COMPARATIVE STUDY OF THE TRIBOLOGICAL PERFORMANCE OF INTERNAL GEOMETRY STRUCTURES OF 3D-PRINTED PLA POLYMER

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DECLARATION

I declare that this project report entitled "Comparative Study of the Tribological Performance of Internal Geometry Structures of 3D-Printed PLA Polymer" is the result of my own work except as cited in the references.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

Signature	:	....
Supervisor's Name	:	....
Date	:	....

DEDICATION

I dedicate my dissertation work to my family and friends. A special feeling of gratitude to my loving parents, Mohd Zaki Bin Dris and Zuwaidah Binti Abdul Kadir whose words of encouragement and push for tenacity ring in my ears.

I also dedicate this dissertation to my many college friends who have supported me throughout the process. I will always appreciate all they have done. I dedicate this work and give special thanks to my best supervisor, Assoc. Prof. Dr. Mohd Fadzli bin Abdollah for helping me a lot throughout finishing this project report.

ABSTRACT

Additive manufacturing, often known as 3D printing, is the technique of creating three-dimensional solid things from a computer file. Additive manufacturing methods are used to create 3D printed objects. An item is formed in an additive method by laying down successive layers of material until the entire object is completed. Each of these layers may be viewed as a horizontal cross-section of the final item, thinly cut. The advent of low-cost 3D printers has increased the popularity of additive manufacturing (AM), often known as 3D printing, for the creation of a variety of items. Selective laser sintering (SLS) and fused filament fabrication (FFF) are two common 3D printing techniques that employ polymeric materials as feedstock (Friedrich, 2018).

Tribometry is the measuring of tribological system friction and wear using a tribometer. Tribometers are devices that are used to analyze the tribological characteristics of a material, such as friction, wear, adhesion, hardness, and other contact mechanics. The goal of this research is to determine the best settings for 3D printing based on the coefficient of friction and wear characteristics of the polylactic acid (PLA) polymer. Fused filament fabrication 3D printing was utilized to create the pin specimens. A comparative study on tribological properties of 3D-printed polylactic acid (PLA) pin with different internal geometries were carried out. The value of coefficient of friction (COF) and wear rate were the responses to be recorded. Both the value was obtained using two different software Minitab and Design-Expert. The value is then compared with the experimental value to determine which software is more accurate.

ACKNOWLEDGEMENT

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I am extremely grateful to my parents for their love, prayers, caring and sacrifices for educating and preparing me for my future. Also, I express my thanks to my peers that never stop to helps and gives courage to me throughout completing this research. Finally, my thanks go to all the people who have supported me to complete the research work directly or indirectly.

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CHAPTER 1

INTRODUCTION

1.1 Background

A comparative study examines and contrasts two or more things or concepts. Comparative studies are studies that show a person's capacity to analyze, compare, and contrast different things or concepts. A comparative research demonstrates the similarities or differences between two subjects. A comparative research is used to discover and quantify connections between two or more variables by monitoring distinct groups that are exposed to different treatments, either by choice or by circumstance. A comparative study is a form of research that is required to advance to higher levels of study. The comparative analysis clarifies the relationship between the two issues. In this research, the problem addressed in this research is determining the appropriate software to employ in order to achieve the most precise theoretical value when compared to the experimental value. The software mentioned are Minitab and Design Expert.

Minitab is a piece of software that aids in data analysis. This is mostly intended for Six Sigma specialists. It gives you a quick and easy way to enter statistical data, alter it, see trends and patterns, and extrapolate answers to present problems. While Stat-Ease Inc.'s Design–Expert is a statistical software program that is specialized to performing design of experiments (DOE). Comparative testing, screening, characterization, optimization, resilient parameter design, mixture designs, and combination designs are all available through Design–Expert. Both Minitab and Design-Expert are a program for statistical analysis It may be used for both learning and doing statistical research. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand.

The multivariate analysis is done using response surface methodology, and the symmetrical design approach is Box–Behnken Design. The effects of layer thickness, nozzle speed and nozzle temperature on the dependent variables, coefficient of friction and wear rate, were investigated. A pin-on-disc tribometer was used to determine the coefficient of friction and wear rate. The predicted and measured coefficient of friction and wear rate were found to be in good agreement. As an important subject in the statistical design of experiments, the response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgomery, 2005).

Although the coefficient of friction (COF) and wear rate of the 3D-printed PLA are minimally affected by the interior geometry of the pin sample, it was vital to create a lightweight tribo-component by decreasing the material used to conserve energy without sacrificing the component's strength. The elastic modulus has a significant impact on the COF and wear rate figures. The quickest run-in duration and lowest COF with good wear resistance were observed in a 3D-printed PLA pin with an interior triangular flip structure. The most common wear processes are abrasive wear and delamination. 3D printing has been widely utilized in recent years for the design and manufacture of various components of various mechanisms and systems. The surface texture of the component during 3D printing is affected by its orientation, which has an impact on the tribological characteristics of tribopairs.

1.2 Problem Statement

Due to the present epidemic, the usage of laboratories for 3D-printing has been limited. As a result, the title of this study has to be altered to a comparative study. A comparative study between two software Minitab and Design-Expert were runs to find which software are more reliable to use in order to achieve certain value that is close to experimental value. The two software is for statistical analysis. For this study there are three factors affecting the result which is layer thickness, nozzle speed and nozzle temperature of specimen. Coefficient of Friction (COF) and wear rate is the responses recorded from the experiment.

Tribological test methods were used to obtain the value for COF and wear rate. Tribotesting may also be performed for general, application independent, characterization of wear and friction. The pin-on-disc test is by far the most popular tribotest. It is simple and straightforward to use for determining the friction and wear rate of sliding contacts. The technique is flexible, since it may be used to test both dry and lubricated contacts. This, along with the comparatively inexpensive cost of testing, frequently makes it the first choice among tribotests. The tribological properties were determined by a dry sliding test with constant test parameters.

The interior structure has an impact on mechanical characteristics and stress concentration at the contact site, resulting in reduced friction and wear in theory. This method may also help to lower the weight of the pieces while keeping or improving their previous tribological performance. As a result, to the best of my knowledge, just a few research on the use of 3D printing have been undertaken and most of them concentrated on increasing mechanical characteristics rather than connecting them with tribological features that might benefit longer product lifespans. In this research, the value obtained from the two software and the precision of data will also be compared to find out which software is the best to use in statistical data analysis.

1.3 Objective

The objectives of this project are as follows:

i. To perform a comparative study on tribological properties of 3D-printed polylactic acid (PLA) pin with different internal geometries.

ii. To compare between two statistical software which is Minitab and Design-Expert to evaluate the value of coefficient of friction (COF) and wear rate.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The goal of this chapter is to provide a complete literature review that summarizes prior published work that is linked to the aims discussed in Chapter 1. This chapter presents a detail background on the internal geometry structure of 3D-printed PLA polymer, analysis of response surface methodology and the tribological properties. This chapter continued with a brief explanation about other matter that is related to this comparative study.

2.2 Internal Geometry Structure of 3D-Printed PLA Polymer

Some of common advantages of existing additive manufacturing (AM) techniques are speed, manufacturing flexibility, high degree of control over part microstructure and wide variety of engineering materials. A 3D model can be done in only one day and almost any geometry can be replicated. Additive manufacturing offered variety of engineering materials such as plastics, metals and ceramics. They also have certain common flaws, such as a lack of essential mechanical characteristics based on material combination, poorer precision, significant computational needs, and restricted biocompatibility. However, with correct method and material selection, the majority of the identified flaws may be effectively avoided in this situation. In comparison to other AM methods, 3D printing produces significantly less features and a coarser surface, as well as being less precise. Although the objects created by 3D printing are not transparent, this AM process is quick and inexpensive, making it popular in a wide range of applications.

The machine, 3D printer, used for these experiments, was the model of Flashforge Creator Pro 3, a product of Zhejiang Flashforge 3D technology Co., LTD. Figure 1 shows the 3D printer that should be used to fabricate the samples.

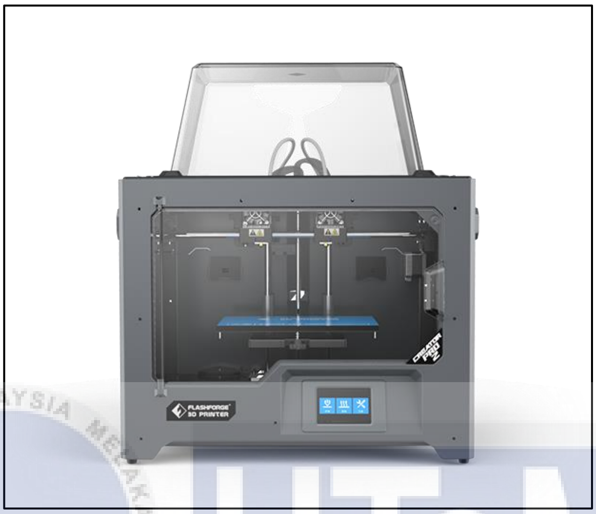

Figure 1: Flashforge Creator Pro 2

2.3 Central Composite Design (CCD)

A CCD consists of a two-level factorial design with 2^K points, where K is the number of variables, a star design with 2^K points to give the design the capacity to describe curvature, and a center point that is generally duplicated to assess reproducibility and model lack of fit. The distance between the center point and the star points dictates the sort of design and makes it versatile. The total number of needed design points (N) is determined by the formula $N = 2^K + 2\,k + C_0$ where k is the number of factors and C_0 is the replication number of center points. It also has rotatability and orthogonality properties. Figure 5 show the response surface models for CCD.

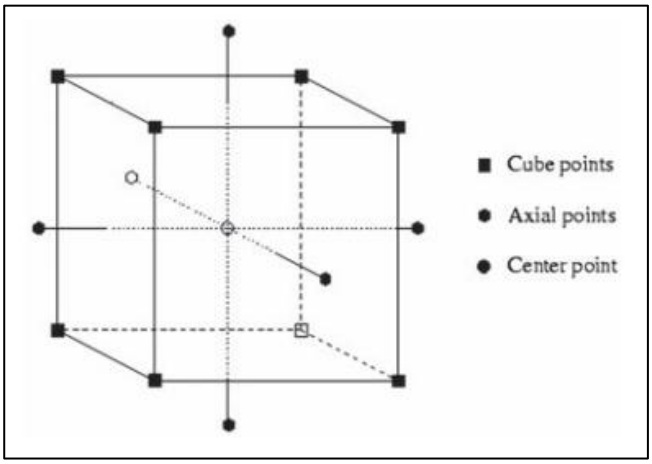

Figure 2: CCD Response Surface Model

Central composite design under RSM is normally performed either by using Design Expert software or Minitab. In this study, both Design Expert and Minitab software was used as optimization software. The steps that will be followed for the central composite design (CCD) are presented in Figure 6 below.

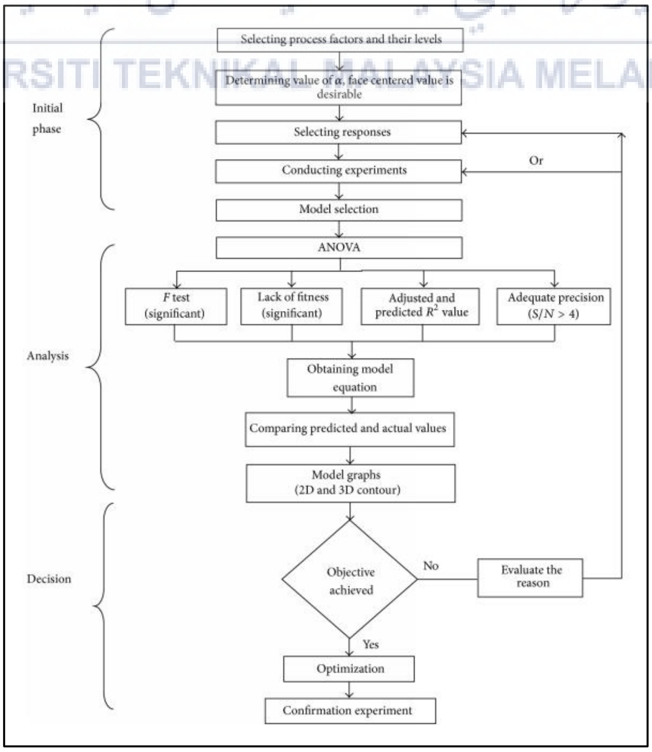

Figure 3: Central Composite Design Flow Diagram.

The value of alpha is crucial to compute in CCD because it can identify where axial points in the experimental area are located. The design can be spherical, orthogonal, rotatable, or face centered, depending on the alpha value. It is computed as and is in the middle of face centered and spherical.

$$\alpha = (2^K)^{0.25}$$

The value of alpha = 1 is preferable since it guarantees the axial point's position within the factorial part zone. It's known as face centered design, and it has three stages for putting elements into the experimental design matrix. Experimental results obtained are analyzed using response surface regression procedure of statistical analysis system. Correlation between responses and independent variables is obtained by fitting them into second order polynomial equation.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_{ii}^2 + \sum_{i=1}^{k} \sum_{i \neq j=1}^{k} \beta_{ij} x_i x_j + \varepsilon.$$

Here, Y represents the responses, k is the total number independent factors, β_0 is an intercept, i, ii, and ij with β represent the coefficient values for linear, quadratic, and interaction effects, respectively, and x_i and x_j in the above equation show the coded levels for independent variables.

2.4 Box-Behnken Design

A spherical, rotating, or nearly rotatable second-order design is the Box–Behnken design. It is built on a three-level incomplete factorial design that comprises of the cube's center point and middle points. It is made up of three interlocking 2^2 factorial patterns and a central point. The basics, benefits, and limits of the Box-Behnken design (BBD) for the optimization of analytical techniques are discussed in this work. It also provides a comparison of this design to composite central, three-level complete factorial, and Doehlert designs. BBDs are a type of rotatable or nearly rotatable second-order design that is based on three-level incomplete factorial designs. Its graphical depiction can be seen in two ways for three factors:

(a) A cube that consists of the central point and the middle points of the edges, as can be observed in Figure 7.

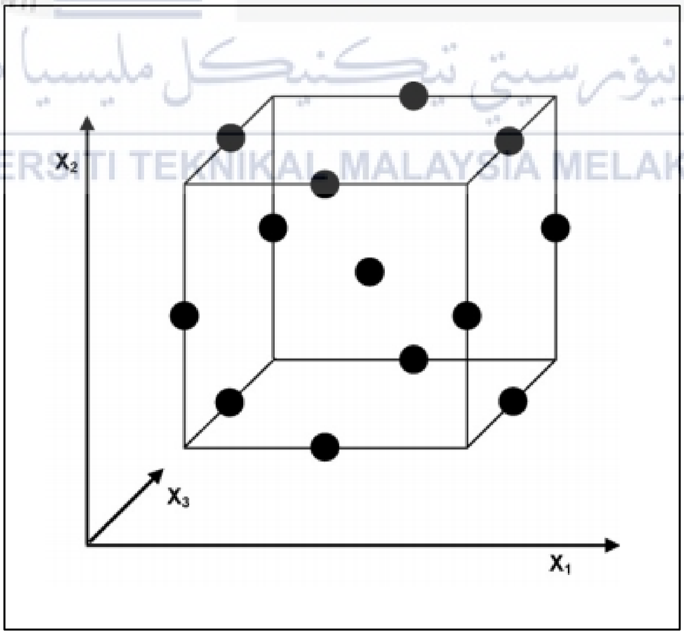

Figure 4: The Cube for BBD and Three Interlocking 2^2 Factorial Design

(b) A figure of three interlocking 2^2 factorial designs and a central point, as shown in Fig*ure 8.*

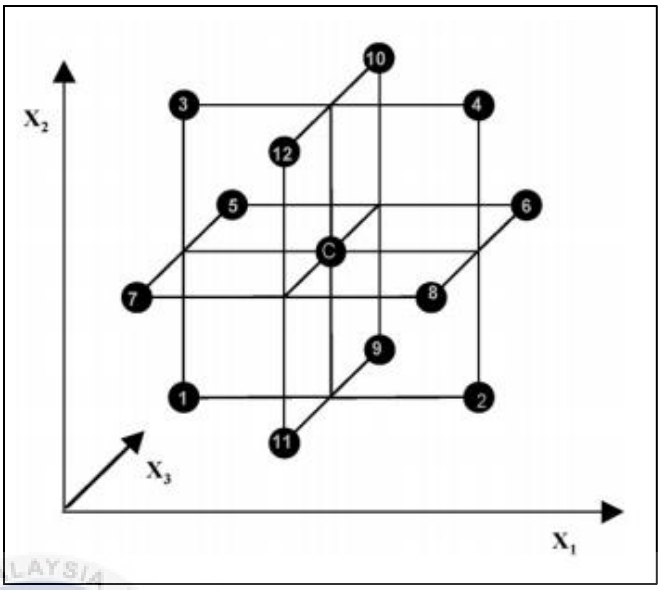

Figure 5: Box–Behnken design

It should be noted that, while the design may be derived from a cube, it is spherical, thus the cube's vertices are not covered by the design, and so prediction in these places is an extrapolation that should be avoided. The number of experiments (N) required for the development of BBD is defined as N = 2k (k − 1) + C_0, (where k is number of factors and Co is the number of central points). For comparison, the number of experiments for a central composite design is $N = 2^K + 2\ k + C_0$. Tables 1 and 2 contain the coded values of the factor levels for BBD on three, four and five factors, respectively.

Table 1: Coded Factor Levels for A Box-Behnken Design of a Three-Variable System

Table 1
Coded factor levels for a Box-Behnken design of a three-variable system

Experiment	x_1	x_2	x_3
1	−1	−1	0
2	1	−1	0
3	−1	1	0
4	1	1	0
5	−1	0	−1
6	1	0	−1
7	−1	0	1
8	1	0	1
9	0	−1	−1
10	0	1	−1
11	0	−1	1
12	0	1	1
C	0	0	0
C	0	0	0
C	0	0	0
	0	0	0

Table 2: Coded factor levels for Box-Behnken designs for optimizations involving four and five factors

Four-factor				Five-factor				
x_1	x_2	x_3	x_4	x_1	x_2	x_3	x_4	x_5
±1	±1	0	0	±1	±1	0	0	0
0	0	±1	±1	0	0	±1	±1	0
0	0	0	0	0	±1	0	0	±1
----------				±1	0	±1	0	0
±1	0	0	±1	0	0	0	±1	±1
0	±1	±1	0	0	0	0	0	0
0	0	0	0	----------				
				-				
----------				0	±1	±1	0	0
±1	0	±1	0	±1	0	0	±1	0
0	±1	0	±1	0	0	±1	0	±1
0	0	0	0	±1	0	0	0	±1
				0	±1	0	±1	0
				0	0	0	0	0

The BBD and Doehlert matrix are slightly more efficient than the central composite design, but much more efficient than the three-level full factorial designs, according to a comparison of the BBD and other response surface designs which is central composite, Doehlert matrix and three-level full factorial design. Even so BBD is far more efficient than three-level complete factorial designs, where one experimental design's efficiency is defined as the number of coefficients in the estimated model divided by the number of experiments. Table 3 establishes a comparison among the efficiencies of the BBD and other response surface designs for the quadratic model.

Table 3: Comparison of efficiency of central composite design (CCD), Box-Behnken design (BBD) and Doehlert design (DM)

Factors (k)	Number of coefficients (p)	Number of experiments (f)			Efficiency (p/f)		
		CCD	DM	BBD	CCD	DM	BBD
2	6	9	7	–	0.67	0.86	–
3	10	15	13	13	0.67	0.77	0.77
4	15	25	21	25	0.60	0.71	0.60
5	21	43	31	41	0.49	0.68	0.61
6	28	77	43	61	0.36	0.65	0.46
7	36	143	57	85	0.25	0.63	0.42
8	45	273	73	113	0.16	0.62	0.40

This table also shows that when the factor number is more than 2, the three-level complete factorial designs are more expensive. Another benefit of the BBD is that it excludes combinations in which all variables are at their maximum or lowest values at the same time. As a result, these designs are beneficial in avoiding tests conducted under severe circumstances, which might result in disappointing findings. They are, on the other hand, not recommended for circumstances in which we want to know the reactions at the cube's extremities, or vertices. The Box-Behnken design is suitable for response surface technique because it allows for the estimate of quadratic model parameters, the construction of sequential designs, the identification of lack of model fit, and the usage of blocks.

The Box-Behnken design is somewhat more efficient than the central composite design, but significantly more efficient than the three-level complete factorial designs, according to a comparison of the Box-Behnken design with other response surface designs. Hence for this study, the Box-Behnken design was used to perform the response surface methodology analysis using Design-Expert and Minitab software.

2.5 Tribological Test

One rationale for doing model testing is to replicate a component's essential tribological load in a real application. Another purpose may be to do a more comprehensive evaluation of the tribological characteristics of materials and lubricants, such as mapping the feasible range of use in terms of contact pressure and sliding speed. The model test you choose should have the most resemblance to the application you're working on. The contact geometry, or the form or shape of the contacting bodies, and whether the contact is conformal or nonconformal, are the initial steps.

The contact geometry directly affects the local conditions in the contact and is considered to be the primary variable for selecting model test and for scaling up and scaling down of tests. Finally, the test duration must be set long enough for the test to be correctly evaluated. The magnitude and distribution of the contact pressure will be determined by the contact geometry. Nonconformal contacts may have line or point contact areas, whereas conformal contacts have dispersed surface areas. Because the applied load is dispersed over a considerably smaller area in a point or line contact, the nominal contact pressure can be substantially larger than in a distributed contact area.