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Analysis of the Effect of Infill Density on the Hard Strength of 3D Printing

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Abstract: 3D printing technology is becoming one of the most convenient fabrication methods and is bringing about major changes in the manufacturing industry. 3D printing with Fused Deposition Modeling technology makes it possible to produce prototypes and components in a shorter time. It is known that different materials, printing techniques, and printing parameters affect the mechanical properties of printed objects. However, studies on the mechanical properties of 3D printed structures are still limited. This research focuses on the use of thermoplastic materials such as Polypropylene, Acrylonitrile Butadiene Stryrene and plastic composites with glass fiber reinforcement and maleic anhydride, in producing filaments for printing lighter vehicle components. This research conducted a further study of the relationship between two molding parameters, namely infill pattern and infill density, conducted on filament materials that have been determined for their composition. This research uses experimental method by varying five types of infill pattern selected grid, gyroid, hexagon, concentric, cubic with two infill density denisty 50% and 75%. The results were obtained through Brinell hardness testing with ASTM-D785 reference standard. The test results showed that the concentric pattern with sample code B2 got the highest hardness value of 37.7023 Kgf/mm², while the lowest hardness value was obtained by the grid pattern with sample A1 at 16.5912 kgf/mm².

Keywords: Fused Deposition Modelling; Infill Pattern; Infill Density; Brinell

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1. Introduction

The presence of 3D printing technology is one of the fabrication processes in the manufacturing world that brings big changes, especially in terms of ekonomi. 3D [1] printing is the development of printing technology that can produce and design sophisticated structures in one unit. Fused Deposition Modelling (FDM) is an Additive Manufacturing (AM) technology whose working system is in the form of adding layer by layer. [2] [3]

In the industrial world, 3D printing is very popular in making prototypes that usually take a long time to be made in a shorter time. This greatly affects the costs incurred in producing quality products. One of the industries that utilizes additive manufacturing (AM) 3D printing technology is the automotive sector. [4] [5]

This utilization is based on the tendency to reduce the weight of components. The weight of components is one of the problems, especially in electric vehicles, where these vehicles are still limited by the maximum mileage and speed based on the weight of the vehicle itself based on Aidin's research in 2022. To overcome these problems, it is necessary to reduce the load by using lighter vehicle body alternatives, one of which is by developing a type of plastic material in fabricating 3D [6] [7] printing products.

In general, the materials used for non-metallic 3D printing are thermoplastics such as Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA). Based on the literature, PLA is most widely used because of its affordable price, easy to obtain, and weightlessness. The type of plastic that functions to increase mechanical strength by adding [8] [9] glass fiber to PP material, so that the proposed mixture with or without fillers provides good mechanical strength or resistance to aging. The material that functions to increase mechanical strength is by adding MAH. [10]

In 3D printing, the strength of a product does not only rely on filaments, but other parameters also affect. These parameters consist of filling patterns, wall thickness, filling density, orientation angle and several other parameters. One of the parameters that should be considered is the infill pattern or commonly called [11] the infill pattern. Various literatures state that the type of infill pattern and infill density have an influence on the mechanical properties of 3D printing and on the time required. [12]

Previous research has examined types of infills that can produce components with short but powerful print times. Specimens made of PLA were given variations in rectilinear, stars, 3D honeycomb, archimedean chords, and cubic support patterns. The printed specimen is then subjected to tensile testing to obtain information about its strength value. The conclusion obtained was that the print with the highest strength was achieved by a specimen using a 3D honeycomb type infill with a strength value of 27.92 Mpa. [11]

This study uses an experimental method to test the hypothesis by conducting controlled and measured experiments. Valid experimental results, it is necessary to plan and design the experiment well. Experimental design is a test to determine the change in output variables because they are influenced by input variables. [13]

The results of this study were obtained through hardness testing. This test was carried out to determine the properties of strong materials by focusing on the relationship between two printing parameters, infill pattern and infill density. Hardness testing with the Brinell method aims to determine the hardness of a material in the form of different types of infill patterns and an increase in infill density to the test object. Brinell hardness testing uses the ASTM-D785 reference standard.

2. Methods

The method used in this study is an experimental method. This method was used to analyze the effect of the selected infill pattern with two variations of infill density on the hardness value of the product specimen. This method includes systematic stages in fabrication, determining parameters, conducting experiments to collect, and analyzing data obtained from testing. This explanation aims to ensure that the experiment is carried out in a structured manner so that the results are reliable and valid.

The tools used in this study were the Wellzoom Desktop Filament Extruder machine, digital scales, grinders, calipers, measuring cups, 3D printing machines and Brinell hardness testing machines. The materials used in this study are Polypropylene, ABS, Glass fiber and MAH.

The variables in this study are divided into three, namely the free variable, the bound variable, and the control variable. The independent variable is a variable that can affect other variables. The independent variables in this study are the types of infill pattern grid, gyroid, hexagon, concentric, and cubic with two variations of infill density of 50% and 75%. Bound variables are variables that cannot be determined by researchers. The variable bound in this study is the hardness test value of Brinell ASTM-D785. The control variables in this study were using the Wellzoom Desktop Filament Extruder machine, the extruder machine rotation was 40 mm/min with a mixed composition of PP filament manufacturing 60%, ABS 5%, GF 30%, + MAH 5% with Creality Ender 3 V3 KE 3D printing machine with bed temperature 90°C, nozzle temperature 230°C, print speed 20-40 m/s.

The procedure in this study explains in detail the stages of the experiment. A systematic explanation of the research procedure is expected to provide a reference for future research. The first step in making samples is to prepare the tools and materials to be used. In this study, the filament was made using the Wellzoom Desktop Filament Extruder extruder. The next step is the process of weighing the prepared materials according to the predetermined percentage. The percentages used in this study are Polypropylene 60%, Acrylonitrile Butadiene Stryrene 5%, Glass fiber 30%, + Maleic anhydride 5%. All of these materials are put into a weighing cup to carry out the mixing process according to the set composition. The next stage is to put the material into the hopper and then level the material on the extrusion machine and wait for the extrusion machine to be at a temperature of 190°C, when the temperature has been reached, turn on the motor switch, then set the machine at a speed of 400mm/min. The next stage is to wait for the extrusion results by always paying attention to the condition of the filament printed by the die, and occasionally measuring the diameter of the filament with a caliper so that the filament size does not exceed the filament diameter tolerance limit.

The next stage is to fabricate Brinell hard test specimens using a 3D printing machine. The initial stage is to prepare printed filament materials as well as specimen fabrication aids such as cutting pliers, chapes, adhesive glue, and the Creality Ender 3 V3 KE 3D printing machine.The next step is to design the test sample object that has been prepared in advance using the ASTM-D785 standard reference, the design is in the form of STL format so that it can be read when it will be connected to the Ultiamker Cura Software. The Ultimaker Cura software is used to translate the design into G-code and set the predefined parameters for the printing process. The next stage is to insert the micro SD ready with the file that has been created to the machine contacts, prepare the filament to be fabricated by placing it in the nozzle box. Start fabrication by turning on the 3D printing machine and then adjusting the temperature bed and nozzle. The controlled temperature for the specimen printing process is 90°C for the bed temperature and 230°C for the nozzle temperature. The last process is to select the name of the file to be fabricated, then select print, then the specimen printing will run. Printing one test sample takes 45 minutes with a filament weight of about 9 -21 grams, and the length of filament required for each 1 sample is about 2.86 meters.

At this stage, prepare the test sample size. The specified size is 60 mm x 40 mm with a thickness of 7 mm for Brinell hardness testing according to ASTM-D785 reference. The following is Table 1 of the sample codes used for hardness testing.

Table 1. Hardness Testing Sample Code

Sample Code		**Infill Pattern**	**Infill Density**	
A1.1	A2.1	Grid	50%	75%
A1.2	A2.2		50%	75%
A1.3	A2.3		50%	75%
B1.1	B2.1	Gyroid	50%	75%
B1.2	B2.2		50%	75%
B1.3	B2.3		50%	75%
C1.1	C2.1	Hexagon	50%	75%
C1.2	C2.2		50%	75%
C1.3	C2.3		50%	75%
D1.1	D2.1	Concentric	50%	75%
D1.2	D2.2		50%	75%
D2.2	D2.2		50%	75%
E1.1	E2.1	Cubic	50%	75%
E1.2	E2.2		50%	75%
E1.3	E2.3		50%	75%

The ASTM-D785 sample test standard is a 5 mm indentor ball with a load of 60 kg. The test was repeated three times in each type of infill pattern using Brinell's reference. The dimensions of the specimen are in accordance with the ASTM D785 standard, shown in figure 1 below.

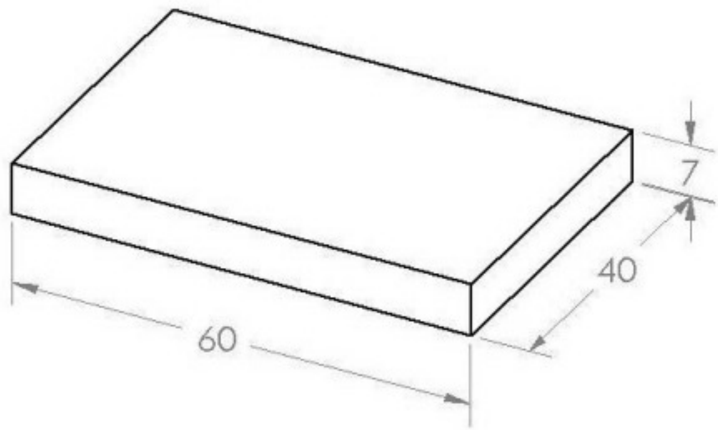

Figure 1. Dimension of Hard Test Specimen

The following are the stages of Brinell hardness testing. The initial stage is to install a 5mm ball indator. Hardness testing was carried out with a Brinell Hardness Tester testing machine using the ASTM-D785 reference standard, a steel ball indenter with a diameter of 5 mm and a test load of 60 Kg. Brinell hardness testing was carried out three times on each variation to ensure that the data obtained was not biased. The next stage regulates the loading according to the provisions of the indenter used. Place the sample on the table of the Brinell tester to be loaded to determine the hardness value of the sample. Turn the table lever to raise the sample until it is depressed with the indenter. The final stage reads the suppression results through a computer that is read from a micron camera with a magnification calibration of 50 microns according to the results at the point of compression. Record the results obtained from the test observation data. Do this step repeatedly three times for each type of infill pattern.

3. **Result and Discussion**

The results of the Brinell hardness test are tests to determine the hardness value of the product specimen. The data from the test results is then presented in the form of tables and graphs to make it easier to analyze and evaluate the influence of parameter variations on the hardness values obtained. Brinell hardness testing data can be seen in Table 2.

Table 3 shows the results of the Brinell hardness test with a total of 30 samples (A1 to E2) printed based on five types of infill patterns with two increases in infill density of 50% and 75% with three replications. Detailed explanation in the sample code, A1 and A2 are sample codes of the grid pattern with a difference in infill density of 50% and 75%. Sample codes B1 and B2 are sample codes for gyroid patterns. Sample codes C1 and C2 are hexagon sample codes. Sample codes D1 and D2 are concentric sample codes. Sample codes E1 and E2 are sample codes for cubic patterns.

Table 3. Brinel Test Result Data

Sample Code		**Brinell Hardness Test Results**							
		Test Replication							
		1		**2**		**3**		**Average Hardness Value (Kgf/mm2)**	
A1.	A2.	18,7984	14,7305	17,1068	13,4269	13,8685	26,5864	16,5912	18,2479
B1.	B2.	33,4615	28,9600	18,3875	30,5833	23,3334	53,5637	25,0608	37,7023
C1.	C2.	17,8593	30,5833	28,0883	28,8120	30,7853	29,7942	25,5776	29,7298
D1.	D2.	21,0175	25,5665	38,7799	17,6941	28,2309	31,6133	24,9580	24,9580
E1.	E2.	14,1699	30,5833	26,1971	27,9467	15,1315	25,1078	27,8793	27,8793

Based on the data listed in Table 4.4, a graph displaying the hardness test values has been made a graph as seen in the The value of the results of the Brinell hardness test uses the ASTM-D785 reference standard. The following is a graph of the hardness test results in Figure 2.

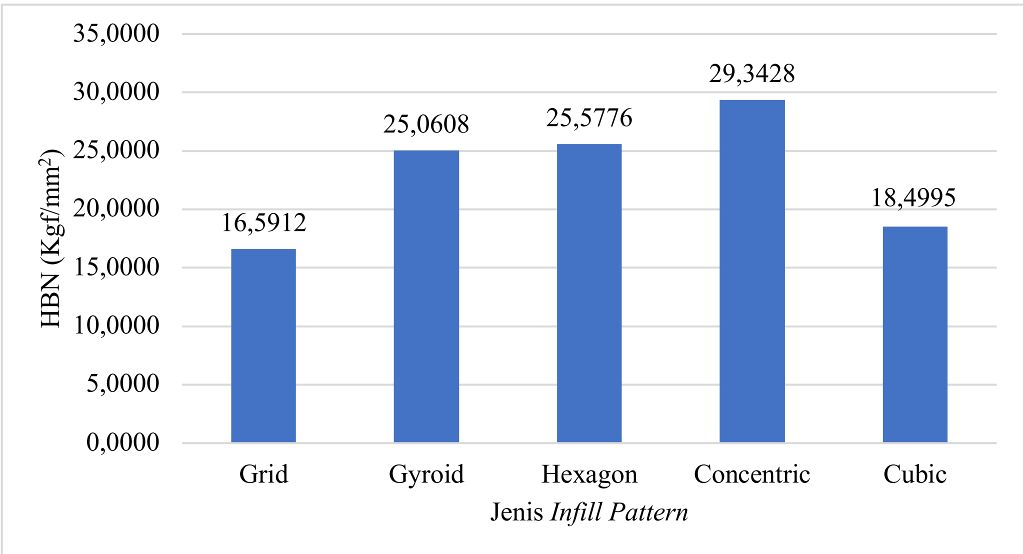

Figure 2. Hardness Value Graph Infill Density 50%

Figure 2 is a graph of the results of Brinell's hardness values on various infill patterns with an infill density of 50%. In the graph, it can be seen that the concentric pattern obtained the highest hardness value among all patterns with a hardness result of 29.3428 Kgf/mm2, while the lowest hardness value of 16.5912 Kgf/mm2 was obtained from the type of infill pattern grid. The gyroid pattern shows a fairly high hardness value of

25.0608 Kgf/mm², the hexagon has a hardness value of 25.5776 Kgf/mm² slightly higher than the gyroid, and the cubic has a hardness value of 18.4995 kgf/mm², this value is higher than the grid but lower than other patterns. The non-optimal structure of the printing pattern can cause the hardness value to be low. The highest hardness value of 29.3428 Kgf/mm2 was obtained from the type of concentric pattern which shows that the concentric pattern is able to provide a strong structure because of the nature of the printing pattern to distribute the load more evenly along the material.

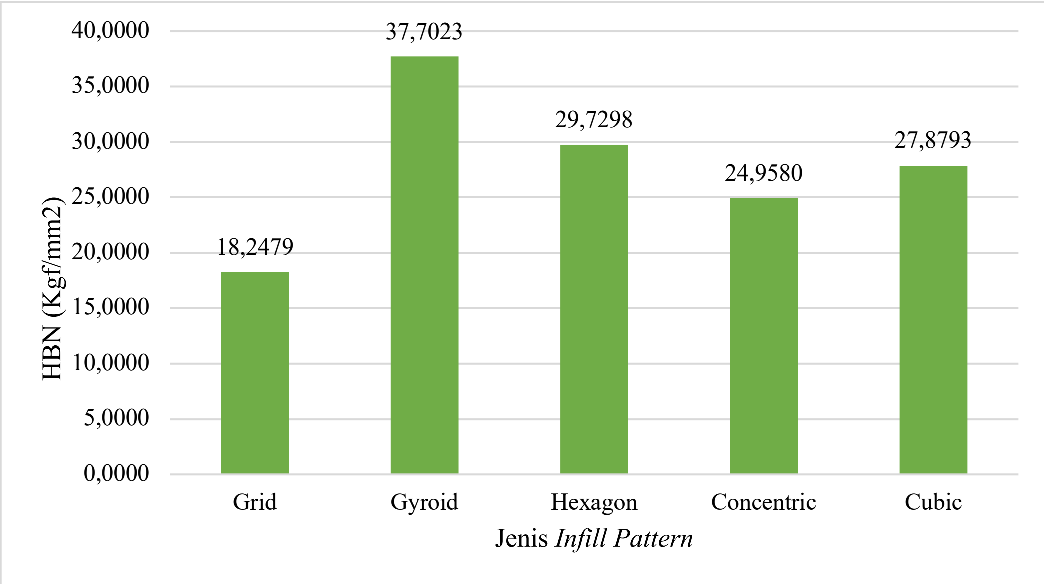

Figure 3. Hardness Value Graph Infill Density 75%

Figure 3 shows that the infill pattern and infill density are directly proportional to the increase in Brinell hardness. In the graph, it can be seen that the increase in infill density greatly affects the hard strength. Previously, at the infill density of 50%, the highest hard strength was obtained by the concentric pattern type, after experiencing an increase in density at 75%, the highest hard strength was obtained by the gyroid pattern type, which was 37.7023 Kgf/mm². The hexagon pattern had the second highest hardness value with a value of 29.7298 Kgf/mm² followed by the cubic pattern with a hardness value of 27.8793 Kgf/mm², the concentric pattern with a value of 24.9580 Kgf/mm², and the grid pattern was still the type of variation that produced the lowest hardness value with 18.2479 Kgf/mm². The increase in hardness on the filling of 75% of the grid pattern can be explained due to the increase in denser filling density. This results in better load distribution properties and reduced deformation. The significant increase in hardness value in the 75% density gyroid pattern is due to the continuous structure of the connected surface, which theoretically provides a more even stress distribution and an increase in hardness at a higher charge density level. The increase in hardness value in hexagon structures with a density of 75% can be explained by the properties of this pattern which is known to provide high strength with lighter weight due to its good geometric shape in distributing pressure loads. The decrease in hardness value at 75% charge in the concentric pattern is caused by uneven load distribution or stress concentration in certain areas. A significant increase in hardness value also occurs in cubic patterns with a density of 75% This result can be explained because the cubic structure has printing properties that provide good dimensional stability and the result of increased hardness which shows that the material is more resistant to deformation at higher densities.

4. Conclusions

Based on the results of the study, it will be concluded that the influence of the selection of infill pattern grid, gyroid, hexagon, concentric, and cubic followed by infill density of 50% and 75%/ on the hardness test value of Brinell. In this study, hardness testing was used to determine the mechanical properties of the specimen sample. The test results showed that the hardness values of all tested samples were characteristic of each variation of increasing infill density. Thus, it can be concluded that the magnitude of the hardness value is obtained from the influence of structural patterns and infill density percentages. The selection of the infill pattern followed by the variation of increasing the infill density greatly affects the strength of the material produced. The A1-E2 sample was obtained from the B2 sample with the highest hardness value of 37.7023 Kgf/mm^2, while the A1 sample had the lowest value with 16.5912 Kgf/mm^2. The infill pattern with an increase in infill density of 50% and 75% has an effect on the resulting hardness value. Based on the results of the study, the B2 sample had the highest level of hardness of any other sample. These results show that this pattern shape is very efficient in distributing tension and increasing the strength of the material. From the results that have been concluded, Brinell hardness testing has an important role in the mechanical properties of materials to measure the resistance of materials to permanent deformation or indentation. Higher hardness values indicate a harder material and more resistant to deformation. However, to validate the strength of mechanical properties against a material is not enough with hard testing alone, other tests such as tensile testing, impact testing, and SEM-EDS testing are needed to see morphological structures that are invisible to the eye in the material.

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