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The effect of 3D printing parameters on the tensile strength of acrylonitrile butadiene styrene filament for designing CNC router machine gears

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Abstract

Print parameters are factors that influence the mechanical strength of 3D printed objects. Based on a literature review, the parameters of layer thickness, printing speed, and fill geometry percentage value influence the mechanical strength of 3D printed objects. This study focuses on a combination of robust 3D printing parameters for designing CNC router machine gears. The purpose of this research was to determine the effect of printing parameters on the mechanical strength of tensile loads on 3D printed objects. From the experimental results, it was found that by providing a combination of layer thickness parameters, printing speed parameters, and fill percentage parameters, it has an effect on the mechanical strength resistance of 3D printed objects to accept tensile loads. From the research it was found that the ideal layer thickness parameter of 0.1 to 0.2 mm does not exceed half the size of the nozzle diameter of 0.4 mm to produce fine raster fibers. From the research it was found that the ideal speed parameter for printing gears with ABS filament material is at speed 30 mm/s to 50 mm/s to produce a stable raster fiber size and the percentage parameter of a good fill for printing gears is at a value of 20% to 40%. The results of the research found the best printing parameters for printing gears with a print parameter formula with a 3D print parameter formula layer height 0.15mm, gyroid infill 20%, with a speed of 30mm/s maximum tensile strength reaching 30.7 MPa with the results of wheel loading simulation analysis gear is able to withstand a maximum workload of 85 Kg.

Keywords:
Gears, 3D printing, filament, tensile stress, acrylonitrile butadiene styrenee.

1. Introduction

Fused Deposition Modeling (FDM) technology is a 3D design printing machine in STL format to be printed into 3D objects [1]. The FDM machine's working system is to melt the plastic thread in the nozzle and a layered printing process is carried out to form a 3D object. In the manufacturing industry, 3D printers have the potential to be used as a means to make machine components, including making driving components in the form of machine gears [2].Planning machine components made using 3D printers must pay attention to the mechanical strength characteristics [3]. Machine components made using 3D perinting will of course receive workloads in the form of tensile loads and compressive loads when the machine mechanism is running [4]. It is necessary to pay attention to the risk of shape deformation in components printed using 3D printing [5]. Therefore, it is necessary to improve the mechanical characteristics of 3D printing results so that they can be used as machine components for the manufacturing industry.

FDM is a technology that is classified as "Material Extrusion". On an FDM machine, 3D objects are formed using melted resin and then printed layer by layer to form a 3D object [6]. Various types of plastic that can be produced using FDM machines include acrylonitrile butadiene styrenee (ABS), polylactic acid (PLA) and polycarbonate (PC) [7]. To choose the type of 3D printing material that will be used as a plastic gear component, you must pay attention to the material characteristics specifications of the material so that its mechanical strength as a machine component can be achieved [8]. The mechanical strength of 3D printed gears is also influenced by the orientation of the printing direction. On a 3D printing machine there are three orientations of printing direction, namely the X axis, Y axis and Z axis. The performance of 3D printed objects is also influenced by the direction of the printing orientation, the mechanical strength of 3D printing results is strongest in the orientation that dominates the printing direction the most. [9]. The mechanical strength of 3D printed gears is also influenced by the proportion of materials used, where with the right material proportions, the uniformity of the mechanical properties of the geometry of the 3D printed object will be even [10]. The mechanical strength of 3D printed objects is also influenced by the extrusion speed, where the extrusion speed must be balanced with the right parameters so that the adhesion between layers can be even [11]. The mechanical strength of 3D printed objects is also influenced by the design and modeling process of the object, where the design created must be planned to have low critical stress to reduce the potential for cracks to occur in the object [12].

To get good printing quality, a strategy is needed. appropriate technical aspects by paying attention to various aspects including material characteristics, print direction orientation, material proportions, object modeling [13]. To determine the quality of 3D printing results that are good and smooth using FDM machine technology, there are various factors that must be considered: 1. Durability of the 3D print, 2. Safety during the printing process, 3. Short printing time [14]. To produce optimal 3D printing results, it is necessary to create printing parameters by considering various complex factors. The 3D printing process requires consideration of the parameters created, because the printing parameters will be used as the Gordeev G-code program [15]. The quality of 3D object printing and the mechanical properties obtained are influenced by the selection of appropriate process parameters [16].

ABS (acrylonitrile butadiene styrenee) plastic material is a very versatile thermoplastic polymer that is used for various manufacturing component materials [17]. ABS is popularly used in industry because it has good machinability. ABS material has an average density value of 1.07 $gram/cm^3$ with a tensile strength of 43 MPa. [18]. ABS material also has the ability to withstand heat up to 110ºC. ABS material has a melting point temperature of 200 °C and has good resistance to chemicals [19]. Judging from its characteristics, ABS plastic material has the possibility of being used as a gear component material, apart from gears, ABS material is also recommended as a rapid prototyping material for other manufacturers [20]. For ABS polymer materials, the recommended extrusion printing temperature is 240 ºC [21]. To obtain good adhesion between layers on 3D printed objects, appropriate room temperature control methods are needed, because the printing process using ABS filament material is very Vulnerable to temperature differences in the printing room, when the room temperature is too cold, bubbles will appear between the layers because the cooling process is too fast, so a temperature control method is needed so that the adhesive between the layers can adhere perfectly [22]

Gears are one of the important components in a machine whose function is to transfer power and connect machine components so that they can move according to the mechanical system. The geometric shapes of the gears are designed according to their mechanical function [23]

Gears are an important component in a machine which functions to transfer power and connect machine components so that they can move according to the mechanical system. To make gears quickly you can apply rapid prototyping technology using the Material Extrusion method [14]. When designing gears, you must also pay attention to hardness factors and tensile properties so that the mechanical function of the gear can be achieved [24]. The geometric shape of the gear is designed according to its mechanical needs. The greater the working power, the larger the geometric shape of the gear that is planned. [23] Gears and various machine components made of plastic certainly have lower performance than metal gears because metal has a strong proportion of material composition [25]. Therefore, to engineer gears made from ABS plastic to have better performance in the CNC router machine drive system, researchers tried to combine the percentage of filler density (tooth geometric filling density) with density variations of 20%, 30%, 40% and researchers also combines layer height with layer height variations of 0.1 mm, 0.15 mm, 0.2 mm.

With the experimental analysis of the combination of varied infill percentages (geometric density of gear filling) and layer height (thickness of layers). It is hoped that the experiment will find the composition of the molding parameters of plastic gears that have the best performance so that they can be used as a driving system for a CNC Router machine.

2. Material and Method.

In this study, the tool used was an FDM machine with the Ender 3 Profesional brand, a product from the company Shenzhen Creality 3D Technology, JinChengYuan, China. The 3D printing machine used to make the tensile test specimens is the Professional 3 ender machine. Table 1 shows the specifications of the Ender 3 Professional machine.

Table 1. Ender 3 machine specifications.

Parameters	Value
Model Number	Ender 3 Pro
Build Size	220*220*250mm
Machine Size	440*440*465mm
Rated Power	270 $watt$
Rated Voltage	AC115/230V
Rated Current	4A/2.1A

The material used to make the gears is ABS (acrylonitrile butadiene styrene) filament from the Sunlu brand, a product of Zhuhai Sunlu Industrial, Guangdong, China. Table 2 shows the company's recommended 3D printing temperature standards.

Table 2. Specifications for ABS Filament.

ABS Filament Print Temperature Recommendations	
Parameters	Value
Heated bed (°C)	95-110
Extruder Temperature (°C)	220-250

Experimental and simulation methods were used in this experiment using a factorial model approach. This method is more effective to determine the relationship of several 3D printed parameters to the mechanical strength of 3D printed plastic gears to tensile strength.

Tensile test specimens with 3D printed ABS (acrylonitrile butadiene styrene) filament material according to the JIS Z2201 standard [26]Fig. 1 describes the standard sizes of the JIS Z2201 tensile test specimens. To validate the size of the specimen, measurements were made on the dimensions of the tensile test specimen using Mitutoyo calipers with a measurement accuracy of 0.02 with a capacity of 150mm.

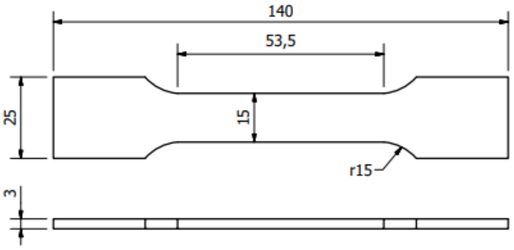

Fig. 1. Dimensions of the tensile test specimen

Fig. 2 explains the dimensions of the CNC router machine gear design that will be printed using a 3D printing machine

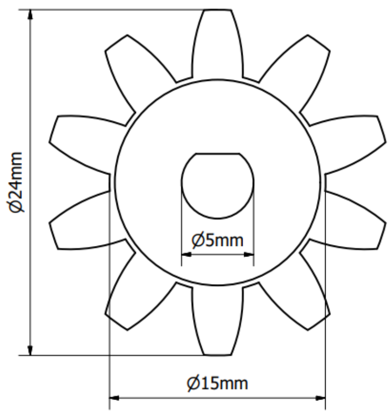

Fig. 2. Gear dimensions.

The dimensional specifications of the gears to be printed are presented in Table 3 as follows:

Table 3. Dimensions ofGears.

Parameter	Value
Modul (M)	2
Number of Teeth (Z)	10
Addendum (Dp)	24mm
Dedendum(Df)	15mm

Table. 4. shows the 3d printing parameters which are left constant to be used as the controlled variable in this experiment.

Table 4. Control variables.

Parameter	Value
Nozzel diameter ($\boldsymbol{mm}$)	0,4
Nozzel Temperature (°C)	240
Bed Temperature (°C)	80
Wall Thickness ($\boldsymbol{mm}$)	1,6

Table 5 shows some of the 3d printing parameters given the intended variations as independent variables in the experiment.

Table 5. Print Parameter.

Parameter	Value		
	Low	Middle	High
Speed (mm/s)	30	40	50
Infill density (%)	20	30	40
Layer height (mm)	0,1	0,15	0,2

The tensile test on the specimen was repeated three times to obtain valid tensile test results. Tensile testing was carried out using the TarnoGrocki Universal Testing Machine. Fig.3 describes the process of the tensile test experiment.

Fig. 3. Tensile test process.

3. Result and Discussion.

To find out the effect of the combined 3D object printing process parameter formula on the strength of the gears, a tensile test was carried out. The tensile test specimens used the JIS Z2201 standard with the following infill gyroid, Table 6 explains the results.

Table 6. Experiment Results.

Layer height (mm)	Infill density (%)	Speed (mm/s)	Stress (MPa)
0,1	20	30	*26,5*
0,1	30	40	*24*
0,1	40	50	*27,2*
0,15	20	30	*30,7*
0,15	30	40	*30,1*
0,15	40	50	*28,6*
0,2	20	30	*27,7*
0,2	30	40	*28,8*
0,2	40	50	*26,7*

From the results of the tensile test using the JIS Z2201 standard, three parameter formulas for 3D object printing were obtained which produced three different qualities. Low quality with the parameter formula for 3D printing layer height of 0.1mm, 30% Infill gyroid, and speed of 40mm/s . the maximum tensile stress reaches 24 MPa. Fig. 4 describes the strain and stress graphs of the tensile test results of the Low quality print parameter formula.

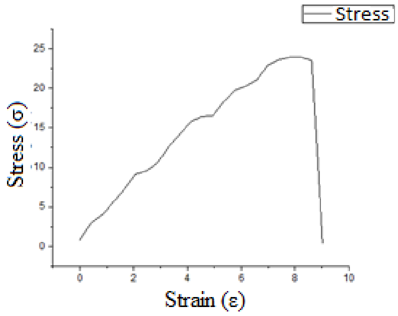

Fig. 4. Graphs of stress and strain on Low Quality printouts.

Middle Quality with a 3D layer heightformula of 0.2mm, 20% Infill gyroid, with a speed of 30mm/s, the maximum tensile strength reaches 27.7 MPa. Fig. 5 describes the strain and stress graphs of the tensile test results for the Low Middel print parameter formula.

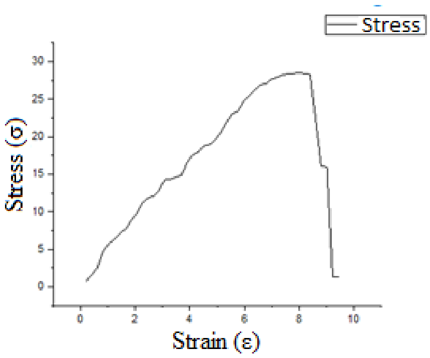

Fig. 5. Graphs of stress and strain on Meddel Quality printouts

High Quality with a 3D printing parameter formula layer height of 0.15mm, 20% Infill gyroid, with a speed of 30mm/s, the maximum tensile strength reaches 30.7 MPa. Fig. 6 describes the strain and stress graphs of the tensile test results for the High Middel print parameter formula.

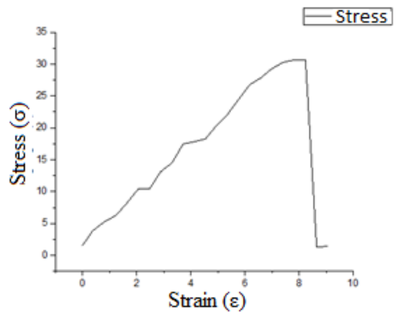

Fig. 6. Graphs of stress and strain on High Quality printouts.

From the data obtained in the tensile test, a loading simulation was carried out on the gears with the best printing parameter layer height 0.15mm, 20% Infill gyroid, with a speed of 30mm/s. the maximum tensile stress reaches 30.7 MPa.

3.1 Simulation Results

To find out the results of the experiment, a simulation was carried out on the gears with the dimensions as shown in Fig. 3. The simulation was carried out to find the maximum stress that occurs on the gears. The simulation is carried out by loading up to 90 kg. Table.7 presents the minimum and maximum stress data that occurs in the gears.

Table 7. Loading Simulation.

Load (kg)	Stress minimum (MPa)	Stress maximum (MPa)
10	1,526	3,575
20	3,053	7,417
30	4,579	10,724
40	6,106	14,298
50	7,632	17,873
60	9,158	21,447
70	10,685	25,022
80	12,211	28,596
85	12,974	30,383
90	13,738	32,171

From the simulation data, a chart can be made that illustrates the ability of the gear when it receives the workload in as shown in the Fig. 7

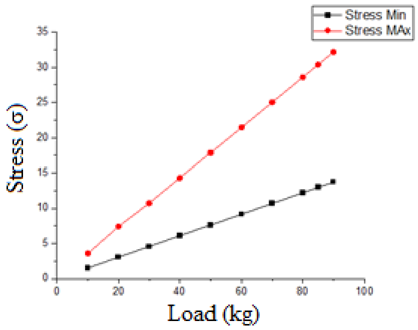

Fig. 7. Graph of maximum and minimum stress.

The stress simulation results on the gear when it receives a workload of 85 kg showns in Fig. 8 which explains the stress acting on the gears.

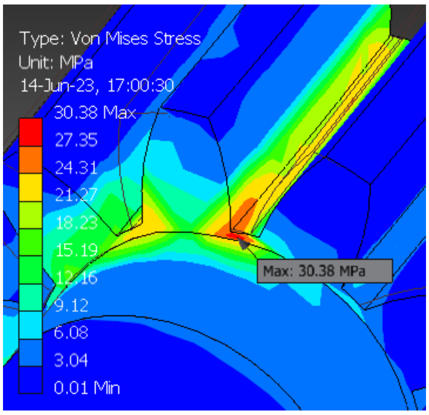

Fig. 8. Simulation of stress acting on the gears.

Fig. 8 shown that the stress that occurs in the designed gear geometry. In the following, the stresses that occur in the gear parts are described in Table 8

Table 8. Stress on Gears.

Stress Location	Stress (MPa)
Top land	3,4
Face	6,08
Flank	18,23
Bottom land	21,27
Tooth thickness	15,19
Fillet radius	30,38

Table 8 describes the stress that occurs at the stress location on the gear parts. From the simulation results, the critical stress load data obtained can be depicted in the chart in Fig. 10 as follows.

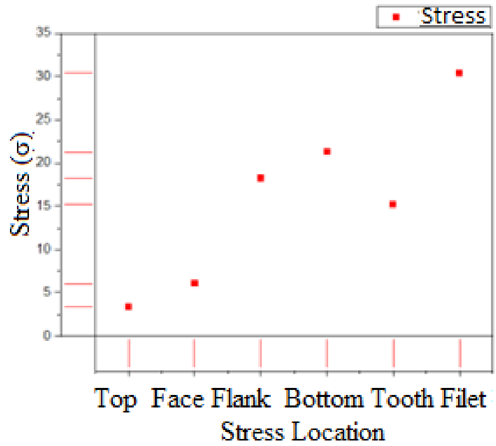

Fig. 9. Graph of stress on the gear parts.

Fig. 9shownsthat the highest stress on the gear is located on the fillet on the diameter of the foot of the gear with a stress value of 30.38 MPa and the lowest stress on the gear is located on the top of the land with a stress location value of 3.4 MPa.

4. Conclusion.

From the research, it was found that the ideal layer thickness parameter of 0.1mm to 0.2 mm does not exceed half the size of the nozzle diameter of 0.4 mm to produce fine raster fibers, this is because if the layer diameter of the nozzle, pores will appear or the gap between layers which as a result will cause a decrease in the mechanical strength of the 3D printed gear wheels. The ideal speed parameter for printing gears with ABS filament material is at a speed of 30 $mm/s$to 50 $mm/s$to produce a stable raster fiber size and strong adhesion between raster fibers, if the printing process speed is too fast it will causing the melted ABS filament that comes out of the nozzle to cool too fast so that the size of the rater fiber is not stable which causes a decrease in the adhesion between the raster fibers.From the results of the research using simulation, it can be concluded that the gears printed by the 3D printing machine can be used as gears for the CNC Router machine drive system. with a safe working load limit of 85 Kg, it was found that the maximum stress value was 30.383 MPa with a loading of 85 Kg, while the stress that the material could withstand from the tensile test results was 30.7 MPa in the best print parameter formula layer height 0.15mm, Infill 20% gyroid, with a speed of 30mm/s.

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