Mechanical Properties of 3D Printed Polypropylene (PP) Reinforced with Kenaf Particles

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Article Info	Abstract
	3D printing builds objects layer upon layer, offering unprecedented design freedom and customization since the core of 3D printing is the layer-by-layer construction of objects. The objective of this study is to determine the mechanical properties of fabricated PP and kenaf/PP composite specimens in terms of tensile and impact tests. The scope of this study is Specimen printing variance of PP, 0 wt.% Kenaf/PP, 3 wt.% Kenaf/PP, 5 wt.% Kenaf/PP, and 7 wt.% Kenaf/PP. All the specimen samples will be printed using fused deposition modelling (FDM), and polypropylene with Kenaf will be used in this study. The result of average tensile strength showed 5 wt.% kenaf/PP were higher than any variance, which is 18.2507MPa. The highest average for impact strength is 3 wt.% kenaf/PP, which is 0.077J.

1. Introduction

Additive manufacturing has gained significant attention from various industries as a versatile and innovative manufacturing process, low material cost, and fast manufacturing time. These few elements have prompted engineers and construction industry researchers to investigate possible advantages of additive manufacturing technology for improved efficiency, timeliness, and user-friendliness. Highly complicated and sophisticated geometries that would be difficult or impossible to create using conventional manufacturing techniques can now be produced thanks to additive manufacturing.

According to the material's perspective, FDM can be used to print thermoplastic polymers. In addition to having a definite environmental benefit due to their recyclability, thermoplastics are the most widely used polymers, which means that a wider variety of materials are guaranteed. These include what are known as "commodities," such as polyolefins (polyethylene PE and polypropylene PP), which are followed by materials with intermediate prices, like acrylonitrile-butadiene-styrene (ABS), and engineering plastics, like polycarbonate (PC), polysulfide (PSU), or polyetherimide (PEI), as well as biodegradable materials, like polylactic acid (PLA) [1], [2].

Despite the numerous benefits of FDM, this technology has several downsides. For example, the temperature of the filament is crucial in regulating the viscosity of the molten filament. The temperature should not be too high to facilitate easy flow through the nozzle orifice, nor too low to prevent the deposed filament from providing insufficient structural support for the layers that follow [3]. Fig. 1. shows an example of FDM technology.
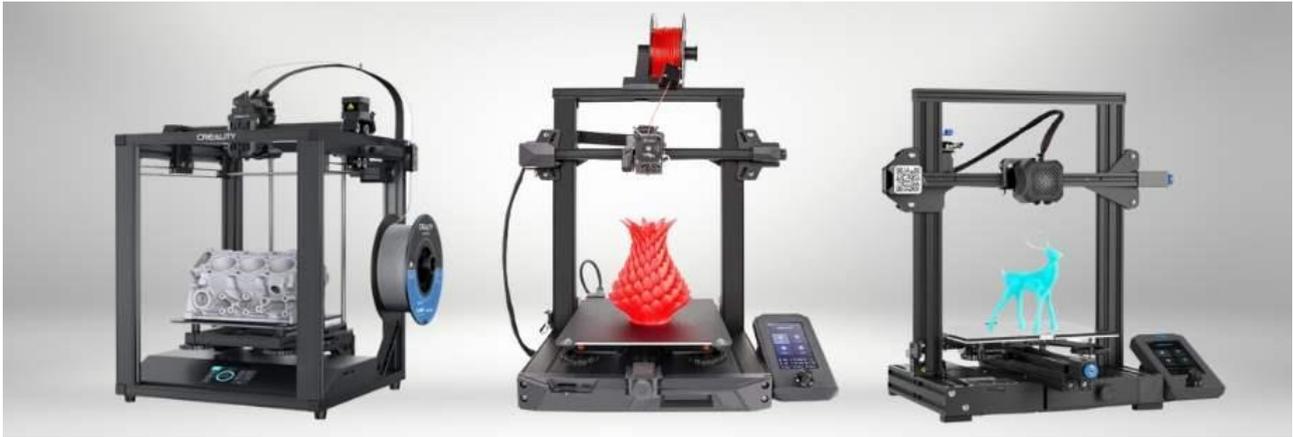
Fig. 1. *FDM technology.*

Hibiscus cannabinus L., also known as kenaf, is a non-woody plant related to cotton and okra and is a member of the Hibiscus family (Malvaceaceae). In theory, kenaf fibre is the third-world crop traditionally grown, following bamboo and wood, which are native to Asia and Africa. The kenaf plant sprouts rapidly four to five months after seeding.

According to Mazuki [4] and Davoodi [5], cellulose (56–64 Wt.%), hemicellulose (21–35 Wt.%), lignin (8–14 Wt.%), and trace amounts of extracts and ash make up the chemical composition of Kenaf fibres. Furthermore, values ranging from 60–80% cellulose, 5–20% lignin (pectin), and up to 20% moisture were reported by Nishimura et al. [6] and Morrison [7].

Moreover, it was confirmed by Ververis [8] and Tsoumis [9] that kenaf bast fibre has a composition of 55% cellulose, 5.4% ash, and 14.7% lignin, whereas core fibre has a composition of 49% cellulose, 1% and 19.2% lignin. Fig. 2. shows the sample of kenaf powder that had been used.

Fig. 2. *Kenaf Powder*

Since polypropylene (PP) is a hard, solid, and crystalline thermoplastic, it is a kind of polyolefin that is a bit more durable than polyethylene. It is a common plastic that absorbs heat efficiently and has a low density. As polypropylene (PP) has the lowest density of all commercial polymers, it was discovered in 1954 and rapidly became quite popular. PP is very resistant to chemicals and can be converted using a variety of techniques, including extrusion and injection molding. A polymer made catalytically from propylene is called polypropylene.

One of the main benefits is that PP resists high temperatures, which is especially useful for things like trays, funnels, buckets, bottles, carboys, and instrument jars that need to be cleaned and sterilized often for use in a medical setting.

According to Islam & Gupta [10], the experimental study found that the inclusion of polypropylene fibres in a fraction range of 0.1% to 0.3% decreased the amount of plastic shrinkage cracks by 50% to 99%.   According to Alhozamy & Soroushian's research [11], adding polypropylene fibres to concrete had no appreciable impact on its flexural and compressive strengths. Nonetheless, there was a noticeable increase in impact resistance and flexural toughness.

Polypropylene copolymer (PPC) is a type of polypropylene that combines propylene monomer with other monomers, typically ethylene, to create a more versatile and durable material compared to homopolymer polypropylene. Fig. 3. shows the PPC pellet that had been used.

Fig. 3. *PPC Pellet.*

2.   Material and methods

2.1. Materials and equipment

The overall study used kenaf/PPC filament to print out the composite specimen. The kenaf/PPC specimens were made from the blends of kenaf powder (63 µm) and PPC pellets, which both were already stored in Universiti Tun Hussein Onn Malaysia (Johor, Malaysia). The specimens were produced from a series of preparation stages before they could be used in a 3D Printer. These are the stages involved.

i. **Kenaf powder sieving stage** – In this stage, the powders were sieved to obtain powder particles with the lowest size, which is 63 µm. It was carried out by using a sieve shaker (Fritsch) located at a polymer lab in the Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia. This stage was to ensure that foreign and larger particles were completely removed from the kenaf powder. The finer powder particles also helped in ensuring better blending of the kenaf powder and PPC pellets at a later stage.

ii. **Kenaf powder and PPC pellets mixing and filament extrusion stage** – The Kenaf/PPC mix and filament were produced simultaneously at this stage. There were three different percentages of kenaf powder loading in the kenaf/PPC pellets, which were 3 wt. % (1.5 g:50 g), 5 wt. % (2.5 g:50 g) and 7 wt. % (3.5 g:50 g). The equipment used in this stage was located at the research centre's lab, Rapid Manufacturing & Product Development (RMPD), UTHM. The kenaf powder and PPC pellets were then fed into the hopper of a single screw extruder with a screw speed of 3 Hz, barrel zone 1, 2, 3, and die zone temperature at 130°C, 140°C, 150°C, and 160°C respectively. Kenaf/PPC filament was then extruded out and cooled within a water bath, including pulling the filament with a roller puller.

Kenaf/PPC filaments were then used as the main printing material of the 3D printer to print out the composite specimen used for tensile and impact tests.

2.2. The printing Kenaf/PPC specimen

2.2.1. 3D printing set-up

The specimen sample used in this study was additively manufactured by using a commercial 3D printer (Creality Ender 3 pro) in the Rapid Manufacturing Laboratory, Universiti Tun Hussein Onn Malaysia. This 3D printer uses the technology of fused deposition modelling, in which the main printing material is in the form of a filament.

The 3D model of tensile strength and Izod impact specimens were created using SolidWorks 2022/2023 and saved as. stl file. The file was then imported into 3D Print software (UltiMaker Cura) for further slicing and printing set-up, and then saved as. gcode file, which was compatible with the 3D Printer.

All two types of test specimens (tensile and impact) were printed out into a solid sample (100% infill density), flat onto the build plate, at a constant printing speed of 50 mm/s and travel speed of 80 mm/s. The nozzle and bed temperature were kept constant at 220 °C and 70 °C respectively. Additional equipment, such as polypropylene-based plates or glue sticks, is compulsory to ensure the adhesion quality of the specimen during the printing process.

2.2.2. Tensile test specimen printing

The 3D model of the fatigue specimen was created based on the dimensions recorded in ASTM D638 Type V, which is in the form of a dog bone as shown in Fig. 4
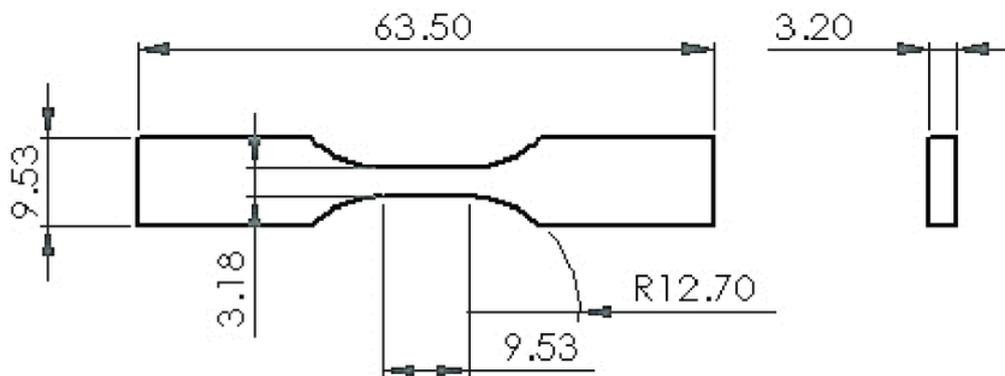

Fig 4. *Dimension of tensile specimen in mm.*

2.2.3. Impact test specimen printing

The 3D model for Izod impact test was created based on the dimensions and shape specified in ASTM D256 as shown in Fig. 5. The shape of the specimen was rectangular with a small notch at the centre of the specimen. The sizes of the Izod specimens were typically 63.5 × 6 × 3.2 mm (length x width x thickness).
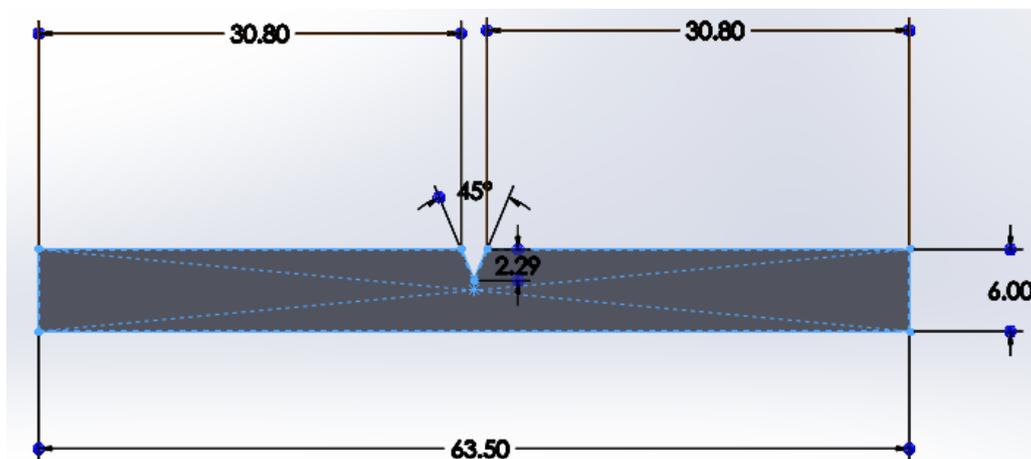

Fig. 5. *Dimensions for notched specimens Izod Impact test.*

2.2.4. Post-process printing specimen

The number of specimens that have been printed for each variation and testing was three pieces as shown in Fig. 6.
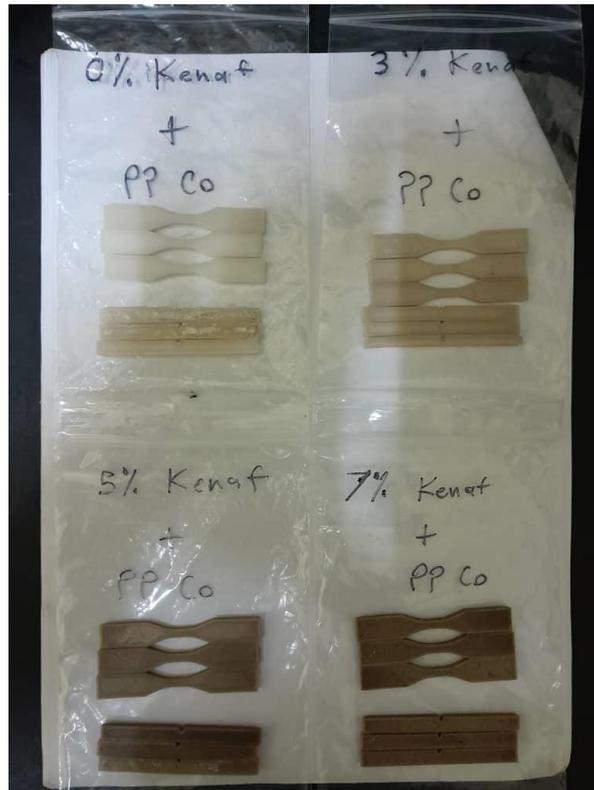

Fig. 6. *3D Printed Kenaf/PPC composites at varying percentage fiber loading for tensile and impact testing.*

2.3. Testing procedures

2.3.1. Tensile test procedures

The tensile test was carried out using a Universal Testing Machine in the Polymer Laboratory, Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia. All three specimens were prepared for each level of % ultimate tensile strength (UTS) for all variations. The testing procedure for the fatigue tests used in this study was based on ASTM D638 itself, where the specimens were placed between the grips or fixtures of the UTM. The test was conducted at tensile rates ranging from 15 mm/min for all the specimen variations.

2.3.2. Impact test procedures

This test was carried out at the Polymer Laboratory, Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia. The procedure of this test was conducted based on ASTM D256 itself. Three notched specimens of each variation were prepared, with 12 pieces as shown in Fig. 6. In a Charpy impact test, a pendulum hammer strikes and destroys a material specimen. During this process, the specimen absorbs part of the impact energy. This impact energy W, as determined in the Charpy test, is measured in joules. The absorbed energy is, therefore, influenced by the notched impact strength of a material.

3. Results and discussion

3.1 Tensile test analysis

There were twelve samples with four variations in this test. Every variation has three samples in total. The initial version, which contained solely neat polypropylene copolymer (PPC), served as the study's standard. The remaining three variations were then made by combining refined kenaf powder with varying weight percentages: 3 wt. % Kenaf/PPC, 5 wt. % Kenaf/PPC, and 7 wt. % Kenaf/PPC. In this test, two important tensile characteristics which maximum stress and percentage strain are considered. Table 1 shows the parameters for each variation of the 3D Printed Kenaf/PPC tensile test in terms of maximum stress, percentage strain, and young modulus.

Table 1 *Tensile test result of 3D printed Kenaf/PPC.*

Variation	Sample number	Maximum stress, MPa	Percentage strain, %	Young Modulus, MPa
PPC	0-1	14.7411	19.3028	76.36
	0-2	20.2027	30.0889	67.13
	0-3	18.1223	29.8917	60.64
3 wt. % Kenaf/PPC	3-1	17.3272	22.1278	78.32
	3-2	13.4266	20.8778	64.32
	3-3	14.8841	21.0028	70.88
5 wt. % Kenaf/PPC	5-1	17.3147	22.0278	78.62
	5-2	18.7016	21.6889	86.23
	5-3	18.7359	21.5222	87.03
7 wt. % Kenaf/PPC	7-1	14.5374	21.9333	66.27
	7-2	13.1793	19.8278	66.47
	7-3	17.0100	25.5944	66.47

The graph maximum stress versus sample number in Fig. 7. shows that the maximum stress for neat PPC sample number 2 was the highest value, 20.2027 MPa, while the lowest value was 7 wt. % Kenaf/PPC sample number 2, which is 13.1793 MPa. The 5 wt. % Kenaf/PPC was the only variation in which maximum stress slightly increased from sample 1 until sample 3.
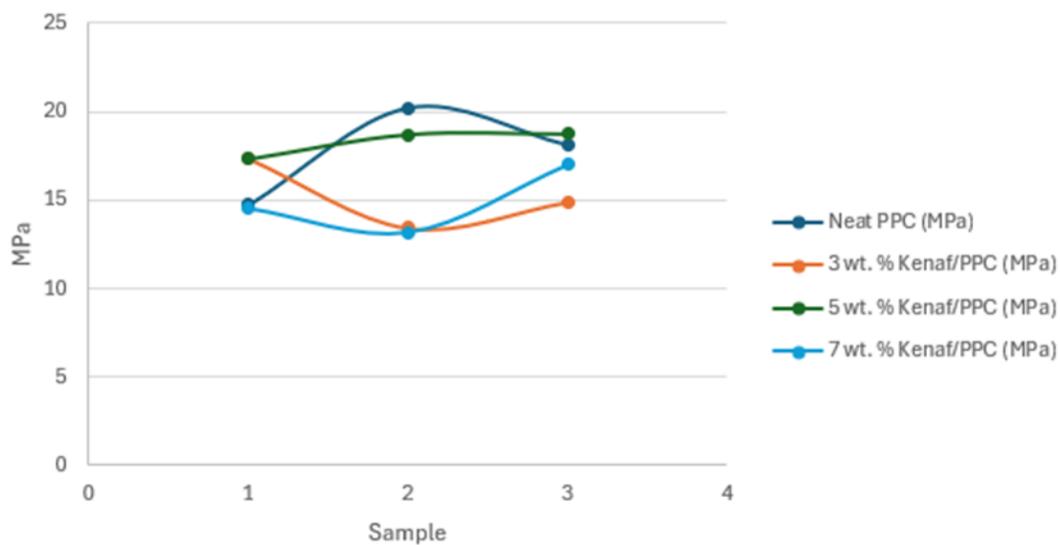
Fig. 7. *Maximum stress – sample number graph*

Graph maximum stress versus sample number in fig. 8. shows that the maximum stress for neat PPC sample number 2 was the highest value which 30.0889 % while for the lowest value was neat PPC sample number 1 which 19.3028 %. The 5 wt. % Kenaf/PPC was the only variation that maximum stress had slightly decreased starting from sample 1 until sample 3.
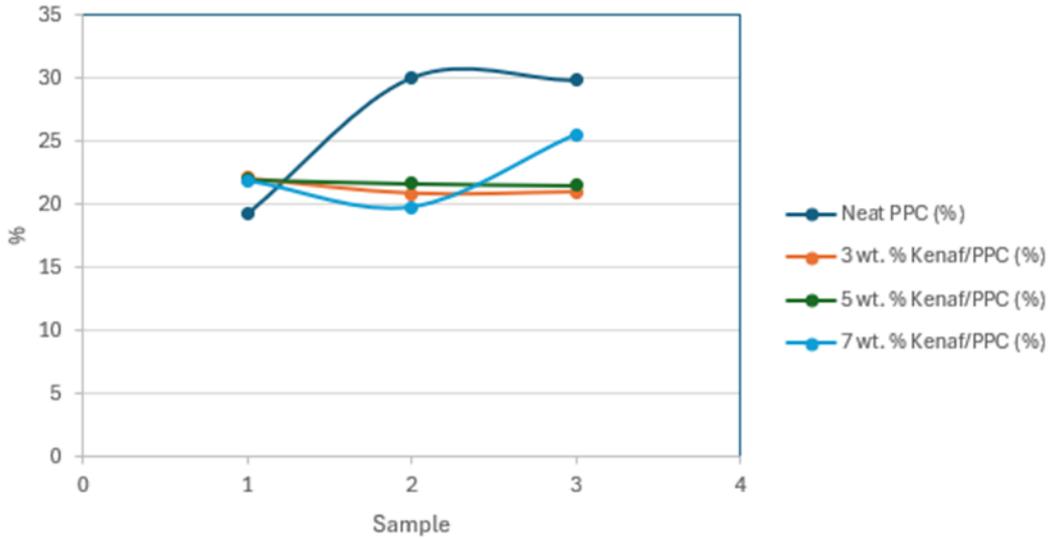
Fig. 8. *Percentage strain – sample number graph*

3.1.1. Average tensile strength analysis

Fig. 9. shows the average tensile strength of Kenaf/PPC composites produced by using FDM 3D printing method with 4 variations each of 3 sample. The highest value of average tensile strength was recorded at 18.2507 MPa which is 5 wt. % Kenaf/PPC. Meanwhile the lowest value of average tensile strength is 14.9089 MPa which is 7 wt. % Kenaf/PPC. For neat PPC, the value recorded for average tensile strength is 17.6887 MPa. Hence, the average tensile strength of 3 wt. % Kenaf/PPC is 15.2126 MPa.
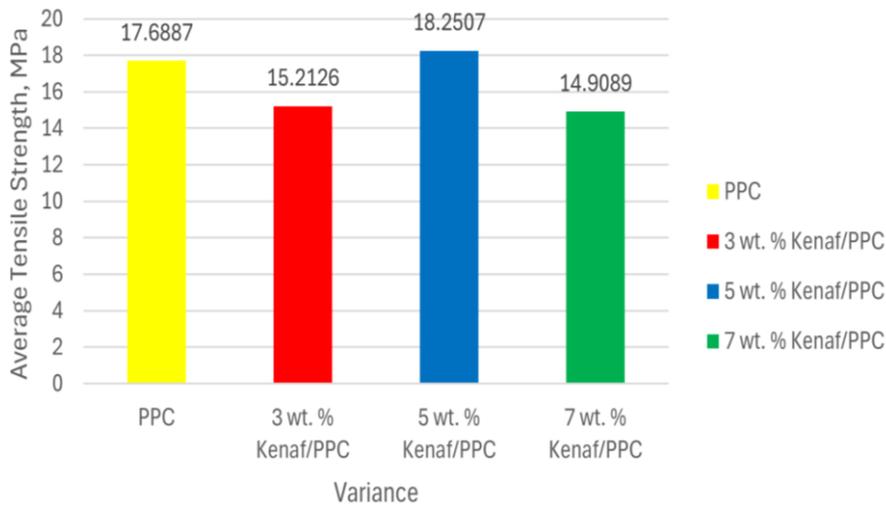

Fig. 9. *Average tensile strength of Kenaf/PPC.*

3.1.2. Average percentage strain analysis

Fig. 10. shows the average percentage strain of Kenaf/PPC composites produced by using FDM 3D printing method with 4 variations each of 3 sample. The highest value of average percentage strain was recorded at 26.4278% which is neat PPC. Meanwhile the lowest value of average percentage strain is 21.3361% which is 3 wt. % Kenaf/PPC. For 5 wt. % Kenaf/PPC, the value recorded for average percentage strain is 21.7463%. Hence, the average percentage strain of 7 wt. % Kenaf/PPC is 22.4518%.
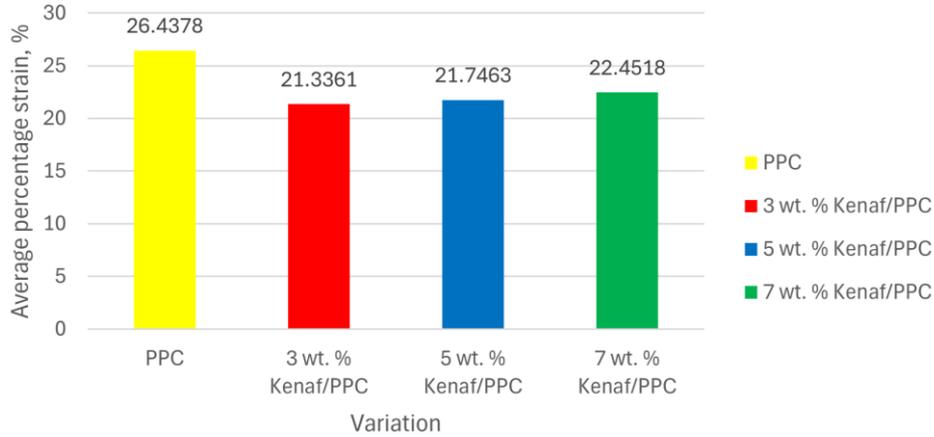
Fig. 10. *Average percentage strain of Kenaf/PPC.*

3.2. Impact strength test analysis

Table 2 shows the parameters for each 3D-printed Kenaf/PPC impact strength test variation.

Table 2 *Impact strength test result of 3D printed Kenaf/PPC.*

Variation	Sample number	Impact strength, Joule
PPC	0-1	0.08
	0-2	0.08
	0-3	0.06
3 wt. % Kenaf/PPC	3-1	0.08
	3-2	0.07
	3-3	0.08
5 wt. % Kenaf/PPC	5-1	0.06
	5-2	0.06
	5-3	0.08
7 wt. % Kenaf/PPC	7-1	0.06
	7-2	0.06
	7-3	0.05

3.2.1. Average impact strength test analysis

Fig. 11. shows the average impact strength of Kenaf/PPC composites produced by using FDM 3D printing method with 4 variations each of 3 sample. The highest value of average impact strength was recorded at 0.077 Joule which is 3 wt. % Kenaf/PPC. Meanwhile the lowest value of average impact strength is 0.057 Joule which is 7 wt. % Kenaf/PPC. For neat PPC, the value recorded for average impact strength is 0.073 Joule. Hence, the average tensile strength of 5 wt. % Kenaf/PPC is 0.067 Joule.
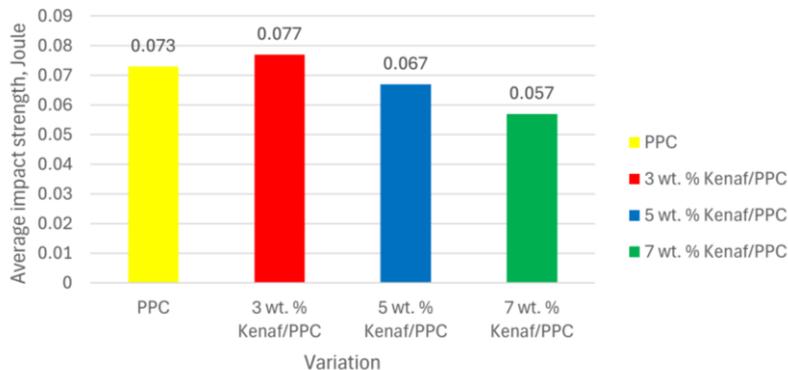

Fig. 11. *Average impact strength of Kenaf/PPC.*

4. Conclusion

The major findings from the present study on the tensile and impact strength applicable mechanical properties can be summarized below:

- Kenaf fiber has been proven that polypropylene copolymer reinforcement could strengthen and weaken the specimen.
- The 5 wt. % Kenaf/PPC could withstand bending better than any variation.
- The elasticity of polypropylene copolymer could secure without any reinforcement.
- The 3 wt. % Kenaf/PPC had the stronger impact strength since PPC has high impact resistance.

Acknowledgement

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

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