Flexural Strength Optimization as Effect of Infill Pattern Variation in FDM 3D Printing of Multi-layers ABS-PLA

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Abstract. 3D printing technology based on the extrusion material method is rapid manufacturing and has complex accuracy, which supports industrial progress. The selection of printing material (filament) is essential in obtaining mechanical, chemical and thermal properties. In this study, the use of ABS and PLA combination is an innovation in the selection of filaments to minimize environmental pollution and improve the mechanical properties of printed products. In addition, implementing print parameters in printed products can affect mechanical properties. In this study, the infill pattern parameter was used as a variable to increase the flexural strength value by performing a bending test on the ASTM D790. Eight types of infill patterns have been tested with the result that there is an increase in the flexural strength value (in per cent) using the infill pattern archimedean chords (20.72%), concentric (14.02%), cubic (11.66%), Hilbert curve and honeycomb (5.7%). There is a decrease in flexural strength value (in per cent) using the infill pattern gyroid (4.34%), rectilinear (18.57%) and octagram spiral (21.29%). The analysis of the shape of the fracture is supported in determining the flexural strength of 3D printed products.

Keywords: FDM 3D printing · ABS · PLA · Flexural strength · Fracture

1 Introduction

3D printing is a rapid manufacturing technique where various materials can be printed using an additive process, and successive layers of materials are laid down in different shapes [1]. The development of additive manufacturing or 3D printing in recent years has been relatively rapid, and its use in medical, industry and business has impacted industry 4.0 [2]. FDM (Fused Deposition Modeling) is primarily the material extrusion principle of printing by melting material in an extruder and then placed into a bed on a 3D printing slowly and repeatedly (layer by layer) to form the desired product [3]. Three-dimensional product modelling for the prototyping process using CAD (computer-aided design). The design is stored in stereolithography (.STL) format, and the process is to

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the 3D printer. The slicing process to desired print parameters of object 3D printing, then the design is stored in G-code. Work order on a 3D printing machine is called G-code. G-code contains information about print parameters, print speed and supporting tools in 3D printing [4].

The printing material in the 3D printing process is generally called filament. The filament has several types, such as polymer, ceramic and metal. The polymer material is a type of filament commonly used in printing 3D printing using the extrusion material technique. It uses many materials such as ABS, PLA, HIPS, PETG, TPU and composites [2]. This research aims to evaluate the flexural strength of multilayered ABS (acrylonitrile butadiene styrene) and PLA (polylactic acid). The use of polymer materials has the advantage of being easy to shape and affordable [5].

On the other hand, using polymer materials has harmful properties, especially for ABS filaments which are not environmentally friendly because these filaments are made from oil (petroleum). In contrast, PLA filaments are environmentally friendly because these filaments are made from sugarcane and corn (organic) [6]. For its mechanical properties, ABS filament is superior to PLA filament. Innovation using a filament combination between ABS and PLA is expected to be an alternative in selecting filaments to obtain optimal flexural strength and be environmentally friendly [2].

The performance of the 3D printing process, especially for engineered structural applications, is affected by the printed material and the process parameters [7]. Print parameters include infill density, infill pattern, layer thickness, raster angle, air gap, feed rate, build orientation and raster width [8]. Infill patterns represent structure inside printed objects. Several infill patterns are available, such as rectilinear, cubic, concentric, honeycomb, gyroid, Hilbert curve, archimedean chords and octagram spiral, as shown in Fig. 2. Each of these infill patterns has its characteristics. Infill pattern is one printing parameter that can affect a printed product's mechanical properties [2]. Using an infill pattern can also affect the print time and the required material consumption [7]. In terms of use, an infill pattern type honeycomb has excellent material resistance combined with low density [9]. The infill pattern types circle, square, grid and Voronoi can determine the compression performance [10]. The infill pattern type rectilinear has a high-value tensile strength using the material PLA [11]. The use of ABS and PLA alloys by varying the printing parameters, especially the infill pattern, can increase the flexural strength of a 3D-printed product.

Based on the literature above, it is evident that the infill pattern affects specific mechanical properties of 3D-printed parts using a combination of ABS and PLA as printing material. All eight infill patterns have been investigated and compared with previous studies by [5] regarding their flexural strength properties. This research aims to understand the effect of infill patterns on flexural strength. Three steps are conducted in this research. First, this research collects the value of flexural strength. Then this research analyzes the data to compare with the previous study [5]. Third, this research analyzes the fracture failure on specimen testing.

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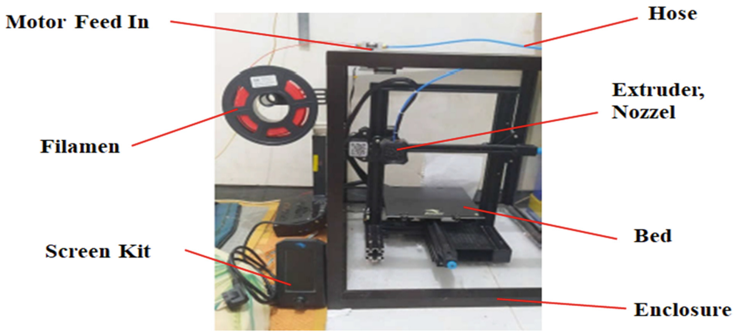


Fig. 1. Creality ender 3 V2 (custom)

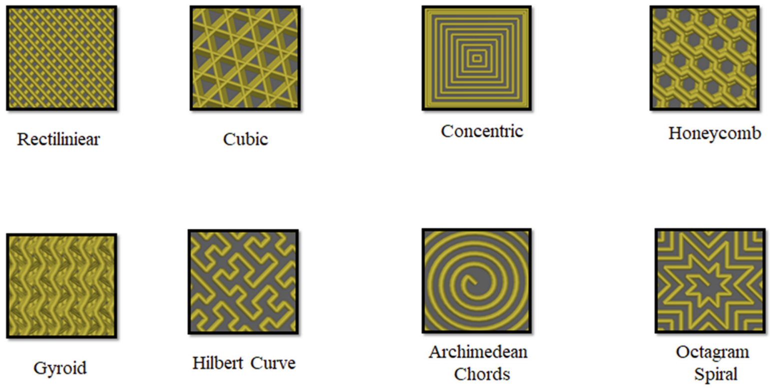


Fig. 2. Eight types of infill pattern

2 Methodology

2.1 Printing Parameter Experiment

The experiment was applied to investigate the influence of the infill pattern of the 3D printing process on flexural strength. This research was conducted in laboratory 3D printing, Department of Mechanical Engineering, Faculty of Engineering, University of Jember. The printing process of the test specimens was carried out using the Creality Ender 3 V2 with a modified extruder hose with a length of 150 cm and the use of an enclosure on the printing machine. It can be seen in Fig. 1.

The filament used has a diameter specification of 1.75 mm. The use of printing parameters, especially the infill pattern, can increase the value of the tensile strength of 3D printing with PLA printing materials [12]. This study used eight infill patterns, including rectilinear, cubic, concentric, honeycomb, gyroid, Hilbert curve, archimedean chords and octagram spiral, as shown in Fig. 2.

Table 1 shows the control variables used in the printing process. The control variable is a constant value or does not change in its application during the printing process. Dependent variables result from the use of independent and control variables. In this

Table 1. Control variables

Parameter	Unit	Value
Composition ABS - PLA	%	50-50
Layer Height	Mm	0.08
Number of Outer Shell Layers		2
Bed Temperature	oC	220
Build Orientation		X-Y
Extrusion Temperature	oC	230
Printing Speed	mm/s	38
Filament Diameter	mm	1.75
Outer Shell Layers		Vertical
Fan		Disable

Fig. 3. ABS-PLA sandwich test specimen

study, the dependent variable was the flexural strength value of a combination of ABS and PLA filament.

The design of an ABS and PLA sandwich consists of 50%-50% bonded in a laminate. For simplicity, it will be termed as an ABS-PLA sandwich in this paper. Figure 3 shows that the red layer is a PLA-type filament, and the white layer is an ABS filament. This research was conducted using three replications for each type of infill pattern. The total number of test specimens that need to be prepared is twenty-four specimens.

2.2 Bending Testing

The specimen is designed based on ASTM D790 standards according to ASTM International for flexural strength tests, as shown in Fig. 4.

The 3D model was then exported in Standard Triangulation Language (STL) file format, which was further processed by a slicing software (prusaslicer) to adjust parameters printing that will be used in the slicing process. The file will be stored as G- code. The G-Code files, which translated the 3D design into position coordinates, were used in an FDM 3D printer to fabricate the specimens layer by layer. Furthermore, insert the printed material first into the extruder hose. After all printing processes are carried out,

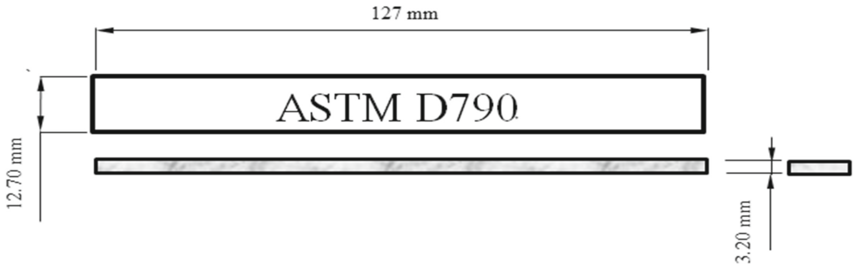


Fig. 4. Standard ASTM D790 bending test specimen

the process can be carried out until it becomes a product based on the design. After that, removing the printed object or product and cleaning the machine, especially bed printing, is essential.

2.3 Calculation of Flexural Strength and Fracture Analysis

Data processing can be done using formulas to obtain stress and strain values. The following is the equation for the stress and strain formula [13]:

$$\sigma = \frac{3PL}{2bh^2} \tag{1}$$

where σ = Flexural strength (MPa)
P = Maximum load (N)
L = Length of span (mm)
b = Width of the test object (mm)
h = Height of test object (mm)

To get the value of strain on the results of the bending test, use the following formula:

$$\varepsilon_b = \frac{6Dd}{L^2} \tag{2}$$

where εb = Strain (%)
D = Maximum deflection (mm)
L = Span length (mm)
D = Specimen thickness (mm)

Analysis of bending test by calculating stress and strain values bending test results, then the process of comparing the test results with previous research conducted by [5] with the flexural strength value of pure ABS (100%) and ABS-PLA sandwich (50%-50%). Observation of the shape fracture that occurs due to the test by taking micro photos of the Fracture of the test specimen.

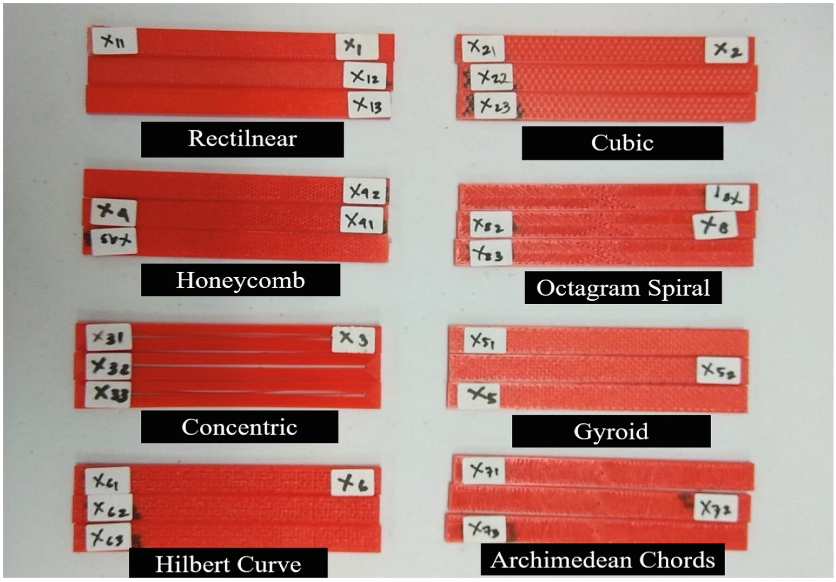


Fig. 5. Printed results of test specimens test

3 Result and Discussion

3.1 Specimen Printing Results

The printing process was carried out using the Creality Ender 3 V2 Custom with the first filament cutting stage according to printing needs, using ABS and PLA alloys in layers in each of the 20 layers. The combination of ABS and PLA filaments is perfectly laminated. Lamination combines two or more layers that are bonded [14].

The combination of ABS and PLA filaments can be used as an alternative in the filament selection. Its use can minimize environmental pollution and determine the strength and characteristics of printed products. According to [2], using a filament combination between ABS and PLA is expected to be an alternative in selecting filaments to obtain optimal flexural strength and be environmentally friendly. The problems in the printing process defect result in warping, shrinkage and surface roughness. Some obstacles have been overcome by using adhesive glue on the bed and setting the bed, which must be parallel to the extruder. Figure 5 is the result of the 3D printing of the test specimen.

3.2 Bending Test Result

The test was carried out twenty-four times according to the number of test specimens that had been printed. This test destroys the test specimen to achieve the flexural strength value. Figure 6 shows all tested specimens.

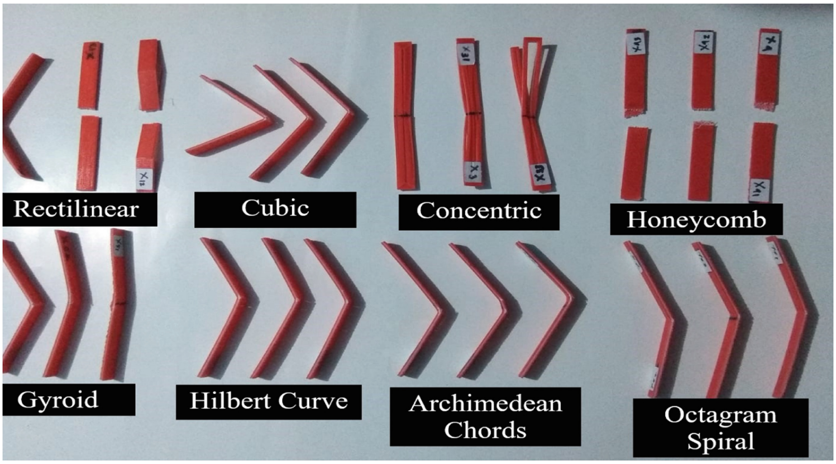


Fig. 6. Test specimen after bending test

Table 2. Average bending test results

Infill pattern	The maximum force (N)	Deformation (mm)
Rectilinear	337.18	22.31
Cubic	462.38	40.38
Concentric	472.38	53.52
Honeycomb	345.03	40.30
Gyroid	396.24	42.31
Hilbert Curve	437.76	55.66
Archimedean Chords	500.09	51.33
Octagram Spiral	325.82	22.32

Figure 6 shows the bending testing for the rectilinear and honeycomb have the same fracture shape. Infill pattern types cubic, gyroid, Hilbert curve, archimedean chords and octagram spiral have the same fracture shape, but the test failed for the infill pattern type concentric. It will produce data in the form of maximum force (newtons) and changes in the shape of the test specimen (deformation), as shown in Table 2.

Figure 7 shows the stress and strain graph using eight different infill patterns. The archimedean chords have the highest flexural strength value of 23.07 MPa, followed by infill pattern of concentric (21.79 MPa), cubic (21.34 MPa), Hilbert curve (20.20 MPa), gyroid (18.28 MPa), honeycomb (15.92 MPa), rectilinear (15.56 MPa) and octagram spiral (15.04 MPa) as shown in Table 3.

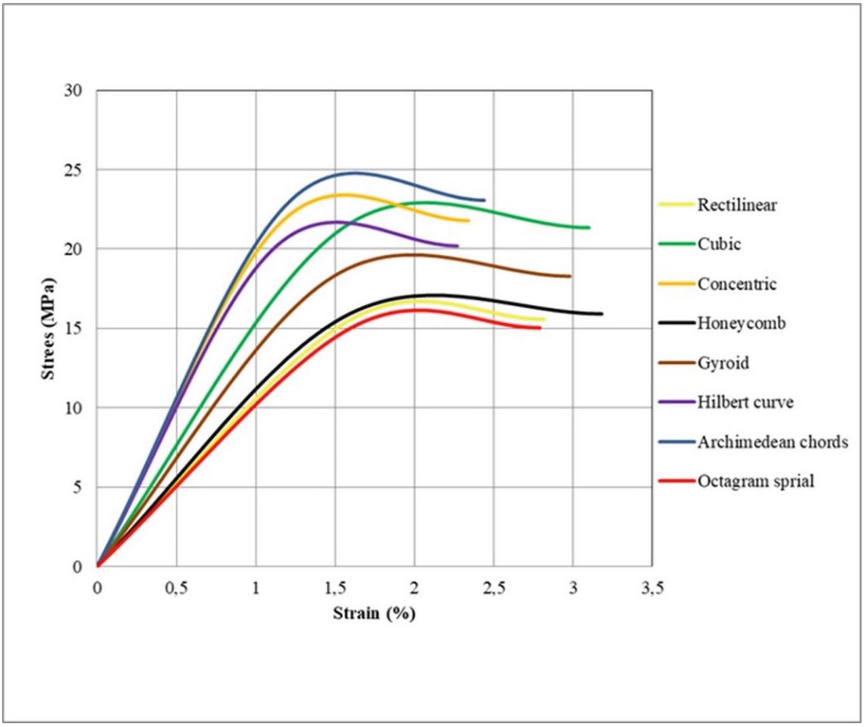


Fig. 7. Graph of stress and strain

Table 3. Average stress-strain value

Infill Pattern	Stress (MPa) ± Std. Dev.	Strain (%)
Rectilinear	15.56 ± 2.55	2.82
Cubic	21.34 ± 0.43	2.32
Concentric	21.79 ± 1.56	1.90
Honeycomb	15.92 ± 0.84	1.55
Gyroid	18.28 ± 5.92	1.35
Hilbert Curve	20.20 ± 1.91	1.22
Archimedean Chords	23.70 ± 0.91	1.17
Octagram Spiral	15.04 ± 3.53	1.39

Based on the collected data shown in Table 3, the flexural strength of each infill pattern, the value of flexural strength, represents the maximum bearable stress. It can be observed that specimens with archimedean chords have the highest flexural strength

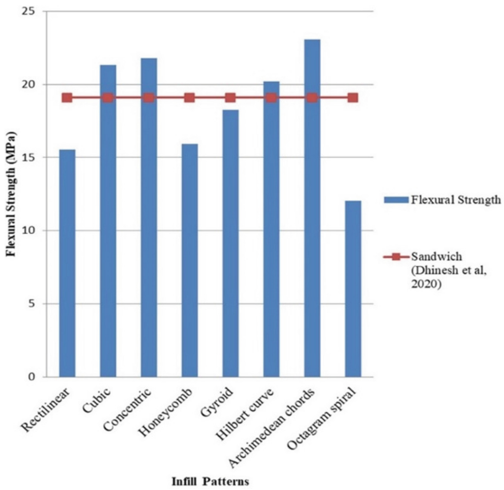


Fig. 8. Comparison with the previous study

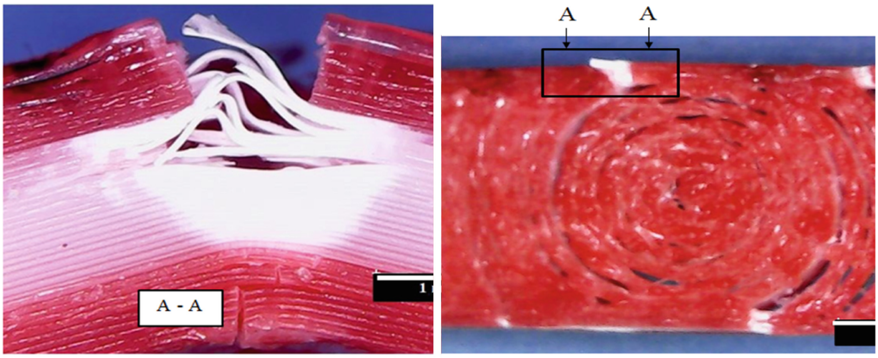
of 23.70 MPa, while the octagram spiral has the lowest value of 15.04 MPa. The error represents the measured flexural strength standard deviation, where 68% of the measurements fall within that range [12]. A slight standard deviation can be seen in all infill patterns, which indicates high repeatability and consistency.

Figure 8 shows the obtained flexural strength value. These values will be compared with previous research conducted by [5]. Increase and decrease in the flexural value compared to the sandwich of ABS + PLA with differentcomposition percentages. Infill pattern type of archimedean chords (20.72%), concentric (14.02%), cubic (11.66%), Hilbert curve and honeycomb (5.7%) experienced an increase in flexural strength value. While infill pattern type gyroid (4.34%), rectilinear (18.57%)) and octagram spiral (21.29%) experienced a decrease in flexural strength.

Some infill patterns of the PLA + ABS have a bending strength better than that of the sandwich of ABS + PLA [5]. Rectilinear, Cubic, Concentric, Honeycomb, Gyroid, Hilbert curve, Archimedean chords and Octagram spiral all have a higher strength. It means that the content of PLA in those patterns is more promising with the advantage of being more degradable or potentially lessening the pollution created by petroleum-based material, such as ABS.

3.3 Fracture Failure

Analysis of the fractures was carried out on the tested specimens. The fractured form or failure criteria caused by a test are divided into two, ductile fracture and brittle fracture. Ductile fracture is concluded when there are fibres in the Fracture. In addition, the deformation that occurs has a high value, as shown in Fig. 9. The brittle fracture would happen if there is no fibre, resulting in very small or even no deformation, as shown in Fig. 10.



(a) (b)

Fig. 9. Fracture in the test specimen with infill pattern type archimedean chords, (a) side view, (b) upper view

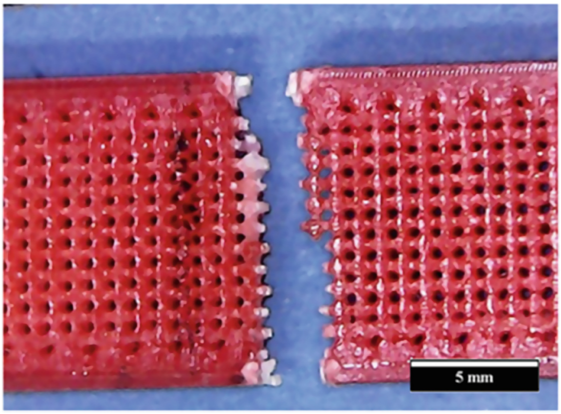


Fig. 10. Fracture in the test specimen with infill pattern type rectilinear

Figure 10 shows that the infill pattern has a brittle fracture. According to [12], the rectilinear infill pattern type has the highest UTS value. Meanwhile, the infill pattern of cubic, gyroid, Hilbert curve, archimedean chords and octagram spiral has a ductile fracture, as shown in Fig. 6. The ductile Fracture, especially in the infill pattern of archimedean chords.

Figure 11 shows the concentric infill pattern. The test failed because no faults were caused due to the large air gap in the test specimen that occurred in each replication. This air gap occurs because the pattern has a basic cylindrical pattern resulting in an air gap. Applying products with a square or beam shape will result in an air gap. According to [15], the fundamental factors affecting the mechanical strength of the final part are the air gap and road angle. Voids in the product are a source of decreased mechanical performance in FDM.

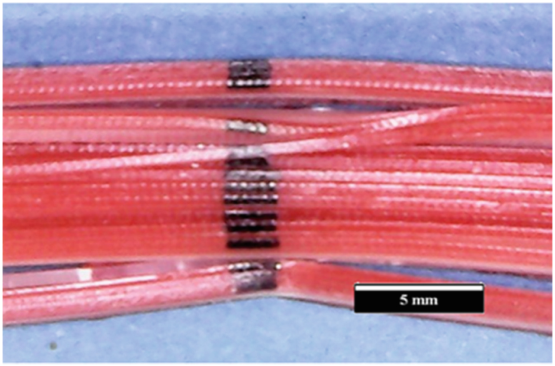


Fig. 11. Fracture in the test specimen with infill pattern type rectilinear

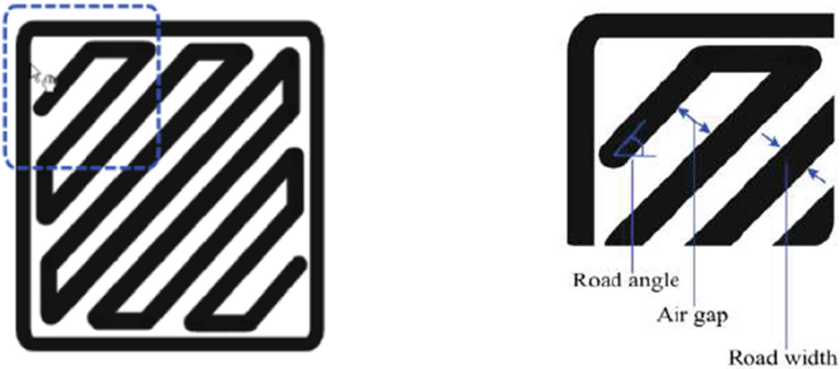


Fig. 12. Insight build parameter [15]

Figure 12 shows that the air gap is the space between the filament path and the layer, which can result in reducing the bond strength of each filament and layer [16]. According to [15] air gap parameter is defined as the space between the beads of deposition material. Using a concentric infill pattern with PLA material in the tensile strength test, FDM has the most considerable strain and high elongation value [12]. Infill pattern type concentric is applied to products with a circle or cylinder shape, making this type of infill pattern stronger and more elastic.

Figure 13 shows honeycomb defects delamination by peeling off the bonds between layers. It may be caused by the lack of bonding between layers which can reduce the flexural strength value. The use of infill density may result in delamination [17], in their research said that infill would cause gaps in the mould structure. Therefore, it can reduce the strength of the mould.

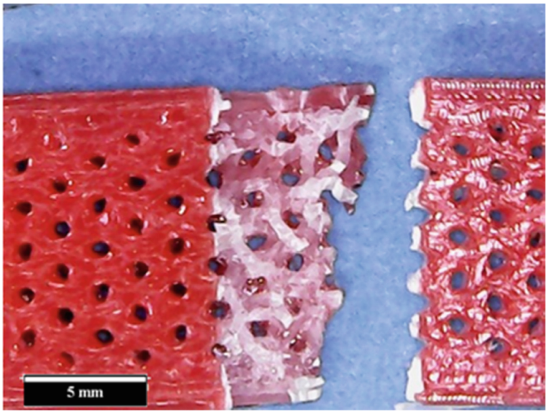


Fig. 13. Fracture in test specimens with infill pattern type honeycomb

4 Result and Discussion

In this research, the influence of infill patterns is analyzed. Based on the analysis, the combination of ABS and PLA filaments can be used as an alternative in the filament selection process. Its use can minimize environmental pollution and determine the strength and characteristics of printed products. Infill pattern can increase the flexural strength value against using ABS and PLA filaments with a composition of 50%-50% (sandwich). Infill pattern the Archimedean chords highest strength value of 23.07 MPa with an increase in flexural strength of (19.9%) compared to previous studies with pure ABS and an increase in flexural strength of (20.7%) compared to ABS and PLA alloy (sandwich).

Based on observations, infill patterns of the rectilinear and honeycomb experienced brittle fractures, while infill patterns of the cubic, gyroid, Hilbert curve, archimedean chords and octagram spiral experienced ductile fractures. For the honeycomb infill pattern, there is a test defect (delamination) on the test specimen, and for the concentric infill, the test failed because there was no fracture in the test specimen due to an air gap.

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