Development Of Pneumatic Extrusion Printed Composite Bone Scaffold

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***Abstract* - A challenge for bone grafting is producing three-dimensional (3D) structures with the specific porosity and reliable mechanical and chemical properties, so that the host will not experience any inconvenience in the future. Various methods exist to produce a bone implant. But the desired properties are not being presented by any conventional materials and the various existing techniques to the expected or required extent. 3D printing is an additive manufacturing technique to produce metallic components with controlled pore size, total porosity and pore-connectivity. In this paper, a simple extrusion-based 3D printing technique is developed to produce porous PCL (Polycapro Lactone) infused with metallic aluminum powder scaffold under normal atmospheric conditions to overcome the existing limitation Therefore, using this simple and cost-effective technique, bone graft substitute scaffolds could be developed as implant for load bearing applications.**

***Index Terms*—Porosity, Bone implant, Polycapro Lactone, Scaffolds.**

I. INTRODUCTION

Increasing accidents every day in the country is leaving many patients with broken bones and severe deformations that are very painful to recover through traditional healing. In addition to these there are millions of people suffering from genetic osteo-imperfections (bone diseases) that if left untreated will cause fatal injuries with worsening conditions. Bone grafting is the only survival option in such cases. However, one underlying problem with such a situation is that the implants cannot be mass produced as the mechanical as well as chemical requirements of an implant differs from person to person. Some of the scenarios where bone implantation is necessary is given below.

The human body has incredible capacity to regenerate, but this regeneration is limited by factors such as the type of tissue, and the need for growth hormones for differentiation and physical size (critical defect). Any injury to a tissue beyond this critical size needs external support. This approach of supporting tissue regeneration is often referred to as tissue engineering (TE) or regenerative medicine (RM). The external supports are called scaffolds. These scaffolds create a platform for the cells to migrate to the site of action and forms new tissue. Hence, scaffolds play an important role in TE and regenerative medicine.

These scaffolds are often loaded with growth factors to hasten differentiation of cells to preferred types of lineage to promote new tissue formation. The physical and chemical composition of scaffolds is critical for cell viability and cell proliferation. There are two perilous features that profile the usage of scaffolds: the choice of biomaterial to create a scaffold and the method of fabrication. Much research has been done on modifying and creating new biomaterials. Biomaterials are defined as any materials that interface with biological systems. Biomaterials are classified based on many criteria such as chemical and physical composition, biodegradability, type of origin, and generations of modifications. Reliant on the target tissue, the choice of biomaterial is made. In current years, much focus was towards engineering biodegradable biomaterials. Based on the biochemical composition, biomaterials are classified into ceramics, polymers, and composites.

The ceramics class of biomaterials have major components of inorganic metal compounds and/or calcium salts. These biomaterials have been primarily used in orthodontic applications. Polymers are used in soft TE because of their similarity with connective tissues. The composite class of biomaterials are blends of ceramics and polymers. These composites have applications in orthopedic and dental TE.

II. METHODOLOGY

2.1 Development of 3D patient specific CAD model

In this step we developed patient specific CAD model form CT scan. In this process we used MIMICS software. This CAD model further used to meet different requirements.

Mimics

Materialize Mimics is an image processing software for 3D design and modeling, developed by Materialize NV, a Belgian company specialized in additive manufacturing software and technology for medical, dental and additive manufacturing industries. Materialize Mimics is used to create 3D surface models from stacks of 2D image data. These 3D models can then be used for a variety of engineering applications. Mimics is an acronym for Materialize Interactive Medical Image Control System. It is developed in an ISO environment with CE and FDA 510k premarket clearance. Materialize Mimics is commercially available as part of the Materialize Mimics Innovation Suite, which also contains 3-matic, a design and meshing software for anatomical data.

Process

The 3D files can also be enhanced for FEA or CFD and can therefore be exported to Abaqus in INP format, to Ansys in INP, CDB and MSH format, to Nastran in OUT, NAS and BDF format, and to Comsol in MPHTXT format. To carry on with Computer-aided design, the files can be exported in IGES format or as Point cloud Wherever Times is specified, Times Roman or Times

New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts. True Type 1 or Open Type fonts are required. Please embed all fonts, in particular symbol fonts, as well, for math, etc.

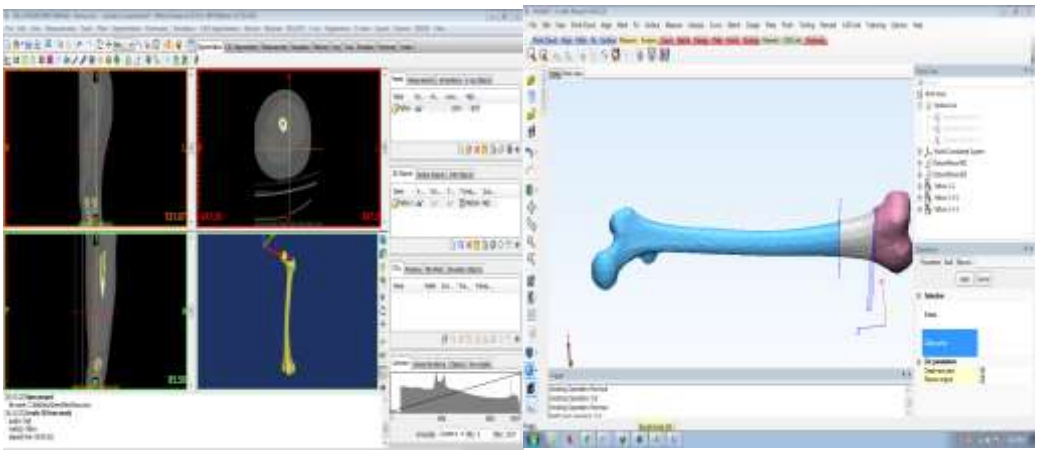

Figure 1 3D model using mimics software and 3D model of developed bone using mimics software

2.2 Design parameters

It is very important to develop porous soft tissue substitute for the selected application. In this process substitute internal structures play an important role on its mechanical properties, bone regeneration etc. Following parameters has to be consider before going to develop G and M code for the developed CAD model to run the pneumatic extrusion machine.

- ✓ Porosity
- ✓ Layer thickness
- ✓ Nozzle diameter
- ✓ Printing temperature

2.3 Generation of G and M code

After selection of suitable values in the above parameters for the developed of prepared CAD model G and M codes based source code has to be developed. This G and M code depend on the type of controller and firmware used to run the pneumatic extrusion machine. The machine has developed with RAMPS1.4 (ATmega 2560 processor) with Marlin-1.1 version. Simplify 3D software has been used to develop the G and M code for the selected controller and firmware.

2.4 Modification of G and M code to run the setup

The source code that is developed by the Simplify 3D software will not suitable for the developed machine. We made few modifications in the developed G and M code to run developed machine.

2.5 Simulation

After modifying the above specified parameters according to the requirements it is necessary to run the working of machine simulation to identify the any errors and modification that are needed for the developed source code.

2.6 Development of pneumatic extrusion machine

In the development of pneumatic extrusion machine different types of materials have been used, like aluminum extruded profiles, linear guide ways, linear rods, bearings, controllers, stepper motors, stepper motor drives, limit switches, bed, connectors, air compressor, band heaters, thermocouple, LCD display, temperature controller, solid state relay, voltage regulator etc., After development of entire machine with all features we performed alignment test on it. In this test identified maximum error is less than 0.01 mm

2.7 Procurement of required resources to prepare the composite material

Polycaprolactone (PCL) is a biodegradable polyester with a low melting point of around 60 °C and a glass transition temperature of about −60 °C.

The most common use of Polycaprolactone is in the manufacture of specialty polyurethanes. Polycaprolactone impart good resistance to water, oil, solvent and chlorine to the polyurethane produced. Polycaprolactone (PCL) has been widely used in long-term implants and controlled drug release applications. However, when it comes to tissue engineering, PCL suffers from some shortcomings such as slow degradation rate, poor mechanical properties, and low cell adhesion. The incorporation of calcium phosphate-based ceramics and bioactive glasses into PCL has yielded a class of hybrid biomaterials with remarkably improved mechanical properties, controllable degradation rates, and enhanced bioactivity that are suitable for bone tissue engineering.

2.8 Preparation of composite material

In this work polymer + aluminum composite material has to be prepared. In this connection 10 grams of PCL polymer and 2 grams of fine aluminum powder has been mixed with chloroform. Here chloroform is the best solvent for the PCL to mix with other materials.

2.9 Selection of suitable nozzle to extrude the composite

Different diameters of nozzles are tried to pneumatically extrude the composite materials. After verifying different parameters like flow of paste, temperature, velocity of X and Y axis etc., 0.61 mm diameter nozzle selected for the development of patient specific segmental bone scaffold.

2.10 Selection of suitable temperature to extrude the composite

Temperature that has been maintained for the development of segmental bone substitute is very important to pneumatically extrude the composite material. From 60 to 950C temperature was varied to identify best value for the prepared composite material. Finally, it is decided that at 900C the flow of composite material good for the specific velocity of the nozzle.

2.11 Fabrication of Patient specific composite bone substitute

Once after the development of bone segmental model, G and M code and composite material with the selected values of temperature, nozzle and pressure final product has developed with variable parameters.

Figure2 Fabricated pneumatic extrusion machine and Composite scaffold (PCL + ALuminium)

III. RESULTS

Finally, a homogenous 3D composite scaffold with the less expensive has been developed. The scaffold having, the pore size is varying from 700 to 800 µm. The scaffold is prepared by using the melt pneumatic extrusion machine. The optimal parameters are found by using the optimality test to find some combinations and that combinations selected are the best combination to develop the scaffold. The best combination of parameters is used develop scaffold are working pressure is 5.5bar, the feed is 50mm/min, the layer height is 10mm, the length is 20mm and the breadth id 20mm. The Polycaprolactone (PCL) and Aluminum powder composite is used to develop the scaffold because they cheap in cost and good properties having. The material is biodegradable and biocompatible. These optimal parameters, materials and set up reduce the cost of the development of scaffold.

IV. CONCLUSION

This work inspected the practicality of fabricating a scaffold with Polycaprolactone and aluminum powder composite utilizing a melt pneumatic extrusion machine with the addition of pneumatic system. This method allows the process to incorporate organic solvent during the printing of a scaffold unlike other processes where heating of PCL is involved. Scaffolds were printed and near optimal printing parameters for polycapro/aluminum compositions were determined. Scaffolds fabricated with a 50:50 PCL/aluminum composite using the parameters of 5.5 bar ,1.19 mm filament spacing and 50 mm/min feed rate were easy to handle with sufficient mechanical integrity. The porosity is observed that varies from 700 to 800 µm. A continuation of this study would include increasing the height of the scaffold. To achieve this, scaffold fabrication process will be modified by avoiding the continuous printing of single layer and incorporating start-stop operations to deposit each filament in the layer. Finally, in this study a scaffold with less cost with good properties is developed.

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