinters powder materials to form a solid part by a laser beam according to the 2D sliced patterns. By paving thin layers of powder based materials and repeating the laser sintering process, a three dimensional model is built layer by layer.

In this work, a layer manufacturing process was developed for forming a hydroxyapatite (HA)-silica bioceramic green part. The process is implemented as shown in Figure 1, this process involves following steps: (a) the bioceramic powder and silica binder are blended as a raw material in ceramic slurry form, (b) the slurry is paved by a scraper onto the elevator to form a slurry thin layer, (c) the paved slurry layer is selective sintered via a CO_2 laser beam, then a solid ceramic layer is formed, (d) the working platform is lowered by an elevator to the thickness of monolayer, (e) repeating steps (b) to (d), a multi-layer part is obtained by stacking solidified layers, (f) the residual slurries are removed and then a 3D bioceramic object is obtained [7].

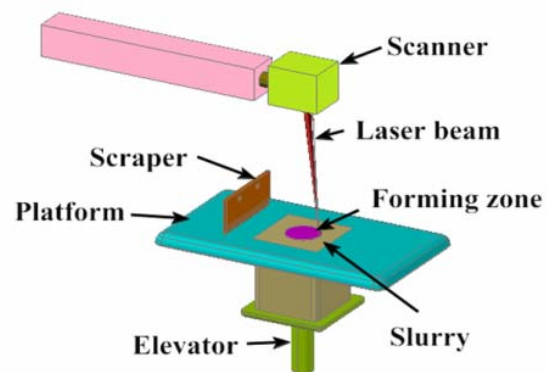


Fig. 1 Schematic of a manufacturing processes of selective laser sintering

In the laser sintering process a range of parameters may be varied as follows: the laser power was varied from 5-25 W, the scan speed was ranged from 50-300 mm/s, the layer thickness was altered from 50-150 μm , and the line overlap of the sintered ceramic was 1/2 of the laser beam width. While the spot size of laser beam was kept constant at 0.4 mm.

B. Hydroxyapatite and Silica Slurry

Three types of materials can be used in RP technology such as powder, liquid, and solid-based. However, another type of material was used in this work. The bioceramics slurries material, comprising of the HA powder and silica sol, was used in the following experiments. Mixing HA powder and silica

binder by a mixer in a proportion of 30 wt. % to 70 wt. % could obtain slurry with a viscosity of 3000 cP.

The reasons for using bioceramic slurry in the laser sintering process are twofold: first, the composition of the bioceramic is in the series of SiO_2 , P_2O_5 , CaO that has the potential to produce synthetic bone scaffold structures; second, these slurries possess greater flexibility and viscosity, which are easily to be paved into a thin ceramic layer and to be constructed to a porous tissue engineering structure [8].

III. RESULTS AND DISCUSSION

A. Laser Curing Process

In laser sintering process, when the bioceramic slurries were exposed by laser radiation, the moisture in the slurry will be evaporated and then the "curing effect" occurs. Thus, the HA powders in a scanning path were solidified in a certain depth and then a single line of cured bioceramic was formed. For a laser power of 10-20 W, scan speed of 50-300 mm/s, and layer thickness of 0.1 mm,

Figure 2 shows the relation between the laser scan speed and the depth of a single line of cured bioceramic. As can be seen, the bioceramic cured depth increases as laser scan speed decreased. The cured depth was deeper because the bioceramic slurry absorbed more laser energy at lower scan speed. When the cured depth was between 0.18 and 0.12 mm, each layer of cured ceramic could be bonded together. Therefore, if the over-cure depth between layers is sufficient, the HA powder can be built to form a bioceramic layer with suitable strength, which maintains the contours of a layer.

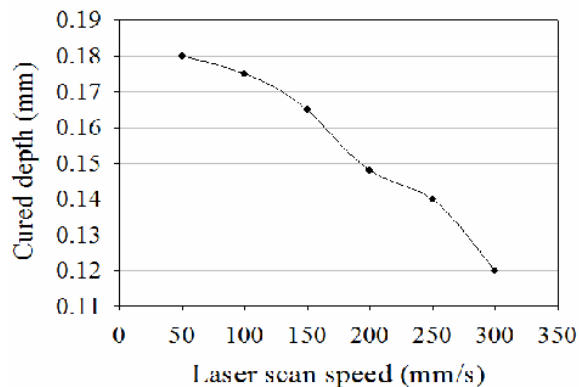


Fig. 2 The relation between laser scan speed and bioceramic cured depth

B. Multi-layer Bioceramics

The procedure for a single line of cured bioceramic is repeated to form a single layer of a bioceramic, which keeps a suitable overlap between the layers. If the overlap was less than 15 %, the bonded strength was insufficient to build monolayer. In contrast, when the overlap exceeded 30%, the cured layer yielded warping due to the laser power density being too high. Thus the formation of the bioceramic layer failed.

When the warp is greater than a paved layer thickness, the layer cannot be built because this warped portion will be removed by the scraper. If the overlap of a cured layer is varied

from 15 to 30%, a cured layer can be successfully constructed. Therefore, valid multi-layer specimen could be built after the coherent monolayers were stacked. The Figure 3 shows a multi-layer of cured bioceramic specimen with the dimensions of 8 mm × 8 mm × 1.5 mm as the overlap is 25%.

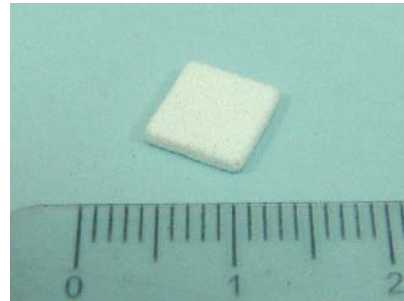


Fig. 3 A multi-layer bioceramic specimen produced by laser curing

C. Laser Energy Density

From experimental results, for a certain laser scan speed, the built layers appeared poor cured condition at lower laser power. When the laser power was increased, the structural strength was enhanced because laser energy density was sufficient. For a given laser power, the shaped integrity of the fabricated specimens increased as scan speed reduced. This improved the solidification of the cured bioceramic at slower laser scan speeds and higher laser power. The main significant factor with regard to the bending strength was the combination of laser energy, scan speed and scan line overlap, which yielded the laser energy density on the scanning zone. Further tests revealed that the laser energy density had an important effect on bending strength as shown in Figure 4. As can be seen, a maximum strength of 4.7 MPa was obtained at 1.5 J/mm². Above 1.5 J/mm², the laser energy was too great causing degradation of the laser cured. Between 1.5 and 0.5 J/mm², laser energy density was suitable for curing the silica sol, thus bending strength increase with laser energy density. Below 0.5 J/mm², the slurry layer could not form due to insufficient energy density.

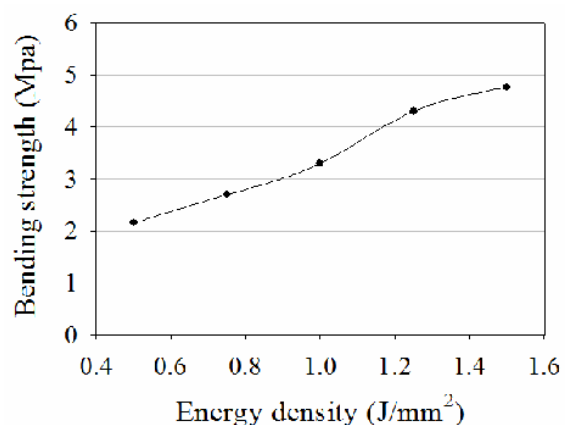


Fig. 4 The bending strength with regard to laser energy density

D. Fabrication Bone Scaffolds

In this work, a feasible parameter window is as follows: laser power 10-20 W, laser scan velocity 50-300 mm/s, and layer thickness 50-100 μm . The suitable process parameters comprise a layers thickness of 100 μm , a laser power of 15 W, a scan velocity of 150 mm/s and a laser frequency of 10 KHz, we confirm the ability of the laser curing process to produce the HA green part of bone scaffold model with hollow shell structure in a fabricating time of 120 minutes. As shown in Figure 5, those bone models had a surface finish of 25 μm , a dimensional shrinkage of 18 %.



Fig. 5 The HA bone scaffold model with hollow shell structure obtained by laser curing under layers thickness of 100 μm , laser power of 15 W, scan velocity of 150 mm/s and a laser frequency of 10 KHz

Figure 6 presents the SEM surface micrographs of a bone scaffold model displayed in Figure 5. It is evident that the HA particles are embedded in the solidified silica sol. The object of this paper is to confirm the feasibility of the laser curing process for fabricating HA bioceramic and to build an hollow shell structure with pores size in the range of 100-600 μm to support the growth of bone [9]. As seen from the Figure 6, the SEM micrograph of the bioceramic bone models fabricated by this process demonstrated that this type of structure was being achieved. From this figure we can see that many porous with various shapes on the scaffold surface are formed in the bioceramic matrix, which can help the bone cell attach on the surface.

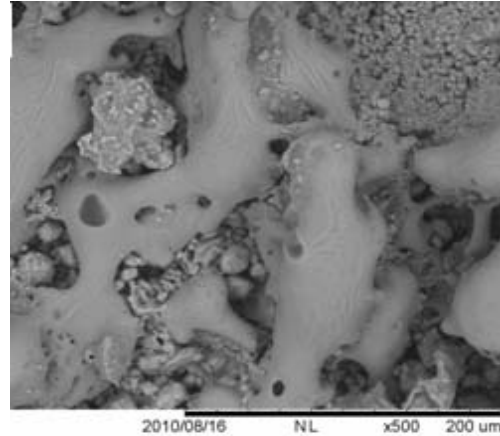


Fig. 6 SEM surface image of the scaffold model fabricated by HA particles and cured silica

IV. CONCLUSION

The proposed process has three features. The first feature is the forming principle is a laser “curing effect”, thus it needs smaller laser energy to form the bioceramic models. The second feature is the bone scaffolds are faster fabricated by a layer additive manufacturing technique. The third feature is the bioceramic slurry is used as raw materials but other SLS processes adopt powder form material. Therefore, it is evident that the laser curing process is different from the traditional methods for forming bioceramic materials.

REFERENCES

- [1] K. Xiao, K.W. Dalgarno, D.J. Wood, R.D. Goodridge, and C. Ohtsuki, Indirect selective laser sintering of apatite-wollastonite glass-ceramic, *Journal of Engineering in Medicine*, Vol. 222, 2008, pp.1107-1114.
- [2] P. Vincenzini, *Mater. Sci. Monogr*, Vol. 17, 1983, pp. 3.
- [3] L.A. Cyster, D.M. Grant, The influence of dispersant concentration on the pore morphology of hydroxyapatite ceramics for bone tissue engineering, *Biomaterials*, Vol. 26, No. 7, 2005, pp.697-702.
- [4] A. Almirall, G. Larrecq, Fabrication of low temperature macroporous hydroxyapatite scaffolds by forming and hydrolysis of a TCP paste, *Biomaterials*, Vol. 25, No. 17, 2004, pp.3671-3680.
- [5] J.C. Lorrison, K.W. Dalgarno, D.J. Wood, Processing of an apatite-mullite glass-ceramic and an hydroxyapatite/ phosphate glass composite by selective laser sintering, *Journal of Materials Science: Materials in Medicine*, Vol. 16, 2005, pp.775-781.
- [6] S.F. Yang, K.E. Leong, Z.H. Du, and C.K. Chua, The design of scaffolds for use in tissue engineering, Part I: Traditional factors, *Tissue Engineering*, Vol.7, 2001, pp.679-689.
- [7] F.H. Liu, Y.K. Shen, Y.S. Liao, Selective laser gelation of ceramic-matrix composites, *Composite Part B: Engineering*, Vol. 42, 2011, pp.57-61.
- [8] F.H. Liu and Y.S. Liao, Fabrication inner complex ceramic part by selective laser gelling, *Journal of the European Ceramic Society*, Vol. 30, 2010, pp. 3283-3289.
- [9] M.J. Gauthier, E. Bouler, E. Arguado, P. Pilet, and G. Daculsi, Macroporous biphasic calcium phosphate ceramic: influence of macropore diameter and macroporosity percentage on bone ingrowth, *Biomaterials*, Vol. 19, 1998, pp. 133-139.