The Design, Fabrication and Analysis of Tissue Engineering Scaffolds

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Aims and Introduction

Project Aims

- Design tissue engineering Scaffold using CAD / G-Code
- Fabricate Scaffold using BFB 3000 rapid prototyping machine
- Test Scaffolds using Dynamic Mechanical Analysis (DMA)

Tissue Engineering is a rapidly developing area which combines the biology of cells, materials science and engineering. The aim is to restore, maintain or improve tissue function. The key to successful Tissue Engineering is the bio-mimicry of the human body. This is achieved through a combination of cells, biological signals and 3D scaffolds.

Scaffolds are typically highly porous 3D constructs. They should be constructed using biocompatible materials that are safe to be placed inside the human body. Most scaffolds are designed to be temporary fixtures which guide the regrowth of a particular type of tissue. The ideal scenario is the seamless transition from scaffold to newly grown tissue. This means the customisation of the scaffold's degradation profile is important. The scaffolds involved in this project are intended to be used to regrow bone tissue.

Rapid Prototyping (RP) is becoming more popular as the technology and understanding advances. The major advantage of RP is its ability to produce components directly from a CAD (Computer Aided Design) file. This is especially beneficial when producing scaffolds as the internal architecture of the scaffold can be controlled and it allows for the predictable production of an interconnected pore network which is essential for tissue engineering scaffolds. There are many different types of rapid prototyping and varying levels of accuracy and quality available. This project utilised the Fused Deposition Modelling (FDM) technique.
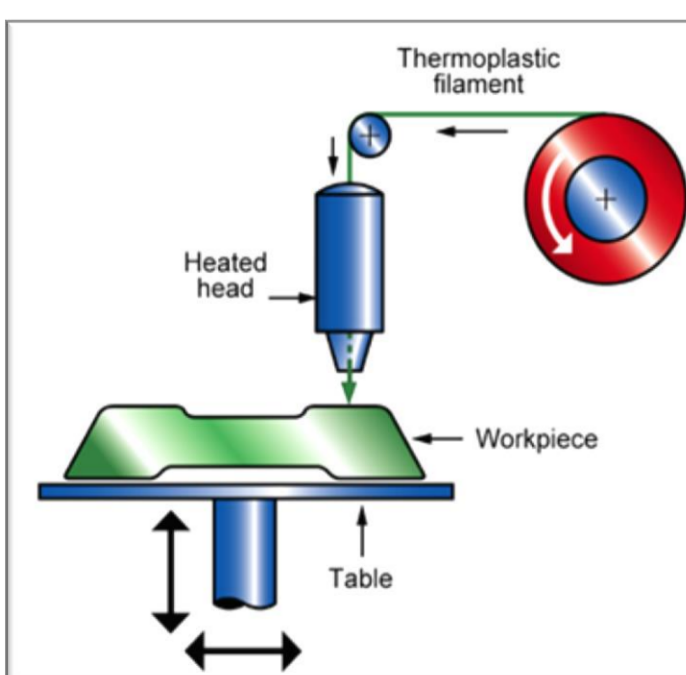
FDM involves the extrusion of molten polymeric material from a moving extruder head. The material is deposited layer upon layer where it solidifies and forms a complete model. This is also known as 3D Printing.

Materials and Methodology

Specification: The scaffold was to be made from PLA using the BFB 3000 3D printer. The scaffolds would be approximately 8mm in diameter. The scaffold should be designed with tissue engineering requirements in mind.

8mm

Actual size of scaffold.

PLA: The material used for the scaffolds was Poly-Lactic acid (PLA), which is a synthetic polymer which is importantly biocompatible and biodegradable. This allows for the placement inside the human body and means the by-products of degradation are safe for the body to absorb. PLA is also relatively cheap and readily available.

Scaffold Production began with the designing of the file to be used by the 3D printer. Initially the standard method was used: using a CAD program to produce a model of the scaffold which was then converted to a compatible language for the 3D printer. However due to the intricate geometries involved in the designs, the accuracy and resolution of this method meant unsuccessful fabrications. In order to rectify this G-Code was used to produce the scaffolds instead. G-Code is the language that depicts the movements of many different types of machines. Learning to use this language was time consuming however the results attained showed it was a valuable investment.

BFB 3000 3D Printer

Using G-Code allowed for the manual control of the machine's parameters and movement. Whilst learning the language many iterations of codes were produced. To begin the disc shaped scaffolds were produced directly from the G-Code. However an easier, faster and better quality method was devised. 60x60mm porous squares were produced and then 8mm diameter discs were cut from these samples using a laser cutter. The combination of rapid prototyping and laser cutting was ideal for simple small batch production.
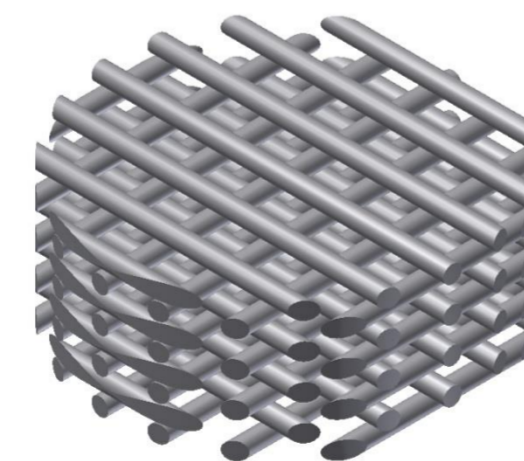
CAD Model

G-Code Sample

Testing the scaffolds was done by using Dynamic Mechanical Analysis (DMA). The DMA machine applies a small sinusoidal force to the sample by means of a force motor and drive shaft. A Linear Variable Differential Transformer (LVDT) accurately measures tiny deformations in the material. From these measurements the viscoelastic behaviour of a material can be monitored under varying conditions. A dual cantilever test was done on strips of the porous scaffolds and compressions tests performed on the discs themselves.

DMA 8000

Results and Conclusions

Many scaffolds were successfully fabricated with varying pore sizes, fibre thicknesses and fibre patterns. The difficulties with the 3D printer were overcome using G-code and a laser cutter.
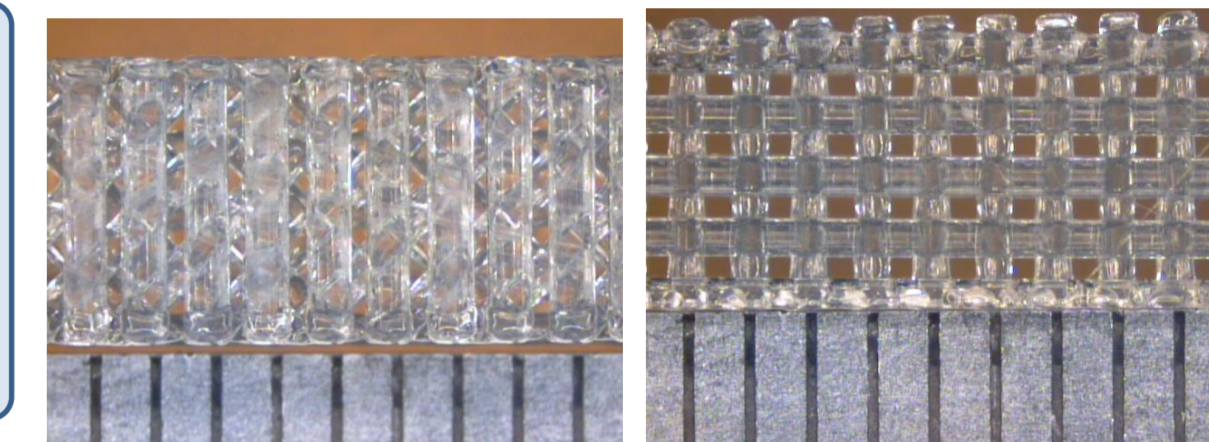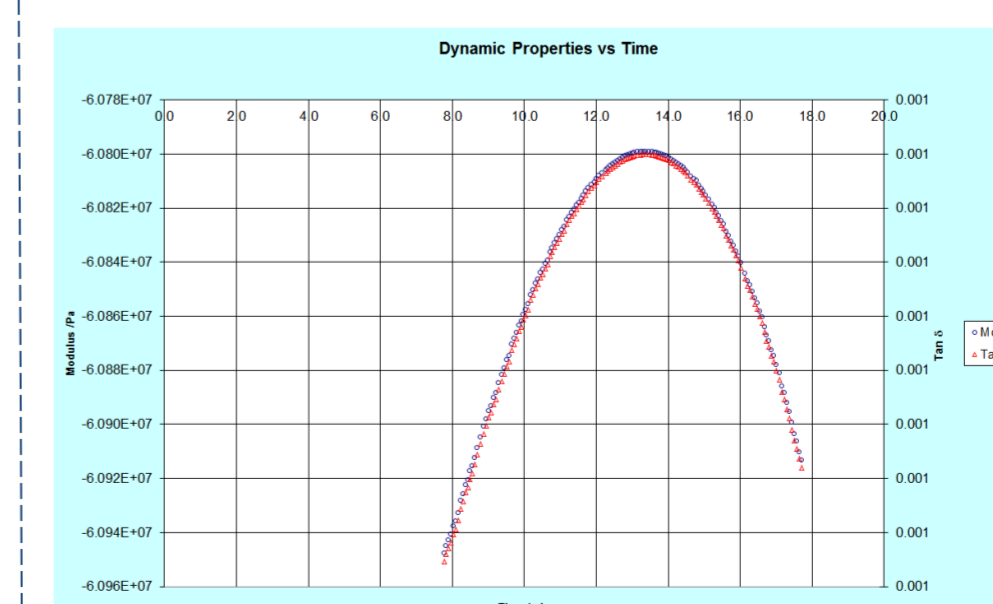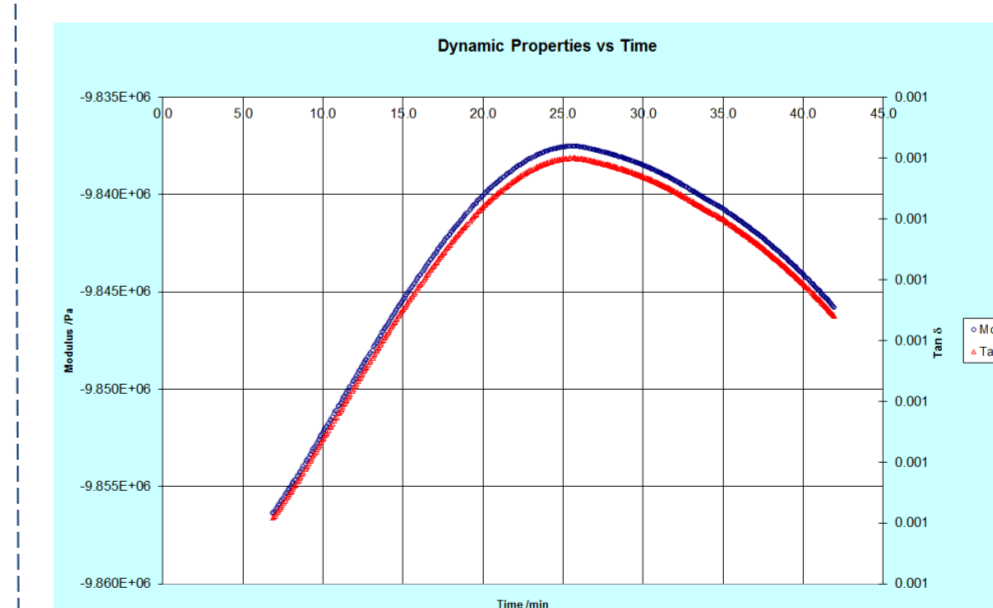
Scaffold Designs with varying fibre patterns

The result of using G-Code was more control over the extrusion of fibres. This allowed for greater control of the scaffolds' architecture especially the pore size. However when using G-code one should be aware that minor adjustments can be time consuming and incorrect code can cause damage to the machine.
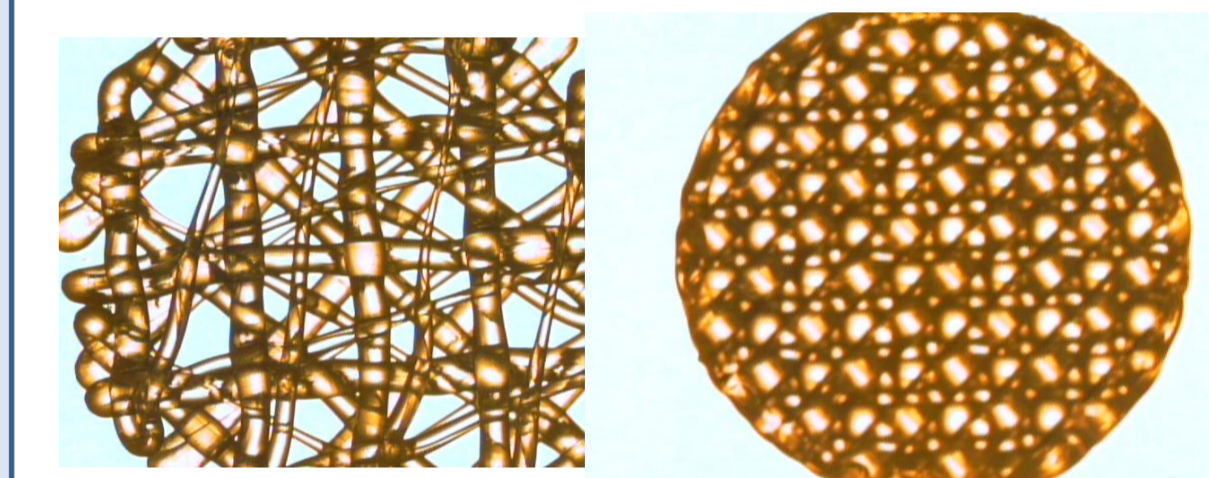
3D Printer only Vs. 3D Printer + Laser Cutter

The combination of 3D printer and laser cutter was very successful and meant that larger samples batches of better quality could be produced. The best results were scaffolds with consistent fibre quality and small consistent pore sizes.

Many experiments were completed using the DMA machine, the results showed that the porosity and fibre layout of a sample was related to the complex modulus. As the porosity of the sample increased as did the magnitude of the complex modulus meaning that as expected a more porous sample would have a smaller amount of stiffness and damping. The combination of using the dual cantilever and compression setups means that a broader range of *in vivo* scenarios can be modelled from the results.

Example Output graphs from DMA machine, showing complex modulus plotted against time and tan(delta).

The future of this project would be some form of biological testing. Cells could be seeded on to samples and then left to culture inside a bioreactor which would attempt to mimic the human body environment. Now that the procedure for producing these samples from G-Code has been ascertained many more customisations could be made to the size and porosity of the scaffold samples as required. The DMA results will be used to evaluate the strengths of the scaffolds as well as their viscoelastic properties.