Exploring SVM Rapid Prototyping in Scaffold Fabrication

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Abstract

Presented in this paper is an initial effort toward medical application of Selective Vacuum Manufacturing (SVM), a simple rapid prototyping technique that is being developed. This preliminary study explored the possibility of applying SVM technique to build scaffold, a structure supporting tissue formation. Three different laydown patterns: solid, $0^o/90^o$, and zigzag were successfully used for fabricating scaffolds from Poly-lactic acid (PLA) powder, and all the built scaffolds provide high porosity which is important for tissue growth. The result suggests further study on improving the mechanical strength of the scaffold, preventing contamination, and scaling down the size of the scaffold.

Keywords*: Selective vacuum manufacturing, Scaffold, Medicine, Poly-lactic acid, Rapid prototype*

1 Introduction

Rapid prototyping (RP) is an innovative technology that allows complex physical prototypes to be directly constructed from 3D-CAD model via a pile of stacked contour layers. RP has been well accepted and widely used in many applications including in medical applications such as tissue engineering. RP has been explored its capability in fabrication of a temporary structure called scaffold where cells can attach, proliferate, differentiate and organize into the healthy tissue as it degrades [1]. The important medical requirements of scaffold are: high porosity with suitable pore size, high surface to volume ratio, biodegradability, biocompatibility, and adequate mechanical properties [2-3]. RP can manufacture scaffold that achieves these requirements with the higher construction speed comparing to the conventional scaffold fabrication techniques, e.g., solvent casting, particulate leaching and gas foaming, that are restricted in ability to control pore geometry/size/distribution and difficult to construct internal channels within the scaffold [4-5]. Up to date, many RP techniques have already been used in this medical application. Some of them are commercial RP techniques such as SLA, SLS and 3DP [6-8] and others are under the development [9-12]. Presented in this paper is a recent study on exploring a feasibility of using SVM, a new RP technique that is being developed, to fabricate the scaffold structure. The details of SVM are presented in the next section. Section 3 is about material preparation and method used for creating scaffolds. Section 4 presents the results related to the characteristics of the fabricated scaffolds including micro-structure, porosity, and mechanical properties. Discussions about feasibility of using SVM in this application are next addressed at Section 5. Conclusion and recommendations are made available in Section 6.

2 Selective vacuum manufacturing - SVM

SVM is an inexpensive RP technique that has been developed from two simple manufacturing processes: sand casting and material sintering. Steps of SVM process are illustrated in Figure 1. Support material, green sand premixed with bentonite 2 wt% and water 4 wt% of green sand, is layered on the platform and then leveled [13]. A vacuum head starts generating cavity following the designed toolpath. A filling head is next traced along the generated cavity to deposit the part material which can be in liquid or powder form. Heater is used to sinter the part material to form a layer profile. All steps are repeated until the full geometry is accomplished.

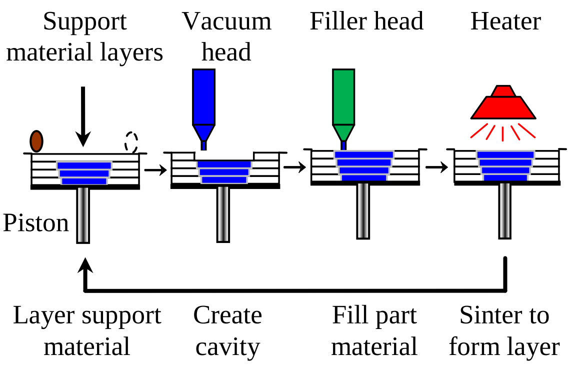

Figure 1: Steps of SVM process

3 Material and method

3.1 *Scaffolding material*

Poly-lactic acid or PLA, an environmental-friendly plastic derived from renewable agricultural products such as corn [14] and cassava [15], has been used in this study. Prior to be used in SVM process, PLA pellets were transformed to be powder-like by spraying PLA solution into the water medium, then air-drying and gently crumbling to get the powder [16].

3.2 *Design and fabrication of scaffolds*

In this study, scaffolds with three different laydown patterns (solid, $0^{o}/90^{o}$ and zigzag) were used to examine the feasibility of using SVM in this particular application as shown in Figure 2(a). All nine scaffolds (three replications each) were created on an alpha-prototype SVM machine. They were the stacks of eight layers of cylindrical discs (Ø40×1 mm).

A LabVIEW program was developed to control the movement of units on the SVM machine that consists of (1) motion for vacuum head and filling unit, (2) motion of heater and scraper unit, (3) motion of storage and layering platform unit. Input to the program was the toolpath of each laydown pattern as presented in Figure 2(b). Figure 2(c) depicted the top view of two consecutive layers created by using the common toolpath with different orientation. The process parameters used in all scaffold fabrications were set as follows: the outer diameter of the vacuum nozzle 1.64 mm, the position of the vacuum head 1 mm below surface of support materials, the contouring speed 4 mm/s, the vacuum pressure 0.25 bar, the inner diameter of the filling nozzle 3 mm , the position of the filling head 0.1 mm above surface of support materials, the filling speed 4 mm/s, the heating power 300 watt, the position of the heater 20 mm above surface of support material and the heater-scanning speed 8 mm/s.

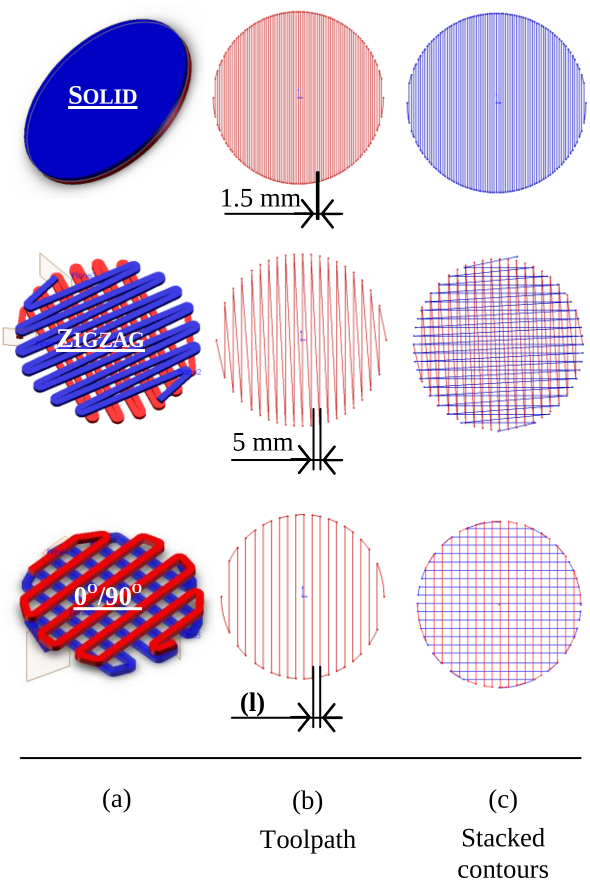

Figure 2: Design of scaffold architectures

3.3 *Testing and analysis*

Three types of tests were conducted for evaluation of the fabricated scaffolds. Details of each test and their procedures are as follows:

3.3.1 Scanning electron microscopy - SEM

Structural formability and geometry of the scaffolds were examined by using JSM-5410 (JEOL). After sputter coating with gold, SEM images of top surface and cross section were taken using a beam intensity of 12 kV at magnification on 35 and 100 times respectively.

3.3.2 Porosity analysis

Porosity (P) of the fabricated scaffold was calculated by using a following equation (1) [17]:

$$P = 1 - \frac{M}{V}\frac{1}{\rho} \tag{1}$$

Where M and V are the actual mass (g) and volume (cm^3) of the scaffold, while ρ is the specific density of PLA (1.25 g/cm^3).

3.3.3 Mechanical test

The compression tests were conducted on all nine scaffolds by using universal testing machine Instron 55R4502 with 10-kN load-cell. The crosshead speed was 1 mm/min. Stress-strain data were computed from load-displacement measurements. The modulus of elasticity was determined from the slope of the linear region on stress-strain curve.

4 Experimental results

4.1 *Micro-structure*

Figure 3 shows the surfaces and cross sections of the three architectures along with their SEM images. PLA powder was sintered to form profile layers. As presented in Figure 3(d)-(f), the micro-structure of sintered granular particles contained both open pores (spaces between granules) and closed pores (softened granules connected as a web). These are the results from solid state sintering process that occurs below melting temperature but the energy is still sufficient to form necking between adjacent particles. Similar connectivity also appeared between layers as shown in Figure 3(j)-(l). However, due to inadequate heating power, most necking parts were quite small that resulted to low strength of the scaffolds. For pore size distribution, the fabricated scaffolds provided micro-pores in range between 106-149 μm on the surface and 55-111 μm at the cross section.

4.2 *Porosity*

From the experiment, porosity of the solid scaffold was 93.7% while the scaffolds created with 0°/90° and zigzag pattern gave higher porosity of about 97.6% and 96.7% respectively.

4.3 *Mechanical properties*

According to the compression tests, the solid scaffold gave higher mechanical properties comparing to the other two architectures. Their mechanical properties are summarized in Table 1.

Table 1: Results of mechanical test

Laydown pattern	Solid	$0^o/90^o$	Zigzag
Maximum load (N)	285.9	30	50
Deformation at maximum load (mm)	6	6	6
Modulus of elasticity at 25% deformation (kPa)	78.4	8.39	11.8

5 Discussions

From the experiment, all fabricated scaffolds gave very high porosity even the solid scaffolds that had no macro-porosity from the laydown patterns. This is the advantage of creating scaffold by this powder-based RP technique unlike most of the conventional scaffold fabrication techniques that the scaffolds are lack of porosity and required the use of porogen (e.g. fine salt) for improving porosity. However this high porosity is a trade-off for low mechanical strength. Increasing of heating power to enlarge the necking areas can help improve this mechanical property but it will cause shrinkage problem on the scaffold. This shrinkage effect can be compensated by adding more PLA powder. Laydown patterns may be introduced to maintain porosity at suitable level. Another issue is on contamination. From observation, the scaffolds were contaminated by support material -

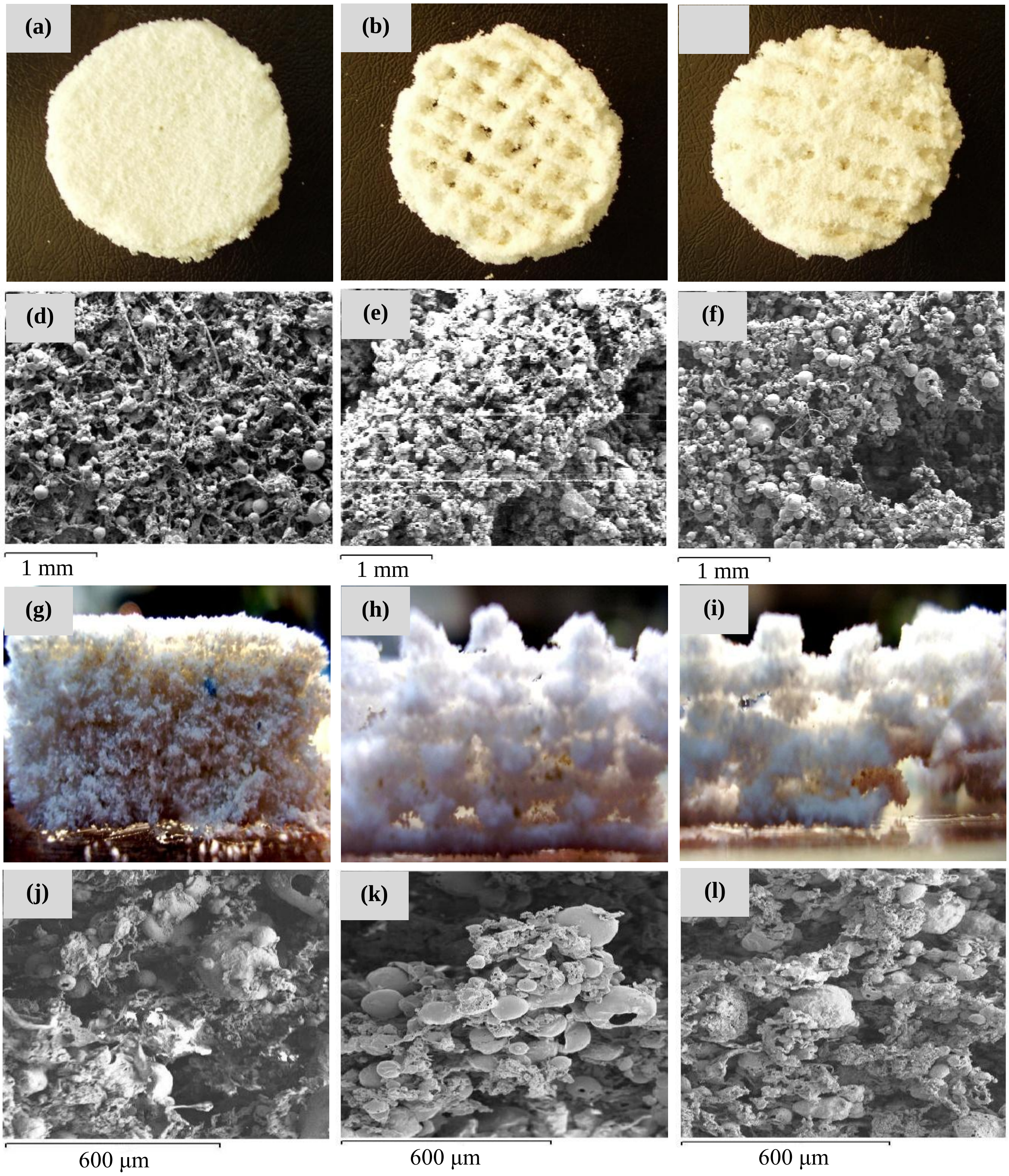

Figure 3: Characteristics of the fabricated scaffolds

Top view of scaffold with: (a) Solid pattern, (b) $0^o/90^o$ pattern, (c) Zigzag pattern
SEM results of surface 35X: (d) Solid pattern, (e) $0^o/90^o$ pattern, (f) Zigzag pattern
Cross section of scaffold with: (g) Solid pattern, (h) $0^o/90^o$ pattern, (i) Zigzag pattern
SEM results of Cross section 100X: (j) Solid pattern, (k) $0^o/90^o$ pattern, (l) Zigzag pattern

that stuck on the structures and could not be easily removed. It seems that replacement of the support material with other powder materials that can withstand heating power for sintering and can be easily removed should be considered. Toward practical usage, SVM machine requires some modifications to be able to fabricate micro-scale scaffolds.

6 Conclusion and recommendations

SVM has been investigated for scaffold fabrication application. Although the fabricated scaffolds cannot provide sufficient mechanical properties, SVM still illustrated its potential to provide micro-porosity that is another medical requirement. Further development will encourage SVM to be an alternative to the other scaffold fabrication techniques. The future study will focus on improving mechanical properties, replacing support material to prevent contamination and scaling down the size of scaffold.

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