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Investigations for mechanical properties of Hap, PVC and PP based 3D porous structures obtained through biocompatible FDM filaments

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In last two decades fused deposition modelling (FDM) has emerged as a standout amongst the most broadly utilized process for fabrication of 3D functional parts in bone tissue engineering. However this technique is still facing substantial problems to produce porous structure having sufficient mechanical strength. In this present research an exertion has been made to develop a bio-compatible FDM filament which has been further used to fabricate 3D porous structure. The results of the study highlighted the effect of FDM process parameters (infill percentage, infill speed and layer thickness) on the tensile properties (percentage elongation at peak, percentage elongation at break and yield stress) of the 3D functional prototypes. It has been observed that infill percentage has major contribution i.e. 92% towards peak elongation, 91% towards break elongation and 80% towards yield stress. The remaining two parameters have very less contribution towards mechanical properties of the 3D structures. For microscopic analysis the microphotographs of scanning electron microscope (SEM) have been taken to ensure the structure produced is porous enough and can be used in a variety of engineering and biomedical applications.

1. Introduction

The additive manufacturing (AM) processes has an imperative role in the realm of bone tissue engineering (BTE). The traditional implant fabrication processes has become obsolete with the advancement in various AM techniques. All AM processes work on the same principal of successive addition of layers to fabricate a final product [1]. The AM acts as a backbone in the bio-manufacturing sector. Recently AM has been successively used to produce the complex 3D tailor made bio-structures [2]. BTE used to replace or restore the physiological functions that have been lost in the damaged or diseased organs [3]. Tissue engineering (TE) involves the combinations of cells and biomaterials for assembly of tissue structures [4]. In BTE the “top-down” approach (see Fig. 1) is used. In this approach, on the scaffolds with biodegradable and biocompatible properties cells are seeded [5–7]. The population of cells is directly proportional to the spacing in the scaffold, but the fabrication of complex functional porous scaffolds using conventional methods still confronts challenges [8–10].

The AM processes has been used to produce the open porous scaffolds of biomaterials for providing the mechanical support to the cells and significant space for the regeneration of tissue [12]. The AM processes produces the sacrificial patterns for casting of patient specific best fit functional implants [13]. According to type of raw material used for building processes the current AM can be broadly categorized into four classes powder form, gas phase, sheet form and liquid phase [14,15]. These techniques are also classified on the basis of source of power used i.e. laser and heat. The laser based AM processes demands more considerations towards their care and maintenance and setups are also exorbitant in contrast to non-laser based methods [16]. FDM stands second after stereo-lithography as most commonly used AM technologies [17]. The fabrication of scaffolds starts from MRI or CT scanned data of implant and converted into 3D geometry by using software such as 3D-Doctor, MIMICS etc. and saved into STL (stereo-lithography or standard triangulation language) format, i.e. appropriately used by any AM techniques [18]. The STL file is sliced into two dimensional layers by using software support [19]. The commercial FDM printers accompanied a temperature controlled hot chamber [20]. The thermoplastic is extruded through the extrusion head on the

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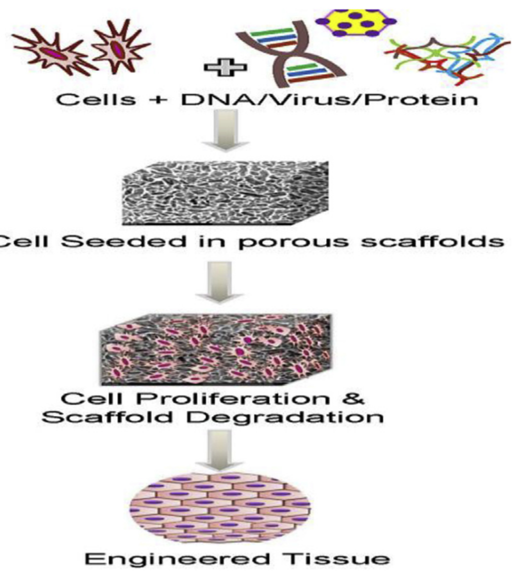

Fig. 1. Schematic of "top-down" approach for tissue engineering [11].

fixtureless platform [21]. To prevent solidified material from the thermal stresses the temperature of the chamber is maintained constant above the glass transition temperature i.e. 72 °C in case of ABS [22–25].

In this research an exertion has been made to develop a new ceramic based FDM filament for clinical dentistry. The biocompatible polymers has been used as base matrixes and reinforced with the bioactive ceramics. The 3D-porous structures have been fabricated by running this in house developed filament on existing FDM setup and further investigations have been made for mechanical properties. The obtained results have been supported by images obtained from the SEM.

2. Materials and methods

The experimentation work starts from the collection of biocompatible polymers PP and PVC in the granular form. The bioactive ceramic hydroxyapatite (Hap) has been reinforced in the parent polymer matrixes. A fixed proportion of Hap and the polymer matrix as 4%HAp+96%polymer matrix (PVC70% + PP30%) have been used for preparing a filament. Twin screw extruder was used for blending and extrusion of FDM filament. Fig. 2 shows in house extruded filament.

To fabricate the 3D structures for mechanical testing and SEM analysis a commercial FDM setup (3D printer, Make-Divide By Zero, India) has been used shown in Fig. 3.

Three different controllable parameters (i.e. layer thickness, infill percentage and infill speed) of FDM has been selected (see Table 1) based upon pilot study.

Whereas other remaining FDM process parameters such as orientation, raster angle, temperature etc. was put as constant throughout in the present research work. Extrusion temperature was set according to melting point of the parent matrix. The standard 3D structures fabricated on FDM (as per ASTM D-638 IV) have been mechanically tested on universal tensile tester (UTT). The complete control log as per Taguchi L9 orthogonal array is shown in Table 2.

A total 3 sets of repetitions/experiments have been performed for 9 settings of different controllable factors (as per Taguchi L9 OA). After performing the tensile testing, the part with best mechanical properties was used for microscopic analysis by taking the microphotographs through SEM.

Fig. 2. In-house extruded FDM filament.

Fig. 3. FDM setup used for 3D printing.

Table 1
FDM input process parameters.

Levels	Parameters		
	Infill percentage %	Layer thickness mm	Infill speed mm/s
Level 1	0.20	0.25	33
Level 2	0.60	0.30	35
Level 3	1.0	0.35	37