Investigation on the Effect of Printing Parameters on Flexural properties of 3D Printed Polymeric Scaffolds

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Abstract. Thermoplastic polymers (PLA) are used for bone scaffold reconstruction that helps facilitate the transportation of oxygen and nutrients, including cell activity such as migration, proliferation, attachment, and differentiation. Throughout evaluation of polymer scaffold of its mechanical properties that could heal human body injuries after implantation. However, these ideal parameters for polymeric scaffolds in terms of flexural characteristics are undefined in tissue engineering applications. The Taguchi approach was employed using an orthogonal array L9 to study the ideal print parameters for 3D printing and the elements that most influence flexural qualities, as well as to forecast the highest flexural strength that could be reached with the optimal printing parameter. Furthermore, the flexural test is an appropriate test to evaluate the mechanical properties of the scaffold. The Taguchi technique determined that a printing speed of 90 mm/s, a layer height of 0.2 mm, and a density of 60% infill was the optimal combination of parameters. Besides, Printing speed showed as the most significant factor contribution while the infill density is the lowest contributor. The maximum level of printing speed, the average percentage of infill, and the medium layer height are the best parameter combinations. Parameter optimization on the most influential contributor indicates the printing speed of the specimen. Thus, the parameter for the selected factor in scaffold fabrication was optimized with a significant contribution. The predicted flexural strength was 383.92 MPa, while actual test obtained was 360.221 MPa with an error of 6.57%.

1 Introduction

One of the issues in using PLA for bone scaffold reconstruction is to obtain the optimum parameters applied for the construction of bone scaffold. The fabrication of scaffold could be built using Fused Filament Fabrication (FFF), which turns out to be a manifesting trend in advanced manufacturing. This well-known manufacturing industry in building thermoplastic parts design and optimization guarantees a prosperous outcome. In reality, its capacity to build geometrical structures in the biomedical field show potential in the biomedical field.

In FFF, an object is built by conducting the extrusion method by choosing melted content in a path layer by layer. Thermoplastic polymers are materials that are generated in the form of a filament. As of late, technical advancement has helped the complex geometry sample to be more reliably generated with a regulated dimension. The concept is to obtain the scaffold form with the shape of the pores, the struts' size, and the orientation critical to the cell's impact[1].

According to Yeong et al. [2], a suitable scaffold formation should possess the following characteristics. (i) Adequate macrostructure to sustain cell proliferation and cell-specific matrix production, (ii) An open-pore geometry that allows for cell growth with a porous surface and microstructures, (iii) Optimized pore scale for tissue regeneration and for preventing pore occlusion, (iv) Suitable surface and recruitment of cells and (v) The formation with non-toxic material with a predictable rate of degradation. Investigation on physical and bioactivity of 3D printed scaffolds has been successfully conducted in previous study [3, 4]. This paper prompted to come out with scientific assurance data of mechanical properties that affected the scaffold applicability in the medical industry in flexural testing by using ANOVA. This included improving upon the problem of tissue defects in tissue engineering in other to release source of references, especially in the biomedical engineering industry.

2 Methodology

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All 9 samples PLA scaffold fabricated by using 3D printer with different parameter [5]. The parameter that has been optimized are printing speed, layer height, and infill density, L3 orthogonal array are selected for the examination S/N ratios with the type of higher is better since the maximum flexural strength is better for the result. Using an array plan, the property of several variables on the concern characteristics would be predictable at the same time, reducing the sum of the tests. The fabrication of a biopolymer scaffold was evaluated using a variety of parameters, including printing speed, layer height, and infill density, as detailed in Table 1. To ascertain the components' contribution to the sample, a Taguchi orthogonal array experiment was undertaken. The method has been using to evaluate the targeted results is by producing actual biopolymer scaffolds for biomedical usage by utilizing Fused Filament Fabrication (FFF) parameter. In other to examine the mechanical properties of the biopolymer scaffold the flexural three-point bending were performed following the ASTM D790 procedure. Since the physical properties of many materials (especially thermoplastics) can vary depending on several parameters such as infill density, layer of height and printing speed in orienting polymeric scaffold.

| Table 1. Sample parameter of 3D printer |
|----------------------------------------|
| Factor                  | Level | |
| A. Printing speed (mm/s)   | 1    | 2  | 3  |
| B. Layer height (mm)       | 0.1  | 0.2| 0.3|
| C. Infill density (%)      | 20   | 60 | 100|

3 Introduction

3.1 Three-point bending test result of 3D printed scaffold

The samples and three of factors investigated for the optimization of the test results of the maximum stress(N/m) for the printed PLA samples are tabulated for 3-point bending tests in Table 2.

| Table 2. Flexural three-point bending test result of 3D printed scaffold |
|---------------------------------------------------------------|
| Runs | Printing Speed (mm/s) | Layer Heights (mm) | Infill Density (%) | Maximum Stress (N/m) |
|------|------------------------|--------------------|--------------------|----------------------|
| 1    | 30                     | 0.1                | 20                 | 335,516              |
| 2    | 30                     | 0.2                | 60                 | 362,653              |
| 3    | 30                     | 0.3                | 100                | 333,474              |
| 4    | 60                     | 0.1                | 60                 | 363,695              |
| 5    | 60                     | 0.2                | 100                | 380,189              |
| 6    | 60                     | 0.3                | 60                 | 362,653              |
| 7    | 90                     | 0.1                | 60                 | 385,210              |
| 8    | 90                     | 0.2                | 100                | 378,631              |
| 9    | 90                     | 0.3                | 20                 | 363,695              |

Fig.1. shows all the sample maximum stress (N/m²) result from combination of the parameters factor. All the factors have their own effect towards the mechanical properties of the 3D printed scaffold. Table 2. and Fig. 3 above, represent the maximum stress obtained from the flexural test, specimen number 7 which is printing speed of 90 mm/s, layer height 0.1 mm, and infill density 60% with the maximum stress of 385,210 N/m² show the good combination for scaffold strength. The higher the printing speed resulted with the higher counteract of the fabricated scaffold over flexural stress. Previously, the layer of height parameter shows that the lower the layer of height, the better flexural strength. Sood et al. [6] reviewed that maximum strength will be at minimum layer of height and high raster angel. This may be attributed to a decrease in the bonding power of bottom layer raster, as well as the ease at which thin and thick raster deform when distorted by excessive heat input.
Young's modulus and flexural strength improved with increasing infill densities, according to the experimental findings of printed composite structures with different infill densities [7]. The experimental result exhibits the 60% infill density have the highest maximum stress. This may result by the combination of parameters effects printed composite structure. The increase of printing speed shows the higher maximum stress that resulted from the gap of nozzle to its platform to produce the best-extruded filament flow and the solid infill to the printed sheet, with no missing extruded materials such as curling and clogging around the nozzle throat. In fact, a good nozzle distance between printed layers will prevent nozzle clogging and damaged printed layers [8].

3.2 Three-point bending test result of 3D printed scaffold

Fig. 2, shows that ANOVA factors towards the scaffold specimen and the value of F is higher than the other two factors. In addition, extrusion and printing speeds are important parameters in other to improve printing quality [9]. The straps and the print head linger in the same region for too long, weakening the various aspects that occur in the apparent deformation if the printing speed is slow [10]. The sequences of primary and secondary influencing factors are as follow: Speed, layer thickness and infill density. In this case, the layer of thickness and infill density will only effect slightly changes unless Factor A is change.

3.3 Statistical result of best combination parameter on porosity 3D printed scaffold

Fig. 3 shows the major response of FFF parameters combination against the maximum stress of scaffold specimen resulted by undergoes the ANOVA analysis from the result of maximum stress N/m² obtained in Table 2. It shows slightly contradict result to compared to the experimental result of Taguchi method. The optimum condition of this study is larger is better, and the level of variables that contribute the highest average values is desired. It is observed that the flexural strength of the material gradually increases with an increase in its speed rate with the ANOVA result of 90mm/s speed. Infill density shown
good flexural strength at 60%, but once it reaches 90% density, the flexural strength shown a downfall. It resulted in the optimal combination is parameter setting of speed 90mm/s, layer height 0.2mm and 60% of infill density.

![Fig. 3. Main effect plot SN graph.](image)

### 3.4 Percentage Error Evaluation

Referring to the previous result, the highest flexural strength obtained is 360.221 N/m² calculating the percentage error between the experimental result with the predicted result. From Table 3 it can be concluded that factor for A3, B2, C2 is the optimum parameter that resulted flexural strength when performed under the optimum conditions obtained from Table 3 was 383.92 MPa. Also, experimental No.7 is optimum condition. Therefore, the experimental and predicted values were compared. As a result, the error value was 6.57 %, which was within ±10 % (90 % confidence level).

| Factor       | Experimental | Predict Flexural Strength |
|--------------|--------------|---------------------------|
| A3, B2, C2   | 360.221      | 383.92                    |
|              | Error:6.57   |                           |

### 3.5 Printing speed parameter optimization

Five sample parameters of 3D printed scaffolds were tested for flexural strength and the results are displayed in Fig. 4. The combination of 90 mm/s printing speed, 0.2 mm layer height, and 60% infill density results in the highest flexural strength; this indicates that 90 mm/s printing speed is still the optimal speed for the parameter combination. According to the graph pattern in Fig. 4, the flexural strength begins to decline at a printing speed of 100 mm/s. It is assumed that a printing speed of 90 mm/s provides the highest flexural strength when the ideal layer height and infill density are used. High printing speed is compatible with a high infill density; nevertheless, because a 60% infill density provides the best flexural strength, other parameters are required to support it. High printing speed is demonstrated to be the best support for a high infill density. According to a study carried out by Cheng et al, the greater printing speeds require higher temperatures so that the material can flow smoothly [11].
4 Conclusion

The printing speeds of 30, 60, and 90 mm/s were evaluated as independent variables, along with layer heights of 0.1, 0.2, and 0.3 mm and infill densities of 20, 60, and 100%. The optimization of 3D printing parameters using the Taguchi method was successfully examined based on the objectives of this experimental investigation. The purpose of this experimental study was to evaluate the optimization of 3D printing parameters using the Taguchi method. In particular, the experimental objectives of the investigation were effectively discovered by applying ANOVA of the major contributing variable of 3D printing represented in flexural strength. On the basis of the ANOVA, the print speed has shown the largest contribution to 3D printed scaffold tensile strength, followed by layer height and infill density. The density of infill did not have a significant influence on 3D scaffold effects. Aside from that, the following conclusions have been reached:

I. Printing speed shows the most significant parameter on the flexural properties of 3D printed scaffolds with 63.91% of the contribution.

II. The Taguchi test was used to estimate the optimum parameter combination, which is 90 mm/s printing speed, 0.2 mm layer height, and 60 percent infill density

III. The percentage error from this optimization is 6.87 %, which this study considers acceptable since lower than 10 % (90 % confidence level)

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