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The Effect of Infill Angle and Build Orientation on the Impact Strength and Production Time of Porous Infill Structure

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Abstract

In developing a lightweight structure, the density of the structure can be reduced by converting a solid structure to a porous infill structure. Previous research has investigated that a triangular infill structure has the highest impact strength compared to other infill patterns. However, the impact strength of this structure may still be improved by adjusting other parameters without extending the production time. This research goal is to investigate the effect of the build orientation and infill angle on the impact strength and the production time of the triangular infill structure. To achieve that goal, this research uses a 3D printing process to manufacture a triangular infill structure made of Polylactic Acid. Seven levels of infill angle and two levels of build orientation are used to find the effect. In this experiment, twenty-six Charpy Impact specimens are printed using the Fused Deposition Modelling machine. Each specimen is printed according to ISO 179 standards and tested using a GT-7045 impact testing machine to measure the impact strength of the specimen. The results of this experiment indicate that the resistance of the on-edge build orientation to the impact load is better than the flat build orientation. The on-edge build orientation type requires less printing time compared to the flat build orientation type for each infill angle. The use of a 45° infill angle exhibits the highest impact resistance. To achieve the shortest printing time, the 0° infill angle is recommended.

Keywords

Infill angle; Build orientation; Impact strength; Production time; Porous infill structure

1 Introduction

One of the important enablers of an efficient electric vehicle is its lightweight structure while maintaining its impact resistance. In developing a lightweight structure, the density of the structure can be reduced by converting a solid structure to a porous infill structure. 3D printing allows the creation of various porous structures composed of a solid shell with a porous interior. Therefore, this research uses a 3D printing machine to manufacture different porous infill structures made of Polylactic Acid (PLA) to understand the impact resistance of the porous infill structure. The PLA is used in this research because it is cheap, easy to obtain, and renewable. The impact resistance of each structure is evaluated by performing an impact test according to ISO 179 standards. Based on the evaluation result, the impact resistance of the porous infill structure made of other materials can be predicted.

3D printing builds an object layer by layer based on a 3D model. One of the widely used 3D printing processes is the Fused Deposition Modeling (FDM) process. FDM can print various polymer materials in the form of a filament. The filament is transformed into layers by heating the material to its melting temperature and then extruding it through a nozzle. The characteristics of the printed object, including its mechanical properties, are influenced by certain parameters of the FDM process. The FDM parameters that influence its mechanical properties are build orientation, layer thickness or layer height, feed rate or infill deposition rate, infill density, deposition angle or raster angle or infill angle, extrusion temperature, infill pattern, the number of outer shell layers, shell thickness, material type, printer type, strain rate, coloring agent, and nozzle diameter or infill width [1].

Based on the previous research, the FDM process parameters significantly influencing the impact resistance are layer heights, the number of shells, infill patterns, infill density, infill angle, and build orientation [2]–[10]. The layer thickness or layer height is the thickness of each extruded layer of material. The number of shells determined the number of horizontal or vertical wall lines or perimeters of each layer. The infill pattern is a parameter that sets the shape of the inner structure of the printed object. The infill density determined the infill percentages or the amount of material used inside the printed object. The infill angle is a parameter that sets the direction of the angle of motion of the extruder when printing layers. The build

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orientation is a parameter that determines the orientation of the printed specimen, whether X-Y, X-Z, or Y-Z.

Research by Biyiklioglu and Kanber found that the triangular infill structure shows the highest impact strength compared to other infill structures [7]. The influence of build orientation on the impact properties of a printed object is investigated in the research by Patterson et al. [8]. They state that the on-edge and flat build orientations are stronger than the vertical build orientation. Research by Rajpurohit and Dave found that an increase in the infill angle causes a decrease in impact strength [9]. This research implemented a linear type of infill pattern to print the object. However, Vidakis et al., who investigate the influence of different printing strategies on the bending and Charpy's impact strength of ABS and ABS-plus fused deposition modeling specimens, state that the change of orientation angle does not seem to affect significantly the failure mode of the specimens tested [10].

Based on the literature review, it is concluded that thicker layer height exhibits lower impact properties for different infill patterns. The triangular infill pattern is found to be strongest compared to the rectilinear infill pattern and other available infill patterns. Higher infill density creates a higher amount of material and results in higher impact strength. Then, increasing the number of shells improves the impact strength at every layer height and infill density value. Finally, the use of the XY plane builds orientation exhibits to have the greatest resistance to impact. However, the various build orientations implemented are investigated when the object is printed using a linear infill pattern. According to Suteja, different infill patterns affect printing time and required material [11]. They also might show different influences on impact strength. In addition, the influence of the infill angle on the impact resistance is not found in the literature. As the triangular infill pattern shown in Figure 1 below is found to be strongest, the influence of the build orientation and infill angle of the object printed by the triangular infill pattern on the impact resistance is required to be found. The influence of the build orientation and infill angle on the printing time is required to be studied because they affect the printing time followed by the production cost. Therefore, the purpose of this research is to find the influence of the build orientation and infill angle on the impact strength and printing time of 3D printed objects made of PLA and printed using a triangle infill structure.

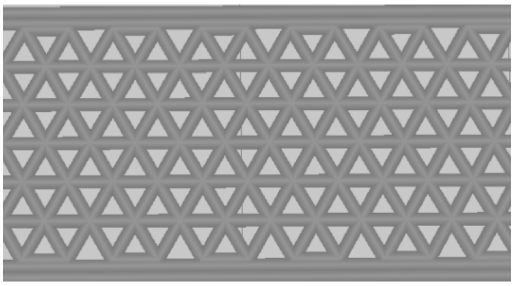

Figure 1 Triangular infill pattern

2 Methodology

In this research, an impact test specimen 3D model is built following ISO 179 standards by using PTC Creo software. The model is made to represent the Charpy unnotched flatwise impact strength specimen of extruded thermoplastic materials. The dimensions of the specimen model are shown in Figure 2. Then, the specimen model is sliced by using Slicer Prusa software developed by Prusa Research and Repetier-Host software developed by Hot-World GmbH & Co. KG. Both are also used to set the FDM process parameter and generate the printing path of the printer nozzle. After that, an Anet E16 FDM Machine is used to print the required number of specimens. Finally, each printed specimen is tested using the GT-7045 impact test equipment to measure its impact strength. The impact testing equipment uses a pendulum with weight and length are 1.6 kg and 0.4 m, respectively. To generate and achieve consistent printing time data, this research implements Repetier-Host v.2.1.6 software as a data acquisition tool.

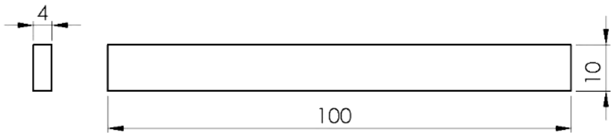

Figure 2 Specimen dimension (in mm)

This research is conducted in two steps. First, the influence of the build orientation on the impact strength and printing time is investigated. The investigated build orientation types are on-edge and flat, as shown in Figure 3. The infill angles used in the first step are only 30°, 45°, and 60° to examine whether the change in build orientation affects the impact strength and the printing time of the printed specimen for each infill angle. Then, this research investigates the influence of the infill angle on the impact strength and printing time when using the recommended build orientation found in the first step. In the second step, the impact strength and printing time of the specimen that uses an infill angle of 0°, 15°, 30°, 45°, 60°, 75°, and 90° are evaluated. Various infill angle investigated in this research is shown in Figure 4. In total, two levels of build orientation and seven levels of infill angle are used in this research. Each step is conducted two times to reduce the effect of errors. Therefore, twenty-six specimens are printed using the FDM printer to determine the effect of the build orientation and the infill angle.

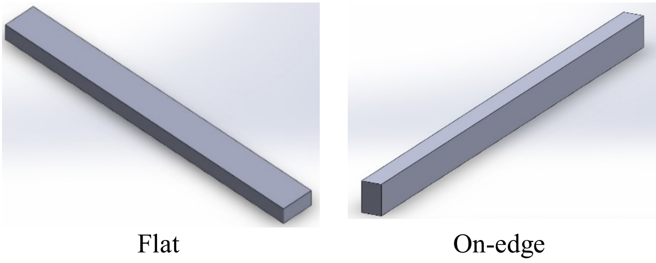

Figure 3 Build orientation type

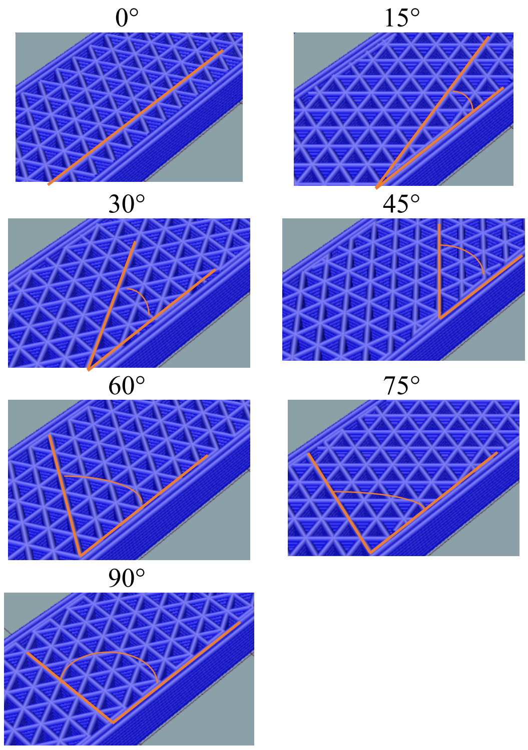

Figure 4 Infill angle

Table 1 presents the constant parameter values of the FDM process used in this research. The extrusion and bed temperature values are determined based on the result of previous research by Dey and Yodo [12]. The value of the layer thickness is determined based on the recommended value for the nozzle diameter. For the infill density, this research implements the highest value that can be used. The feed rate for infill and the number of outer shells are determined based on the default value recommended by the slicer software. In addition, the humidity and ambient temperature are kept as constant as possible and assumed not to affect the impact strength of the printed specimen.

Table 1 Value of each constant parameter

Parameters	Value
Nozzle Diameter	0.4 mm
PLA Filament Diameter	1.75 mm
Infill Pattern	Triangular
Nozzle Temperature	200 °C
Bed Temperature	60 °C
Layer Thickness	0.3 mm
Infill Density	90 %
Number of Outer Shell Layers	2 layers
Feed Rate for Infill	80 mm/s

3 Results and Discussion

The responses of this research are the impact strength of the printed part and the required printing time. The impact strength is calculated based on the initial and final angle of the impact test equipment pendulum. First, the impact energy is calculated based on the angle difference. Then, the impact strength is calculated by dividing the impact energy by the original area of the cross-section of the specimen. The result of the first experiment is presented in Table 2.

Table 2 First step experiment result

Build Orientation	Infill Angle	Impact Strength Average (kJ/m2)	Printing Time (second)
Flat	30°	16.51	830
Flat	45°	18.55	830
Flat	60°	16.17	820
On-edge	30°	16.83	790
On-edge	45°	21.90	779
On-edge	60°	20.28	762

Figure 5 shows the average of the impact strength as a function of flat and on-edge types of build orientations for three different infill angles. The on-edge build orientation type shows greater impact strength than the flat build orientation type for each infill angle. The use of the flat type of build orientation creates a stack of triangular layers parallel to the direction of the impact load, as shown in Figure 6. Meanwhile, the on-edge orientation creates a stack of triangular layers perpendicular to the impact load. More triangular infill of the on-edge build orientation experiences the impact load compared to the flat build orientation. As a result, the resistance of the on-edge build orientation to the impact load is better than the flat build orientation.

Figure 7 shows the printing time as a function of flat and on-edge types of build orientations for three different infill angles. The printing time depends on the printing path of the printer nozzle. The printing path of the flat build orientation is longer than the on-edge because it has more ineffective movement that does not fill the porous infill structure. Therefore, the flat build orientation type requires more printing time compared to the on-edge build orientation type for each infill angle.

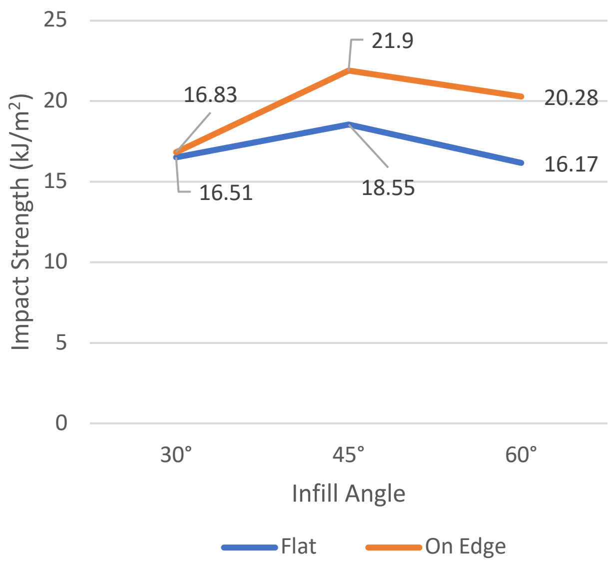

Figure 5 The effect of build orientation on impact strength

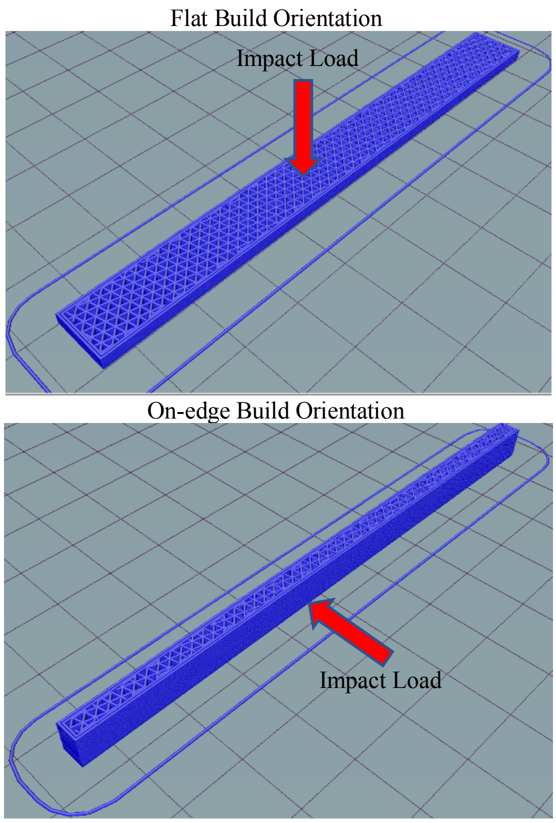

Figure 6 The direction of impact load

The result of the second experiment is presented in Table 3. The result is represented as two graphs in Figure 8 and Figure 9. Figure 8 shows the average of the impact strength as a function of different infill angles for on-edge types of build orientations. Figure 9 shows the printing time as a function of different infill angles for on-edge types of build orientation. The on-edge build orientation is implemented because it is recommended according to the first experiment result.

As shown in Figure 8, the impact strength value increases from the infill angle of 15° to 45° and then decreases to 75°. Compared to the research by Rajpurohit [9], it is found that the effect of the increase of infill angle on the impact strength using linear infill structure is different compared to triangular infill structure. By using the triangular infill structure, the highest impact strength value is obtained at an infill angle of 45°.

The triangular infill structure can transmit and distribute the impact energy effectively because the triangular infill provides good support to the structure behind the walls of the part. The change in infill angle used in triangular infill structure affects the impact strength value of the structure because it determines the distribution of impact energy to the next infill. The use of a 45° infill angle exhibits the highest impact resistance because it effectively distributes the impact energy to all infills.

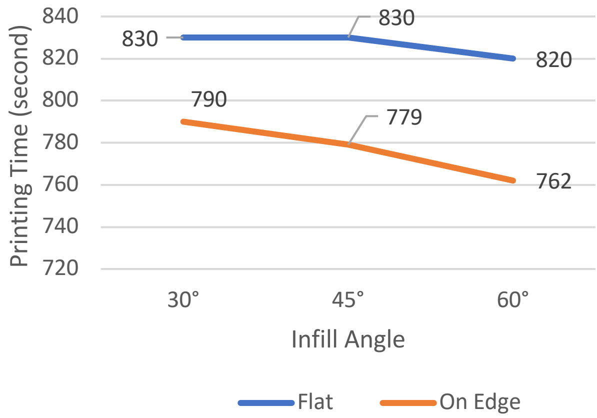

Figure 7 The effect of build orientation on printing time

Table 3 Second step experiment result

Build Orientation	Infill Angle	Impact Strength (kJ/m2)	Printing Time (second)
On-edge	0°	20.92	715
On-edge	15°	17.70	785
On-edge	30°	27.33	790
On-edge	45°	30.69	779
On-edge	60°	28.15	762
On-edge	75°	24.65	759
On-edge	90°	25.86	765

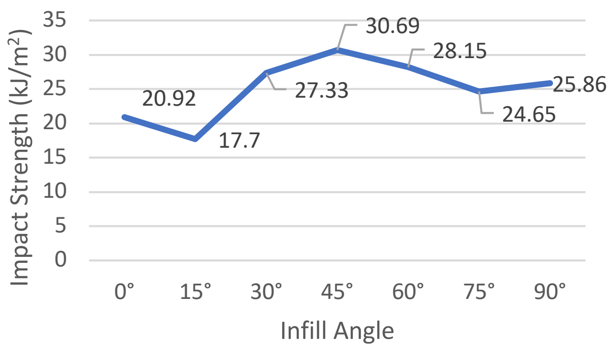

Figure 8 The effect of infill angle on impact strength

Figure 9 shows that the value of the printing time increases from the infill angle of 0° to 30° and then decreases from 30° to 75°. By using the triangular infill structure, the lowest printing time value is obtained at an infill angle of 0°. The use of a 0° infill angle generates the most effective movement that fills the porous infill structure. Therefore, this infill angle requires the shortest printing time compared to other infill angles. The longest printing time is required when using a 30° infill angle because the triangular infill structure uses an equilateral triangle shape. This triangle shape repeats the shape of the infill structure every 60°.

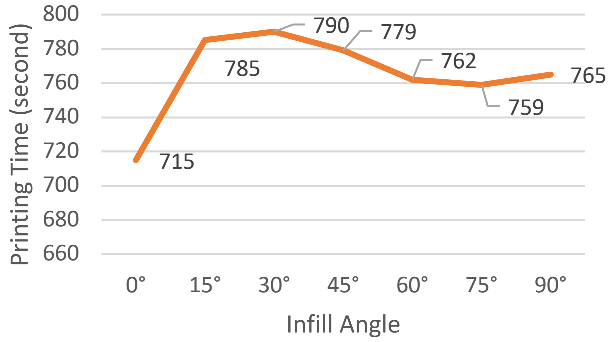

Figure 9 The effect of infill angle on printing time

4 Conclusion

The goal of this research is to find the effect of the build orientation and infill angle on the impact strength and printing time of 3D printed objects made of PLA and printed using a triangle infill structure. Based on the results of this research, it can be concluded that the on-edge orientation creates a stack of triangular layers that experience more impact load compared to the flat build orientation. As a result, the resistance of the on-edge build orientation to the impact load is better than the flat build orientation. The increase in infill angle has the highest impact strength value at an angle of 45°. The printing path of the on-edge generates a more effective movement that fills the porous infill structure. Therefore, the on-edge build orientation type requires less printing time than the flat build orientation type for each infill angle. The use of a 45° infill angle exhibits the highest impact resistance because it effectively distributes the impact energy to all infills. The use of a 0° infill angle generates the most effective movement that fills the porous infill structure. Therefore, 0° infill angle requires the shortest printing time compared to other infill angles.

The result of this research can be elaborated for further research. The infill angle might influence the compression and bending strength as well. Therefore, the next research will be conducted to explore the influence of the infill angle of an object printed using a triangle infill structure on the compression and bending strength.

Acknowledgments

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