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Study on Effect of Infill Density to 3D Printed Part by Using Chi Mei Polylac® PA-757 ABS Filament

Muhammad 'Ariff Zakaria Ahmad Nizar[1], Khairu Kamarudin[1]*

[1] Department of Mechanical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: In additive manufacturing, it is very important to ascertain the suitability of material used in the process, especially fused filament fabrication (FFF) as poor selection of material will severely affect the printer part mechanical properties. This paper aims to determine the compatibility of Chi Mei Polylac® PA-757 ABS pellet with FFF printer which was initially made for injection moulding purposes. The ABS pellet was extruded into filaments using Wellzoom desktop filament extruder B and used to print test sample using Ultimaker 2+ with different infill densities, which then put into tensile and Izod (notched) impact test with ASTM D638 and ASTM D256 standard respectively. Tensile properties and impact resistance of printed sample was compared with previous work and pellet mechanical properties. Through FFF process, samples printed using Chi Mei Polylac® PA-757 ABS pellet lost around 9-19% of its tensile properties and nearly 25.00 % of its impact resistance. Tensile properties increase linearly as infill density increases, while impact resistance increase exponentially as infill density increases. Further improvement in future research to Chi Mei Polylac® PA-757 ABS pellet mechanical properties is highly suggested by either combining with other polymer or mixing with additive material.

Keywords: ABS, Filament Extruder, Infill Density, Tensile Properties, Impact Resistance, Polylac® PA-757

1. Introduction

Additive Manufacturing (AM) is no longer foreign in the world of manufacturing, since the birth of 3D printing in 1980s. The process starts by slicing a 3D CAD model into multiple layers, then print the part by stacking printing material, layer by layer on top of each other until the process complete [1].

Fused Filament Fabrication (FFF) is one of the AM technologies which uses filament made up of polymers. Major benefits of FFF include high manufacturing speed, cost efficiency, customized devices

*Corresponding author: khairu@uthm.edu.my

and on demand preparation. Sometimes, support was necessary to be added into the printed model by slicing software to prevent the model from collapsing during the printing processes [2].

A few researchers mentioned that there is various selection of materials which is used in FFF process such as polypropylene (PP), wood, metals, and carbon fibre [3], [4], [5]. ABS is a popular thermoplastic polymer created by polymerizing styrene and acrylonitrile with polybutadiene. It is extremely resistant to physical and chemical corrosion. Chi Mei Polylac® PA-757 ABS pellet is one of numerous ABS variants manufactured by CHIMEI Corporation, a Taiwan-based performance materials manufacturer. Currently Chi Mei Polylac® PA-757 ABS pellet is use for injection moulding purposes in Modern Machining laboratory, UTHM Pagoh.

Wellzoom desktop filament extruder B machine will enable to produce filament for FFF printer in the laboratory. Since there is readily available ABS pellet (Chi Mei Polylac® PA-757) in the laboratory, it will be logical not to rush into buying new pellet. Therefore, this research will analyse the compatibility of Chi Mei Polylac® PA-757 ABS pellet with FFF printer available in UTHM Pagoh Modern Machining laboratory.

1.1 Problem statement

Although one past research managed to justify the suitability of Chi Mei Polylac® PA-757 ABS pellet to produce filament for FFF using Wellzoom desktop filament extruder B machine [6], there is still much to be explored when it comes to print using Ultimaker 2+, especially since only the extrusion temperature was focused while the same printing parameter is used in the past research. Therefore, this research aims to explore different infill densities to determine whether the filament produced from Chi Mei Polylac® PA-757 ABS pellet can achieve higher tensile properties and impact resistance as the printed part infill density increases.

1.2 Objective and scope

This research objectives are to justify the compatibility of Chi Mei Polylac® PA-757 ABS filament with Ultimaker 2+ FFF printer by comparing the tensile strength and impact strength value of printed samples with past research. Next, is to analyse the effect of infill densities 20.00 %, 40.00 %, 60.00 %, 80.00 % and 100.00 % on ultimate tensile strength, Young's modulus, impact strength and impact energy of parts printed using Chi Mei Polylac® PA-757 ABS filament by tensile and Izod (notched) impact test.

Filaments are fabricated using a Wellzoom B2 Desktop Filament extruder at 230 °C extrude temperature using only Chi Mei Polylac® PA-757 ABS pellet. Infill density of 20.00 %, 40.00 %, 60.00 %, 80.00 % and 100.00 % will be used to print test samples. Line pattern, layer thickness of 0.15mm, nozzle temperature of 250 °C, bed temperature of 85 °C and printing orientation with is going to be kept constant for each test sample. SOLIDWORKS 2019, Ultimaker Cura software and Ultimaker 2+ machine will be used to design, slice and print test samples. Tensile tests are according to ASTM D638 type V, using Lloyd Instruments LR 30K Plus universal materials testing machines. Izod impact tests were according to ASTM D256, using CEAST 9050 Series Pendulums. Total of 50 sample will be tested, 25 samples for tensile test and the rest for Izod impact test. The relationship between infill density to tensile properties (ultimate tensile strength and Young's modulus) and impact resistance (impact energy and impact strength).

1.3 Significance of research

This research will help in making decision whether to purchase new ABS pellet which had better suitability with FFF process, or use the existing ABS pellet. In term of cost, it will be a great save of money if the existing ABS pellet was compatible with the Ultimaker 2+ printer. Regarding storage space, purchasing new pellet will definitely increase the space needed for storage. On the other hand, less stock of material means less space needed. The outcome of this research will benefit individuals or manufacturers that opting to use Chi Mei Polylac® PA-757 ABS pellet for FFF process. This research will serve as baseline for further research to be conducted in term of compatibility with FFF processes. It would help in decision making whether to purchase new ABS pellets or use the available ABS pellets.

2. Materials and Methods

Chi Mei Polylac® PA-757 ABS pellet was the main material used to fabricate filament, which then used to print tensile and Izod impact test sample with different infill density. The printed samples were put into tensile and Izod impact test. Result obtained was analysed and compared with previous research to justify the pellet suitability with FFF printer.

2.1 Materials

Chi Mei Polylac® PA-757 ABS pellet is an acrylonitrile butadiene styrene that was manufactured for general use with high rigidity, high gloss and medium impact strength [7]. Listed in Table 1 is the mechanical and processing properties of Chi Mei Polylac® PA-757 ABS pellet as provided by.

Table 1: Mechanical properties and processing properties of Chi Mei Polylac® PA-757 pellet [8]

Properties	Value	Comments
Tensile Strength at Break	31.0 MPa	6 mm/min, ASTM 638
Tensile Strength, Yield	46.09 MPa	6 mm/min, ASTM 638
Elongation at Break	20.00 %	6 mm/min, ASTM 638
Izod Impact, Notched	206 J/m	Thickness 3.17 mm, ASTM D256
Fracture Energy	0.653 J	Thickness 3.17 mm, ASTM D256
Melt Temperature	232 - 260 °C	Nozzle temp not greater than stock

The infill density of 3D printing products depicts the closeness of the infill inside the shell as in Figure 1. Higher infill density will increase compressive and tensile strength [9]. Past research regarding effect of infill density impact strength, tensile strength, and Young's Modulus is summarise in Table 2.

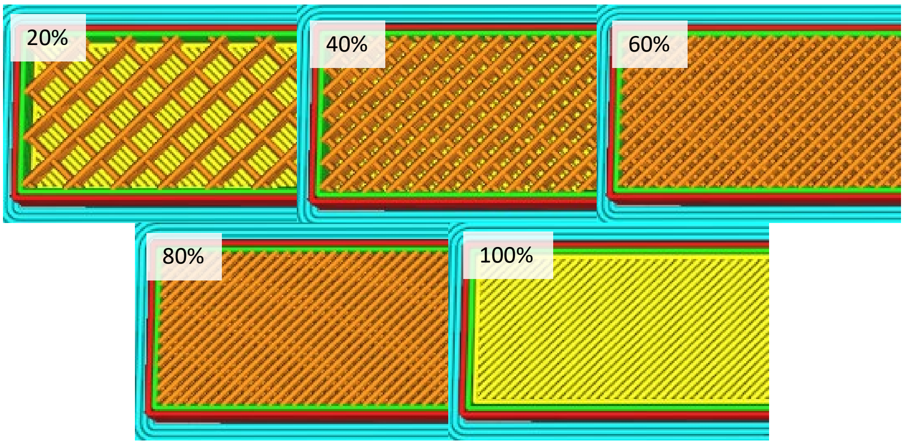

Figure 1: Depiction of different infill density

Based on past research on ABS by past researchers and manufacturer specification sheet of Chi Mei Polylac® PA-757 pellet, the expected range of tensile strength, Young's modulus, impact strength and fracture energy value were able to be created [10], [11], [12], [13], [14].

For tensile strength, the range is between 32 MPa to 46.09 MPa, while the Young's modulus is between 1.63 GPa to 2.3 GPa. The range of fracture energy is around 0.653 J, while for impact strength is between 96 J/m to 206 J/m.

Table 2: Past research regarding infill density, impact strength, tensile strength, and Young's Modulus of FFF process

Author	Result	Material
[15]	Infill density affect tensile strength and elastic modulus	PLA
[13]	Infill density affect modulus, elongation, and failure mode.	PLA, ABS, ASA, PC/ABS, PETG, Nylon
[16]	Impact strength is directly related to infill density.	PLA
[17]	Infill type and density influence ultimate tensile strength and yield strength.	PLA
[18]	Tensile strength is influence by infill density.	Nylon
[12]	Tensile strength, impact resistance and printing time increase as infill density increase.	ABS
[11]	Interior fill influence dimensional precision the most.	ABS plus-P430
[19]	Denser interior fill provided the best surface finish	Wood-PLA
[10]	Infill percentage affect energy absorbed and impact energy.	ABS, PLA and Nylon
[14]	Infill pattern influence mechanical properties of pure thermoplastic materials.	ABS and ABS plus

2.2 Methods

The flowchart in Figure 2 shows the process that had been performed from start to finish, in sequential order for this research. The flowchart will provide further understanding on how the compatibility of Chi Mei Polylac® PA-757 ABS filament with Ultimaker 2+ FFF printer will be justified by analysing the effect of infill densities 20.00 %, 40.00 %, 60.00 %, 80.00 % and 100.00 % on ultimate tensile strength, Young's modulus, impact strength and impact energy, then comparing the result with previous research and specification datasheet provided Chi Mei Polylac® PA-757 ABS manufacturer.

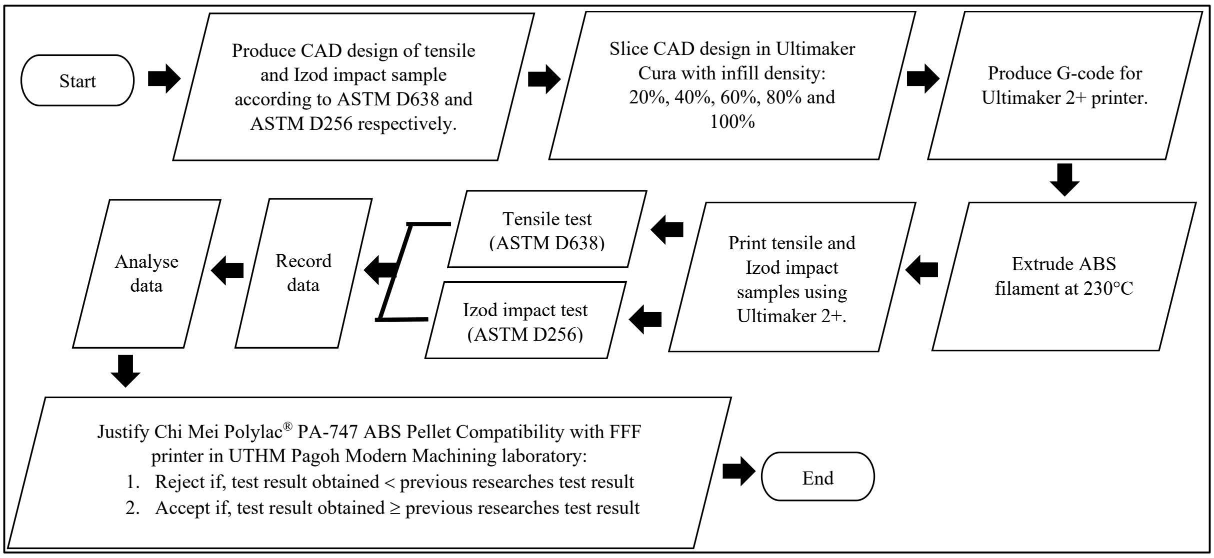

Figure 2: Process flowchart for research method

Ultimaker Cura software is used to create STL file and G-code for Ultimaker 2+ printer that is used in this research. The settings tuned in Ultimaker CURA for Ultimaker 2+ printer for this research were displayed in Table 3. Other than displayed settings in Table 3 is kept to their initial value.

Table 3: Setting for Ultimaker 2+ printer using Ultimaker Cura software

Settings	Value	Unit
Layer thickness	0.15	mm
Infill density	20, 40, 60, 80, 100	%
Support	ON	
Adhesion	ON, Brim	
Infill pattern	Lines	
Nozzle temperature	250	°C
Bed temperature	85	°C
Printing speed	45	mm/s
Infill speed	50	mm/s
Inner wall speed	33	mm/s
Fan speed	0	%

The Chi Mei Polylac® PA-757 ABS pellet is extruded into filament using Wellzoom desktop filament extruder B at 230°C as confirmed by one researcher as the suitable temperature to extrude Chi Mei Polylac® PA-757 ABS pellet [6].

Figure 3: Tensile sample (ASTM D638 Type V) and Izod impact sample (ASTM D256)

The tensile test was conducted using Lloyd Instruments LR 30K Plus universal materials testing machines with ASTM D638 Type V standard sample as in Figure 3. The machine was control using computer software named NEXYGEN. The test was setup using speed 1.00 mm/min, 30 mm gauge length and cross-sectional area of 10.78 m^2. Meanwhile, Izod (notched) impact test was carried out using Instron CEAST 9050 Series Pendulums with ASTM D256 sample as in Figure 3. The thickness selected was 3.17 mm.

3. Results and Discussion

The decision regarding of Chi Mei Polylac® PA-757 ABS pellet compatibility with FFF printer in UTHM Modern Machining laboratory will be made and discussed. Also, the impact of infill density towards tensile properties and impact resistance will be analysed, discussed and compared with the established data of ABS polymer. Also, problem or other difficulties faced during the research will be discussed.

3.1 Results

The data obtained from the test of tensile and Izod impact (notched) was tabulated in Table 4. From the data gathered in tensile and Izod impact test, average value was calculated based on samples tested.

Table 4: Data from tensile and Izod (notched) impact test

Infill density	Max. load, N	Max. load deflect, mm	σ max. load, MPa	E, GPa	Impact strength, J/m	Impact strength, kJ/m2	Fracture energy, J
20%	382.885	0.91043	35.518	1.541	56.91	5.6	0.1805
40%	407.865	0.90357	37.836	1.626	58.815	5.79	0.1865
60%	437.29	0.92654	40.518	1.698	60.725	5.975	0.1925

80%	384.57	0.8607	41.047	1.706	76.07	7.49	0.241
100%	450.845	0.90323	41.823	1.864	155.945	15.35	0.4945

The stress against strain percentage graph (Figure 4) was created by NEXYGEN software that came with Lloyd Instruments LR 30K Plus universal materials testing machines. From the graph, 100.00 % infill density showed the highest strain percentage at sample 1 with 8.21 %. The lowest strain percentage is at 4.03 % by 20.00 % infill density sample 2. In term of stress, 80.00 % infill density for sample 1 displayed the highest stress at 42.718 MPa, followed by 100.00 % infill density sample 2 at 42.448 MPa. the lowest stress is 33.496 MPa by 20.00 % infill density sample 1.

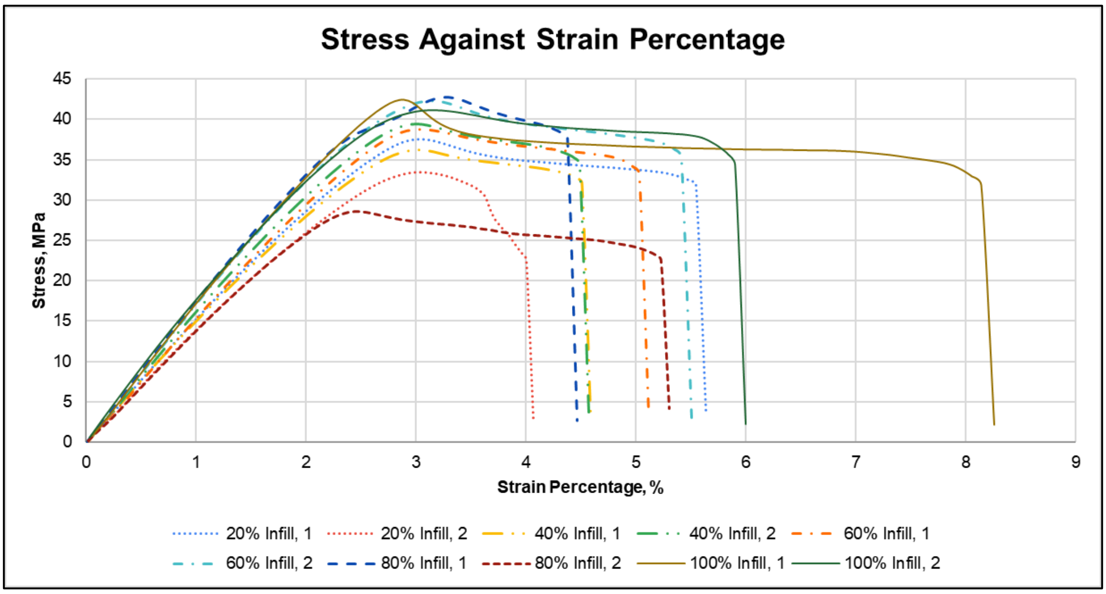

Figure 4: Graph of Stress Against Strain Percentage

From the graph of ultimate tensile strength (UTS) against infill density (Figure 5), the trend showed that increase in infill density will also increases the UTS. As infill density increases from 20.00 % to 40.00 %, the average UTS increases by 6.13 %. The average UTS increase by 6.62 % when infill density increases from 40.00 % to 60.00 %. However, the increment of average UTS shrunk to 1.29 % as infill density increased to 80.00 %. At 100.00 % infill density, the average UTS also showed slight increment of 1.85 %. The highest recorded UTS was at 100.00 % infill density with average of 41.832 MPa, while the lowest is recorded at 20.00 % infill density with average of 35.518 MPa.

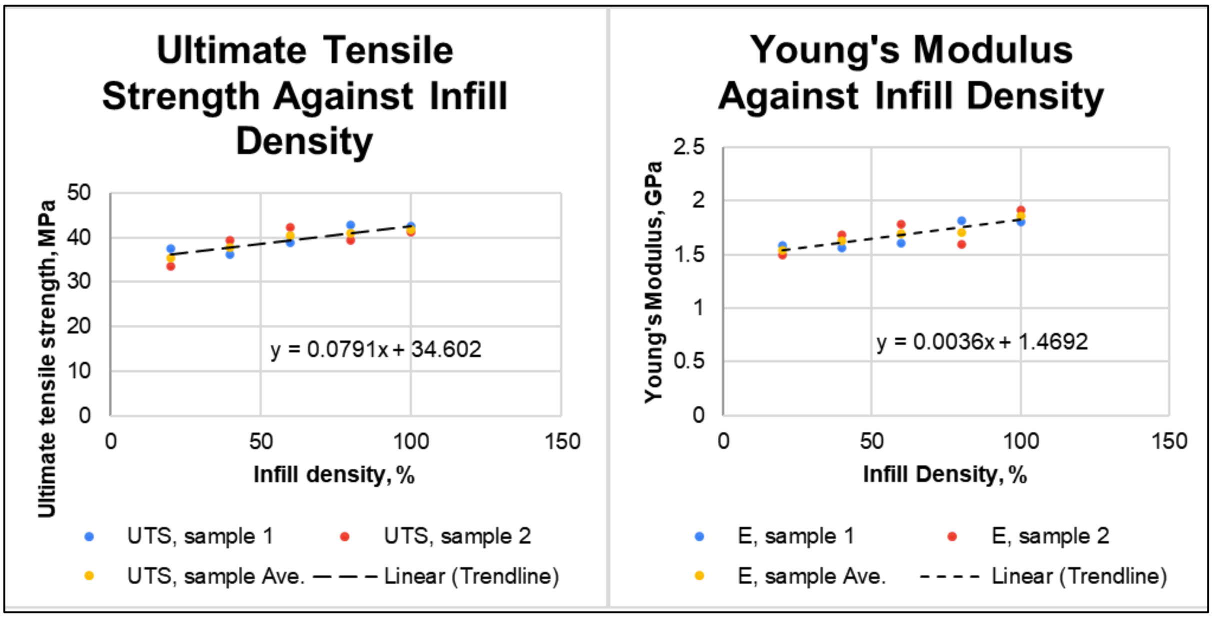

Figure 5: Graph of Ultimate Tensile Strength and Young's Modulus against Infill Density

The Young's Modulus against infill density graph (Figure 5) also showed the same trend as in graph of ultimate tensile strength (UTS) against infill density such as the infill density increase, Young's Modulus also increases. The highest value was obtained at 100.00 % infill density with average of 1.8635 GPa, followed by 80.00 %, 60.00 %, 40.00 % and 20.00 % infill density with the lowest Young's Modulus obtained is 1.541 GPa.

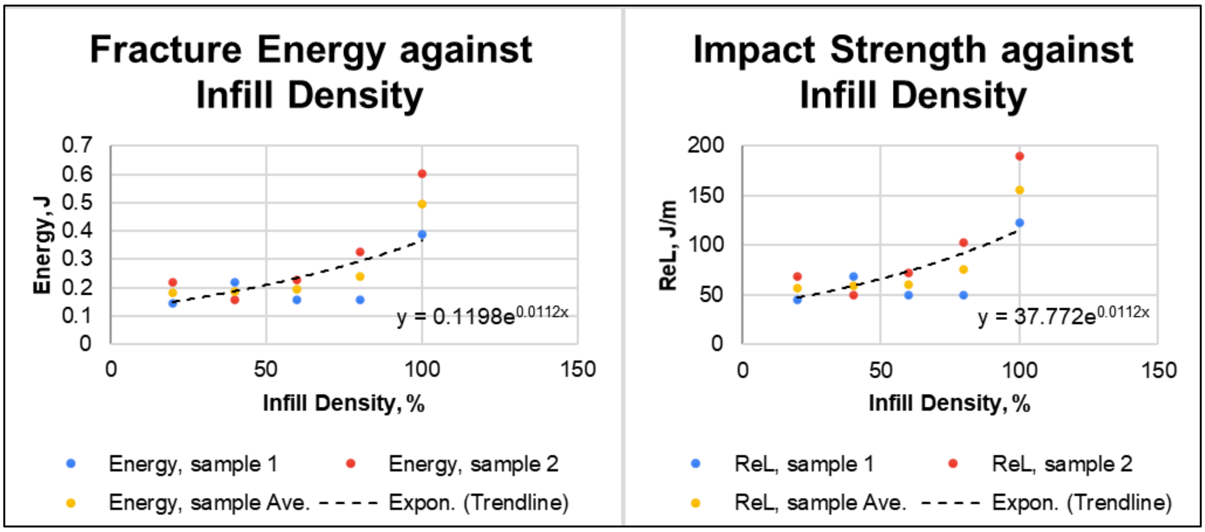

Figure 6: Graph of Fracture Energy and Impact Strength against Infill Density

From the graph of fracture energy against infill density (Figure 6) it was observed that fracture energy increases exponentially as infill density increases. The increment of fracture energy from infill density of 20.00 % to 40.00 % is averaged at 3.20 % increment. The same pattern also occurs as the infill density increase from 40.00 % to 60.00 % which is averaged at 3.10 %, but as the infill density increase from 60.00 % to 80.00 %, the fracture energy significantly rose by 20.20 %. The fracture energy doubled as infill density goes from 80.00 % to 100.00 % with 51.20 % increment. The highest fracture energy is at 100.00 % infill density, with 0.4945 J. While the lowest value for fracture energy is 0.1805 J at 20.00 % infill density.

Impact strength was derived from fracture energy. Fracture energy is divided with either cross sectional area under the notch or thickness of the sample. In the graph impact strength against infill density created in Figure 6, fracture energy, J was divided with thickness of printed sample, m, hence J/m. Since impact strength is derive from fracture energy, the trend is similar for both impact strength and fracture energy. The highest impact strength is at 100.00 % infill density, with 155.945 J/m. While the lowest value for impact strength is 56.91 J/m at 20.00 % infill density.

3.2 Discussions

From the result provided, the Chi Mei Polylac® PA-757 ABS pellet available in Modern Machining Laboratory, UTHM Pagoh is suitable to be used with FFF printer such as Ultimaker 2+ if impact resistance is less of a concern. The justification is made based on the result achievement of Chi Mei Polylac® PA-757 ABS pellet in tensile test and Izod (notched) impact test.

For tensile test, the printed sample managed to obtain highest UTS at 41.832MPa, while the lowest is 35.518 MPa. The printed sample had 9.24 % less UTS from Chi Mei Polylac® PA-757 pellet through FFF process at its highest infill density. Meanwhile, the highest value of Young's modulus was obtained at 1.864 GPa with the lowest is 1.541 GPa. At the highest infill density, the printed sample lost 18.98 % of its rigidity as compared to Chi Mei Polylac® PA-757 pellet original Young's modulus. Despite the loss of strength and rigidity the printed sample managed to stay in the range of UTS and Young's modulus obtained from [10], [11], [12], [13], [14] and manufacturer specification sheet which is 32 MPa – 46.09 MPa for UTS and 1.63 GPa – 2.3 GPa for Young's modulus.

Next, Izod (notched) impact test showed a bit of mixed result as the impact strength highest value is 155.945 J/m, while the lowest value for impact strength is 56.91 J/m. Through FFF process, the printed sample lost impact strength by 24.30 % at 100.00 % infill density as compared to the manufacturer specification sheet. The fracture energy of printed sample also lost 24.30 % at 100.00 % infill density with 0.4945 J/m as compared with Chi Mei Polylac® PA-757 pellet. For both impact strength and fracture energy of printed sample, only infill density 100.00 % managed to comply with the established work by [11] and [14].

The tensile test and Izod (notched) impact test showed that Chi Mei Polylac® PA-757 pellet was suitable to use for FFF printer (Ultimaker 2+) and process, as long as the printed part was not intended to resist high impact. Any printed part that requires impact strength and fracture energy higher than 155.945 J/m and 0.4945 J is not advisable to use Chi Mei Polylac® PA-757 pellet.

4. Conclusion

To summarize this research, the findings and data obtained are beneficial for manufacturer or individual that had or planning to buy Chi Mei Polylac® PA-757 pellet for FFF process. The said pellet is suitable for FFF process or printer (Ultimaker 2+) which print part that does not emphasize on impact resistance.

The printed sample had 9.24 % less UTS from Chi Mei Polylac® PA-757 pellet through FFF process at its highest infill density. The printed sample also lost 18.98 % of its rigidity as compared to the original Young's modulus. The highest value of Young's Modulus was obtained at 1.8635 GPa with the lowest is 1.541 GPa.

The printed sample lost impact strength and fracture energy by 24.30 % at 100.00 % infill density as compared to Chi Mei Polylac® PA-757 pellet. The impact strength highest value is 155.945 J/m, while the lowest value for impact strength is 56.91 J/m.

The infill density contributes significant impact on the tensile properties and impact resistance. Increase in infill density will also increases the UTS, Young's modulus, impact strength and fracture energy. At 100.00 % infill density tensile properties and impact resistance is at the highest, with UTS at 41.832 MPa, Young's modulus at 1.8635 GPa, impact strength at 155.945 J/m and fracture energy at 0.4945J.

For further research in the future, the following recommendation can be considered:

- The pellet must first be dried by using oven to get rid of any moisture. Air bubbles will cause irregular diameter and make it almost impossible to print any part due to poor quality filament, if at all possible.
- ABS part is tricky to print as it does not stick to the build plate easily especially if made of glass. Using glue or hairspray helps ABS part to stick firmly during printing process and avoid warping. Warping causes printed part to have inaccurate dimensions.
- In the ever growing world of additive manufacturing especially FFF, selection of filament material is very important in achieving specific objective for printing part. Further research can be done by combining Chi Mei Polylac® PA-757 pellet with other polymer or additive material to increase its tensile properties and impact resistance.

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