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Investigation of tensile and flexural properties of kenaf fiber-reinforced acrylonitrile butadiene styrene composites fabricated by fused deposition modeling

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Abstract

Employment of natural fiber for the filament of fused deposition modeling (FDM) can be found in numerous studies from different areas. However, the presence of fiber such as kenaf in polymer filament could cause mechanical properties degradation with regard to the fiber loading owing to low compatibility between natural fiber and polymer matrix. Therefore, this study aims to study the mechanical properties of three-dimensional (3D)-printed structures of composites specimens with varying volume percentages of kenaf fiber. From the tensile and flexural testings, the findings revealed decrements in the tensile strength and modulus of kenaf fiber-reinforced ABS (KRABS) composites from 0 to 5% contents of kenaf fiber which were 23.20 to 11.48 MPa and 328.17 to 184.48 MPa, respectively. The raising amount of kenaf fiber at 5 to 10% raised the tensile strength and modulus from 11.48 to 18.59 MPa and 184.48 to 275.58 MPa, respectively. Flexural strength and modulus of KRABS composites were decreased at to 5% from 40.56 to 26.48 MPa and 113.05 to 60 MPa, respectively. With further kenaf fiber addition from 5 to 10%, the flexural strength and modulus were increased from 26.48 to 32.64 MPa and 60 to 88.46 MPa, respectively. These results were supported by the finding from the morphological analysis, where the presence of porosity and fiber pull out implied the poor interfacial bonding between kenaf fiber and ABS matrix. This study has successfully demonstrated the tensile and flexural performances of different volume percentages of KRABS composites filament for FDM through experimental research.

Keywords: Kenaf fiber composite, Fused deposition modeling, Tensile properties, Flexural properties, ABS composite

Introduction

Fused deposition modeling (FDM) is an additive manufacturing (AM) technology using long and continuous solid filament as a feedstock. This technology is quite popular, particularly in engineering applications in fabricating engineering components, conceptual models, and prototypes. The principle of material extrusion applied in FDM technology

is worked by melting or softening materials to produce layer upon layer of materials and produces three-dimensional-printed objects. The advantages of FDM such as simple fabrication process [15], fabricating geometrically complex shapes [17], less expensive machine [25], and cost-effectiveness [20] to produce 3D objects with good resolution have speed up the development of FDM technology nowadays.

FDM is a widely used feedstock material in thermoplastic polymers, e.g., ABS, polycarbonate (PC), polylactic acid (PLA), polyethylene (PE), and polypropylene (PP), [20, 40]. Grujovic et al. [8] stated that the FDM has the possibility and ability to use a custom-made composites filament. Parandoush and Lin [26] mentioned that, presently, researchers tend to develop filament with short fiber additive. However, there is still a deficiency considering the feedstock for FDM [20]. The fiber-reinforced polymer filament of FDM would cause thermal degradation and degrade the tensile characteristics of the 3D-printed parts. During the growing of extensive research on materials for FDM, natural fiber-polymer composites (NFRPC) have gained the attention from researchers towards environmentally friendly materials. These types of filaments also had been found in various applications of FDM, such as biomedical [27], automotive [6], consumer goods [33], and textile and fashion industry [5].

Nowadays, the environmentally friendly natural fiber composites are well-developed and diverse types of natural fibers have been studied for composites development, including hemp, kenaf, banana, flax, and rubberwood [12, 23]. Natural fiber has tremendous potential in industry and contributes to safe handling, cost reduction, and biodegradability [1]. Besides, it has become a substitute to synthetic fibers and is broadly commercialized due to its lightweight feature and safe environmental aspects [1]. However, the addition of natural fillers in polymer gives disadvantages such as low chemical compatibility between fiber and matrix, the tendency to uptake moisture, and low bulk density [21]. The incompatibility between hydrophobic and hydrophilic material leads to decreasing mechanical performance [34]. Kenaf fiber is one of the common natural fibers found in many composite applications where it contains higher cellulose content and has good mechanical properties [28]. Ibrahim et al. [11] revealed that the tensile strength decreased at 30 and 40% of kenaf fiber loadings. They speculated that the insufficient amount of matrix, high fiber-to-fiber interaction, and agglomeration of fibers in matrix cause the tensile strength to decrease. Kariz et al. [13] studied the addition of wood particles with PLA for 3D printing and found that the value of tensile strength declined as the content of wood particles increased. Filament with the addition of wood surface was more porous, rougher, and visible wood particles clusters were observed. Wang et al. [38] observed that the 5% of fiber content of the composite filament FDM has improved surface quality, mechanical properties, and reduced porosity on the printed parts. There is a study that discussed the factors that significantly influenced the mechanical properties of the natural fiber-reinforced composites developed through FDM. As mentioned by Mazzanti, Malagutti, and Mollica [18], the mechanical performance of the 3D-printed parts were highly dependent on the printing process parameters, e.g., printing speed, printing temperature, infill density, and raster angle. Moradi, Aminzadeh, Rahmatabadi, and Hakimi [22] found a direct relationship between mechanical properties and infill patterns. Therefore, they suggested that the engineer had carefully selected the appropriate infill patterns to ensure the 3D-printed part could have sufficient strength regarding

their applications. These printing process parameters are also highly dependent on the thermal and rheological characteristics of the filament. Information on the melting temperature, glass transition temperature, thermal degradation, shear viscosity, and melt flow index are required for the operator to set up an appropriate printing process parameter to fabricate the good quality and mechanical properties of the 3D-printed parts. Kontarova et al. [14] suggested adding plasticizer during compounding of filler and polymer matrix to enhance the mechanical performance of composites filament for FDM. While Haryati et al. [10] suggested treating the kenaf fiber with the 1% concentration of silane to obtain good mechanical characteristics of the 3D-printed kenaf/PLA composite. Moreover, a study was conducted by past researchers on the hybridization of kenaf composite with glass fiber and the results showed comparable mechanical properties of the composite with pure synthetic fiber composites [29]. Thus, an investigation of mechanical properties of kenaf fiber-reinforced ABS composites is required to identify the capability of composites filament for applications of FDM.

In this work, different volume percentages of kenaf fiber-reinforced acrylonitrile butadiene styrene (ABS) polymer composites were developed using a twin-screw extruder to obtain composites filament. The mechanical properties of the composites were analyzed, e.g., tensile and flexural properties. Then, a morphological test was conducted to detect the fracture surface of composites after tensile and flexural testings.

Methods

Figure 1 indicates the process of sample preparation and testing for kenaf fiber-reinforced ABS composites.

Materials

Kenaf (*Hibiscus cannabinus*) fibers in the form of powder were supplied by ZHF Industries Sdn. Bhd. (Malaysia). An average length of 120 μm of kenaf fiber was used in this study. The 100% pure ABS pellets were supplied by Macrocom (M) Sdn. Bhd. (Malaysia).

Sample preparation

The mixture of kenaf fiber and ABS pellets was compounded and extruded using an HTGD-20 twin-screw extruder machine with the diameter of the filament of 1.75 mm. The temperature setting parameters of twin-screw extruder extrusion in producing filament are presented in Table 1. The varying volume percentages of kenaf fiber were used, which were 0, 2.5, 5, 7.5, and 10% of kenaf fiber-reinforced ABS composites.

For the 3D printing process, a 3D printer manufactured by FlashForge Corporation model Creator Pro 3D Printer (as in Fig. 1) was used to fabricate 3D-printed sample. The sketches of tensile and flexural testing samples were drawn using Catia Software. Then, a slicing software was used to convert the file format of the drawing, which was Flash Print software developed by FlashForge Cooperation, and the desired parameters of filament processing were set at the software. The parameter of the 3D printer used for the fabrication of the sample is presented in Table 2.

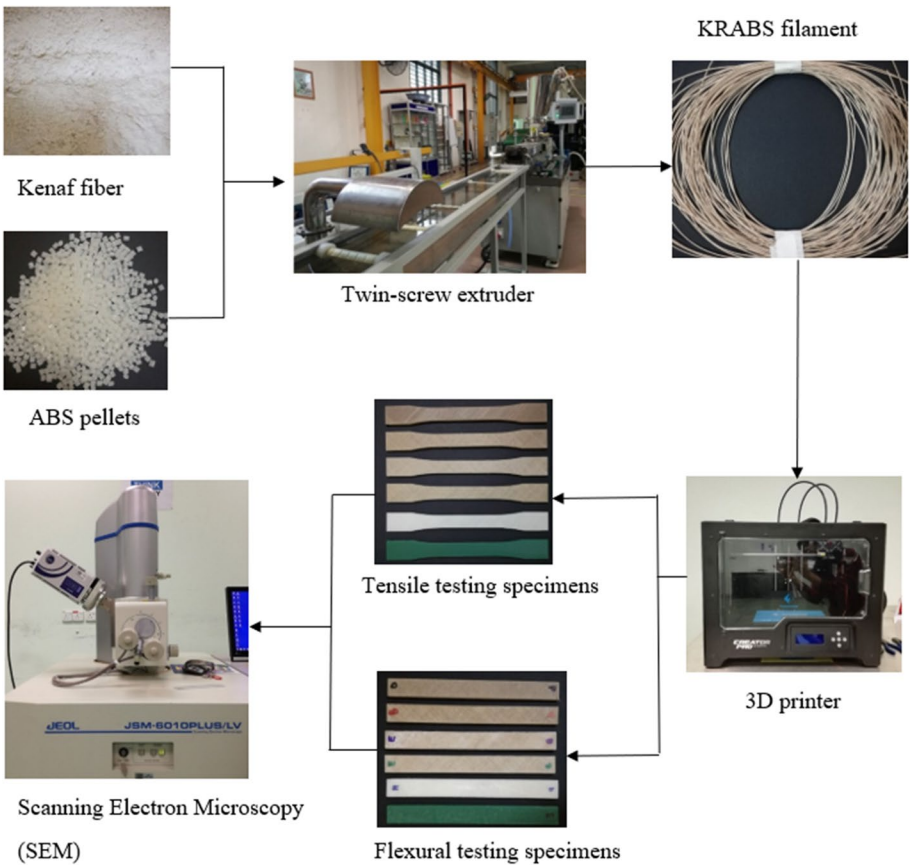

Fig. 1 Fabrication and testing process

Tensile test

The tensile test measured the material while it was being pulled by force. This test was carried out to determine the tensile strength of the 3D-printed samples. The sample for the tensile test was prepared in dumbbell-shaped type 1. ASTM D638 standard was used in the tensile testing [2]. The test was conducted via Shimadzu Universal Testing Machine with a 20-kN load test and a constant crosshead speed of 5 mm/min. The values of percentage of elongation and tensile stress were attained from the stress-strain curve. The ultimate tensile strength (σ_t), maximum strain (ε_t), and modulus (E_t) were calculated by using Eqs. 1, 2, and 3, respectively.

$$\sigma_t = \frac{P}{A} \tag{1}$$

Where σ_t (MPa) is the ultimate strength, P (N) is a load at the peak of the stress-strain curve, and A (mm^2) is the cross-sectional area of the specimen.

$$\varepsilon_t = \frac{l}{l_o} \tag{2}$$

Where ε_t is the maximum tensile strain, l (mm) is the maximum elongation, and l_o is the strain gauge length, 50 mm as referred to as ASTM D638.

Table 1 Temperature setting of twin-screw extruder machine

Temperature zones	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Die
Measured value (°C)	160.2	200.8	221.0	231.3	230.6	230.1	240.5	241.4	253.2	252.4
Set value (°C)	160.0	200.0	220.0	230.0	230.0	230.0	240.0	240.0	250.0	260.0

Table 2 Parameters of 3D printer

Layer height	Layer height	0.18 mm
	First layer height	0.27 mm
Shells	Perimeter shells	2
	Top solid layers	3
	Bottom solid layers	3
Infill	Fill density	100%
	Fill pattern	Line
	Combine infill	Every 2 layers
Speed	Print speed	40 mm/s
	Travel speed	80 mm/s
Temperature	Left extruder	230 °C
	Platform	105 °C

$$E_{\mathrm{t}} = \frac{\sigma_t}{\varepsilon_t} \tag{3}$$

where E_{t} (MPa) is the tensile modulus, σ_{t} (MPa) is the ultimate strength, and ε_{t} is the maximum tensile strain.

Flexural test

The flexural test was carried out to determine the flexural strength and modulus of the 3D-printed sample. The sample for flexural testing was prepared in a shape of rectangular shape.

ASTM D790 standard was used for flexural testing [3]. The flexural test was conducted using Shimadzu Universal Testing Machine with a 20-kN load test and a constant crosshead speed of 5 mm/min. Then, the span-to-depth ratio for this test was set to 1:16. The sample was tested until a maximum strain of 5% was reached or until rupture occurred on the skin surface of the sample. The ultimate flexural strength (σ_{f}), maximum flexural strain (ε_{f}), and flexural modulus (E_{f}) were computed using Eqs. 4, 5, and 6, respectively.

$$\sigma_{\mathrm{f}} = \frac{3PL}{2bd^2} \tag{4}$$

Where σ_{f} (MPa) is ultimate flexural strength, P (N) is the load at the peak of the stress-strain curve, L (mm) is the support span, b (mm) is the width of sample, and d (mm) is the thickness of the sample.

$$\varepsilon_{\mathrm{f}} = \frac{6Dd}{L^2} \tag{5}$$

Where ε_{f} is maximum flexural strain, D (mm) is the maximum deflection at mid-span, d (mm) is the thickness of sample, and L (mm) is the support span.

$$\mathrm{E_f} = \frac{L^3 m}{4bd^3} \tag{6}$$

Where E_f (MPa) is the flexural modulus, L (mm) is the support span, m is the gradient of the stress-strain curve, b (mm) is the width of sample, and d (mm) is the thickness of the sample.

Morphology analysis

Scanning electron microscopy (SEM) was employed to study the fracture that occurred. Prior to testing, all samples were platinum-coated using an Auto Fine Coater model JEOL JEC-3000FC and left for 60 s in the sputter coater to confirm all the intended areas were coated with platinum. The scanning was performed using SEM model JEOL JSM-6010PLUS/LV. The machine scanned a focused electron beam over a surface to create an image. The electrons present in the beam cooperated with the samples to generate signals to gain information regarding the morphology. Samples were taken from fracture samples of tensile test and cross-section samples from the flexural test for each percentage of kenaf fiber-einforced polymer composites. Samples were examined and conducted with two different magnifications, which were SEI 5 kV WD 10 mm SS 50 × 30 500 µm and 5 kV WD 10 mm SS 50 × 200 100 µm. Samples were placed onto the sample holder and focused onto the fracture surface to determine matrix cracking, fiber-matrix adhesion, fiber pull-out, and delamination.

Results and discussion

Tensile test

A tensile test was done for different loadings of kenaf fiber–ABS composites, and Fig. 2 represents the load versus displacement curves for all samples. The decreasing curves trend was observed from 0% kenaf–ABS composites to 10% kenaf–ABS composites.

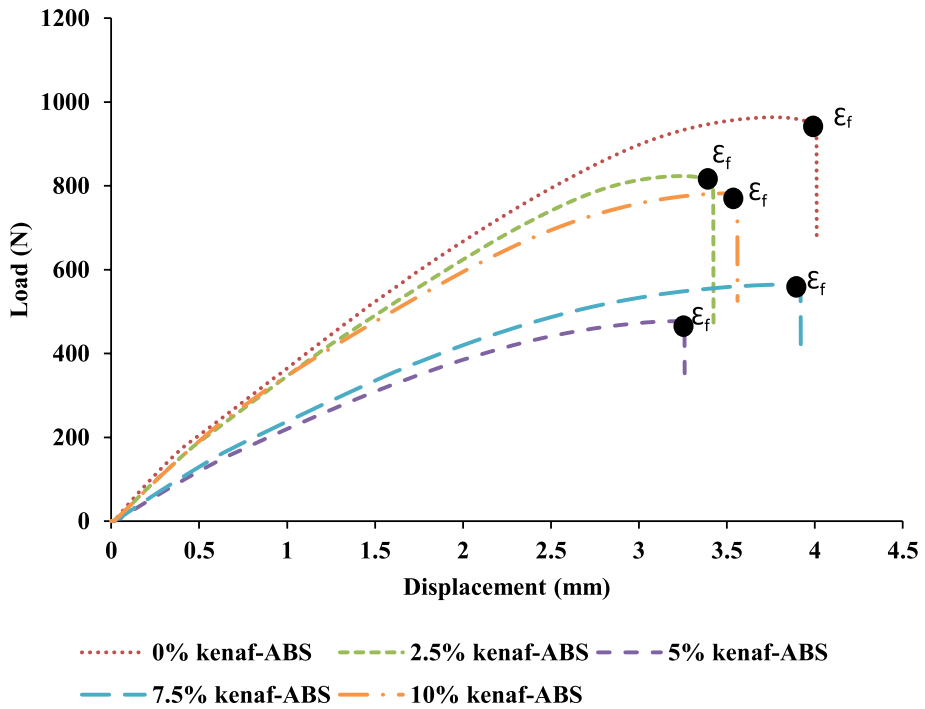

Fig. 2 Load versus displacement

As displayed in Fig. 2, the composite consisting of fibers and ABS as a matrix material exhibited the uniaxial stress-strain response. Initially, the fibers and matrix deformed elastically and exhibited a linear curve at the beginning. The matrix continued to plastically deform while the fibers continued to stretch elastically, until very nearly linear. The composite failure began as the fibers started to fracture, which corresponded to the strain of approximately at ε_f. The failure of the composite was not catastrophic because the fibers were not fractured at the same time, and some of the matrix molecules were still intact and continued to deform plastically.

The average maximum load for 0% kenaf fiber was 965.20 N, followed by 2.5% and 5% kenaf–ABS composite gave 893.65 N and 477.49 N, respectively. However, the average maximum load increased at 7.5% and 10% of kenaf–ABS composites, which were 558.45 N and 773.30 N, respectively. The displacement of kenaf–ABS composites was reduced from 0 to 10%. 0% kenaf–ABS composites gave the highest displacement of 4.01 mm, whereas 5% kenaf–ABS composites gave the lowest displacement of 3.26 mm. This indicated that rising the content of kenaf fiber in composites did not affect the displacement, as it was directly perpendicular to the load that caused the composites to fail.

Figure 3 indicates the tensile strength of all samples. The graph shows that the increased content of kenaf fiber from 0 to 5%, the tensile strength was firstly decreased, with a sharp decline of tensile strength occurring from 2.5 to 5% of kenaf fiber contents from 21.48 to 11.48 MPa, respectively. The tensile strength of 0 and 2.5% kenaf fiber composites were 23.20 and 21.48 MPa, respectively, with a 7.41% difference. The largest reduction of tensile strength occurred from 2.5 to 5% of kenaf fiber contents with a 46.55% difference. Then, the tensile strength increased from 5 to 7.5 to 10% with increasing kenaf fiber contents from 11.48, 13.42, and 18.59 MPa, respectively. The difference in tensile strength between 5 and 7.5% of kenaf fiber composites was 16.9%. Comparable results were discovered by Torrado et al. [35] in their results that the lowest tensile strength was at 5% of jute fiber with 8.63 MPa, since the fiber possesses a great voids number in the cross-section. Furthermore, Salleh et al. [31] obtained similar results where the addition of kenaf fiber with high-density PE (HDPE) composites reduced the tensile strength of composites. The increasing content of kenaf fiber led to poor

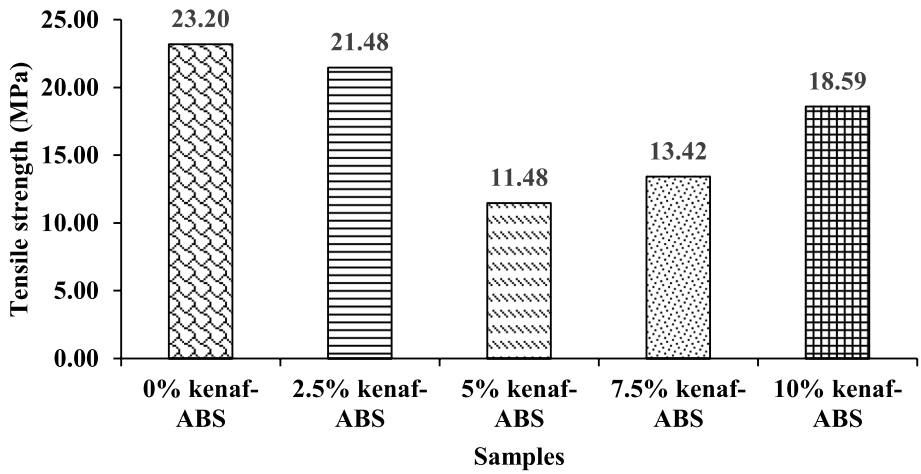

Fig. 3 Tensile strength for kenaf–ABS composites

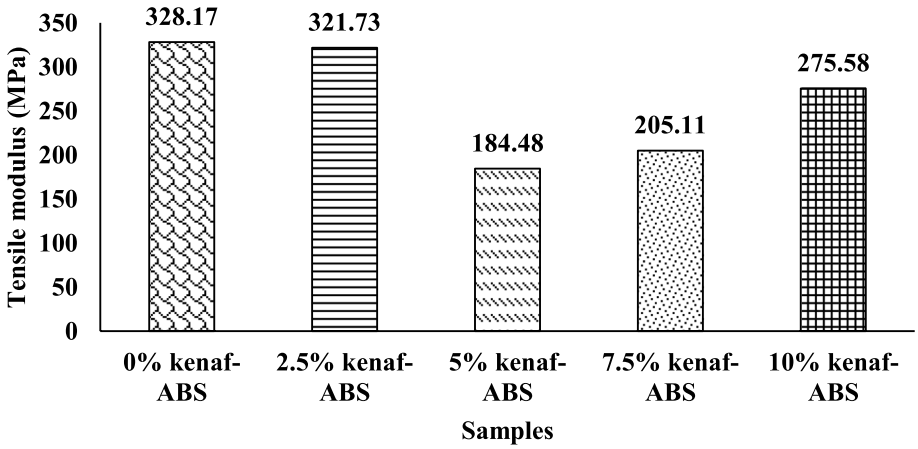

Fig. 4 Tensile modulus for kenaf–ABS composites

Table 3 Tensile strength and modulus for all samples

Sample	Tensile strength (MPa)	Tensile modulus (MPa)
0% kenaf–ABS	23.20 ± 2.84	328.17 ± 67.59
2.5% kenaf–ABS	21.48 ± 3.00	321.73 ± 16.50
5% kenaf–ABS	11.48 ± 0.53	184.48 ± 30.40
7.5% kenaf–ABS	13.42 ± 0.84	205.11 ± 27.73
10% kenaf–ABS	18.59 ± 2.88	275.58 ± 29.89

fiber-matrix adhesion, and debonding occurred during tensile deformation. Debonding between fiber and matrix led to the void formation, causing cracks to propagate easily through regions containing the voids. In addition, the uneven dispersion of kenaf fiber into composites also influenced the tensile strength of composites [24].

The tensile modulus for different loading of kenaf fiber content are presented in Fig. 4. The value of tensile modulus decreased with the rising kenaf fiber content. The values of tensile modulus decreased from 0 to 2.5% were 328.17 and 321.73 MPa respectively. Then, there was a sudden decrease from 2.5 to 5% of kenaf fiber composites, where the value of tensile modulus for 5% was 184.48 MPa. The difference in tensile modulus between 2.5 and 5% of kenaf fiber content was 42.66%. Continued increment in the content of kenaf fiber from 5 to 10% increased the tensile modulus, where the tensile modulus of 7.5 and 10% of kenaf fiber contents were 205.11 and 275.58 MPa, respectively.

Mohammad and Arsad [19] concluded that kenaf fiber is an ideal reinforcement for high-performance polymer composites. However, the high content of kenaf attributed to the degradation of composites as kenaf fiber was prone to degrade during sample processing. Thus, it affected the mechanical behavior of composites and lowered the tensile modulus. Table 3 presents the tensile strength and modulus summary for different kenaf loadings in the kenaf fiber-reinforced ABS composites.

Figure 5a shows the micrograph of 0% kenaf–ABS that was closely packed too, but there were little gaps between the beads of matrix-matrix chains. A good chemical bonding at the interface between the beads of polymer is required to obtain higher

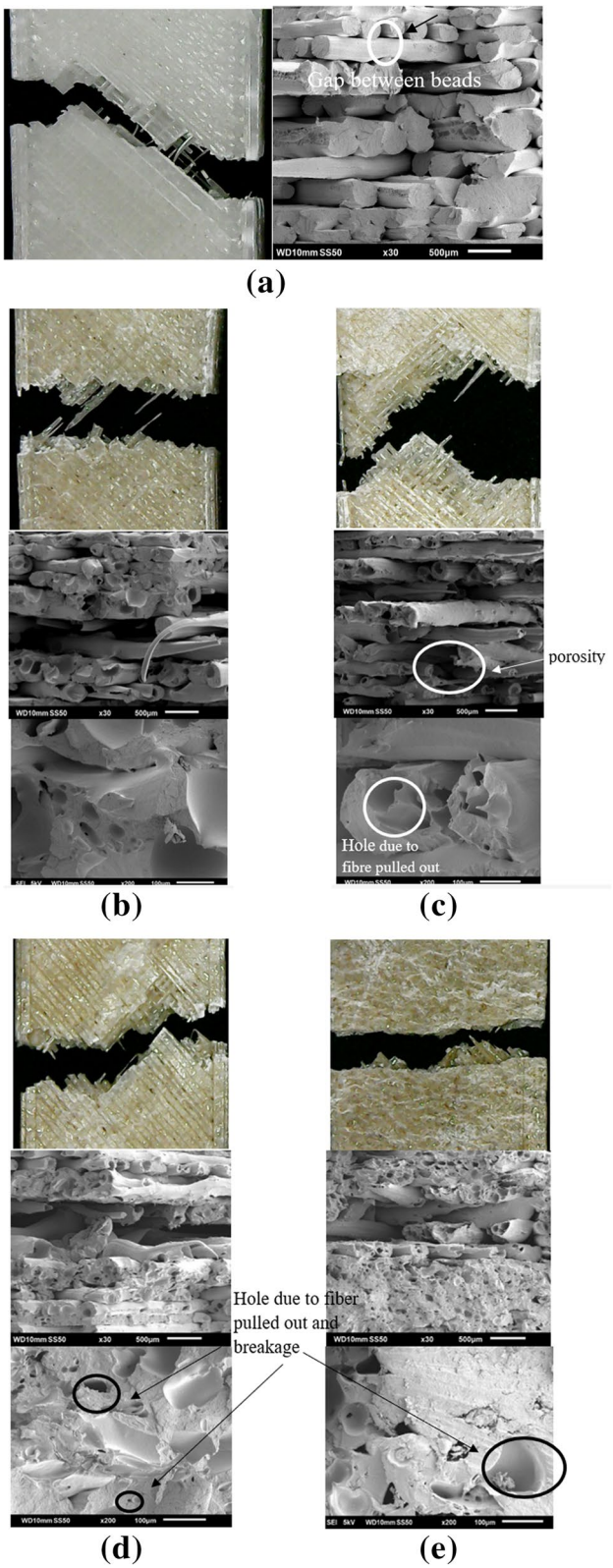

Fig. 5 Visual picture and SEM for tensile test (**a**) 0% kenaf–ABS (**b**) 2.5% kenaf–ABS (**c**) 5% kenaf–ABS. Visual picture and SEM for tensile test (**d**) 7.5% kenaf–ABS (**e**) 10% kenaf–ABS

mechanical properties [4]. Besides, both fractured samples did not have porosity; therefore, it led to higher mechanical properties compared to samples with the addition of kenaf fiber. As supported by Singh et al. [32], the mechanical properties of a 3D-printed sample with no porosity was higher compared to the printed samples with the presence of porosity, producing lower mechanical properties.

Figure 5b–e shows that the micrograph obtained from SEM of 2.5, 5, 7.5, and 10% of kenaf–ABS composites, respectively. It was found that, as the content of kenaf fiber increased, the distribution of porosity increased. Figure 5b indicates 2.5% kenaf fiber content with the smallest and least porosity. The largest porosity occurred at 5% kenaf fiber–ABS content, yielding the weakest specimen, with the lowest tensile strength. The second-largest porosity was found at 7.5% kenaf–ABS composites at the fracture interface of the specimen. The 7.5% kenaf fiber content also possessed a relatively lower tensile strength. Then, Fig. 5e shows that the adhesion between printed 10% kenaf–ABS composites were closely packed compared to other fiber content samples, varied with a high value of tensile strength for 10% kenaf–ABS composite. Furthermore, Fig. 5b–e illustrates that many kenaf fibers were pull-out were observed from the matrix and broke, particularly at 5 and 7.5% of kenaf fiber–ABS content, denoting the inadequate interfacial bonding between kenaf fiber and thermoplastic matrix to provide suitable reinforcement in composites [4]. Similarly, Zhang et al. [42] found as the content of fibers in ABS matrix increased, the porosity were also increased. As shown in Fig. 5, porosity occurred when the addition of kenaf increased because the fibers were being pulled out, producing holes within the polymer matrix. Hence, the poor compactness of the composite structure was due to poor interfacial bonding between the fiber and polymer molecules, and stress was not well transferred between the fiber and polymer molecules. Consequently, the tensile strength of the composite was degraded.

Apart from that, the extrusion and printing processes affected the mechanical performance of printed parts [4, 7, 39]. Temperature and viscosity play a crucial role as the material flowed through the nozzle, and the interface between beads formed on the platform was included [36, 37]. Filament with higher content of fiber had difficulties flowing evenly through the nozzle, resulting in poorly printed parts that led to uneven filled materials. The printing speed affected the deposited material onto the platform; thus, it influenced the contact area layer by layer of material [13].

Flexural test

A flexural test was carried out for different volume percentages of kenaf fiber–ABS composites, and Fig. 6 presents the load against displacement curves for all samples. The decreasing curves trend from 0 to 10% kenaf–ABS composites was observed due to the increasing content of kenaf fiber in composites. As displayed in Fig. 6, the curve is divided into three regions which include the linear region, small load drop region, and final failure region. The small load drop region was obviously found in 0, 7.5, and 10% kenaf fiber–ABS composite, where it was identified before the peak stress due to delamination of the fibers stitching or inherent manufacturing defects.

The average maximum load for 0% kenaf is 54.09 N, followed by 2.5 and 5% kenaf–ABS composites that gave 44.04 and 35.32 N, respectively. However, the average maximum load increased at 7.5 and 10% of kenaf–ABS composites, which were 36.01 and

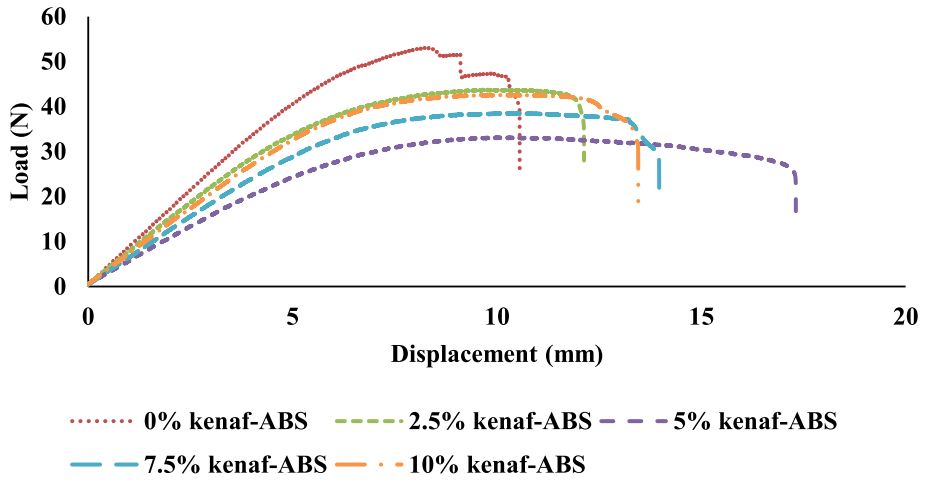

Fig. 6 Load versus displacement for flexural testing

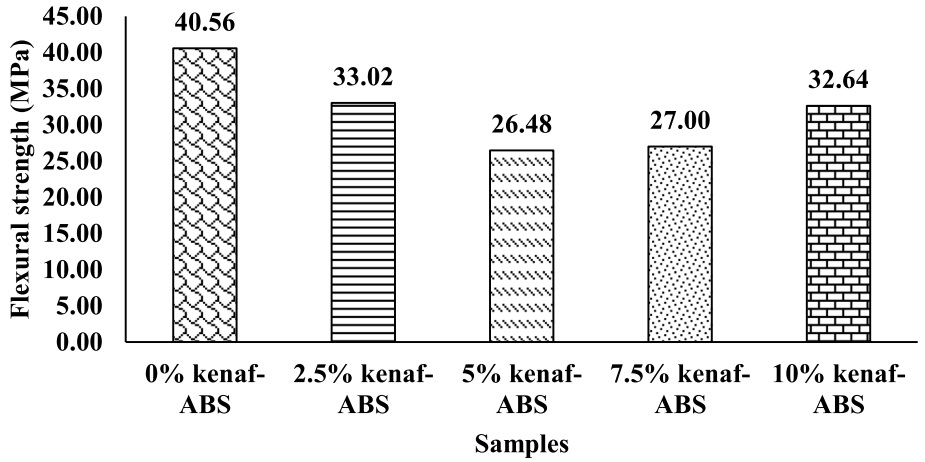

Fig. 7 Flexural strength for kenaf–ABS composites

43.54 N, respectively. The displacement of 5% kenaf–ABS composites was the longest. The displacement of kenaf ABS composites was increased from 0 to 10% kenaf–ABS. There was an enormous difference between displacements of composite; 10% kena–ABS composites gave the highest displacement, whereas 0% kenaf–ABS composites demonstrated the lowest displacement. Meanwhile, there was a slight difference in displacement between 2.5 and 7.5% of kenaf–ABS composites.

Figure 7 illustrates the flexural strength of all samples. The graph illustrates that with the increased content of kenaf fiber from 0 to 5%, flexural strength was firstly decreased, then a sharp reduction of flexural strength took place from 2.5 to 5% of kenaf fiber content. The flexural strength of 0 and 2.5% kenaf fiber composites were 40.56 and 33.02 MPa, respectively, with a 20.49 % difference. The largest reduction of tensile strength occurred from 2.5 to 5% of kenaf fiber content with a 21.98% difference. Then, the flexural strength was slightly increased from 5 to 7.5% and to 10%, with increasing kenaf fiber content from 26.48, 27.00, and 32.64 MPa, respectively. Parallel results were obtained by Lee et al. [16], where the addition of kenaf fiber content decreased the flexural strength of composites,

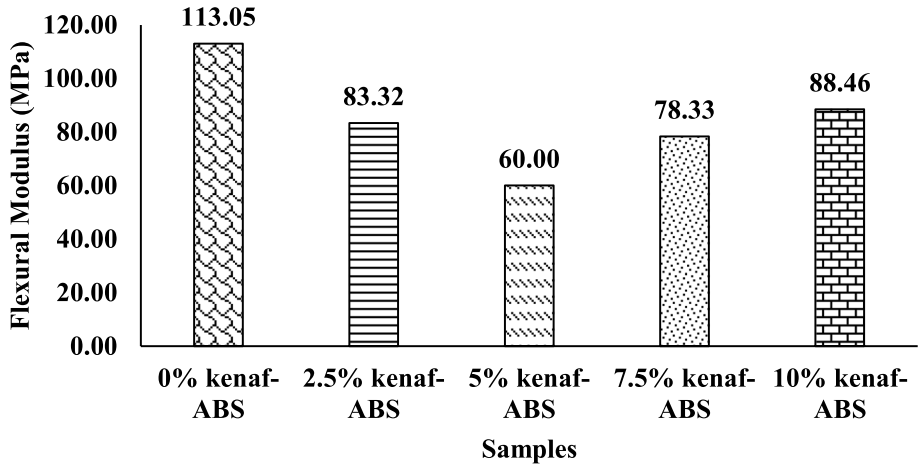

Fig. 8 Flexural modulus for kenaf-ABS composites

Table 4 Flexural strength and modulus for all samples

Sample	Flexural strength (MPa)	Flexural modulus (MPa)
0% kenaf–ABS	40.56 ± 4.50	113.05 ± 14.98
2.5% kenaf–ABS	33.02 ± 7.20	83.32 ± 10.05
5% kenaf–ABS	26.48 ± 3.38	60.00 ± 19.47
7.5% kenaf–ABS	27.00 ± 1.66	78.33 ± 10.13
10% kenaf–ABS	32.64 ± 2.97	88.46 ± 9.83

and 0% kenaf fiber composites revealed the highest flexural strength. The decrement of flexural strength was attributed to the increasing content of kenaf fiber, which allowed it to act as a stress concentration spot. Then, a greater reduction from 0% to 5% kenaf fiber content was due to a greater formation between fiber–fiber interaction than fiber-matrix interaction and bad dispersion of fiber in the matrix [9]. Other than that, processing of composites at high temperatures could lead to the damage of fibers [41]. Thus, the high content of fibers could result in greater damage to composite properties.

The flexural modulus for different loading of kenaf fiber content are presented in Fig. 8. The values of flexural modulus were decreased from 0 to 2.5%, which were 113.05 and 83.32 MPa, respectively, with a 30.28 % difference. Then, there was a sudden decrease from 2.5 to 5% of kenaf fiber composites, where the value of tensile modulus for 5% was 60 MPa. The difference in flexural modulus between 2.5 and 5% of kenaf fiber content was 32.54. Continued increment in the content of kenaf fiber from 5 to 10% raised the value of flexural modulus, where the flexural modulus of 7.5 and 10% of kenaf fiber content were 78.33 and 88.46 MPa, respectively. Table 4 presents the summary of flexural strength and modulus for different loadings of kenaf fiber-reinforced ABS composites.

Figure 9 shows the visual picture and SEM of the side view flexural fracture for each sample. Figure 9a shows matrix cramping and delamination that occurred upon the flexural test. Besides, the presence of porosity on the deposited layer and delamination was obviously seen in Fig. 9b–e, where adding kenaf fiber into the polymer matrix caused the porosity. The poor interfacial adhesion between fiber and matrix

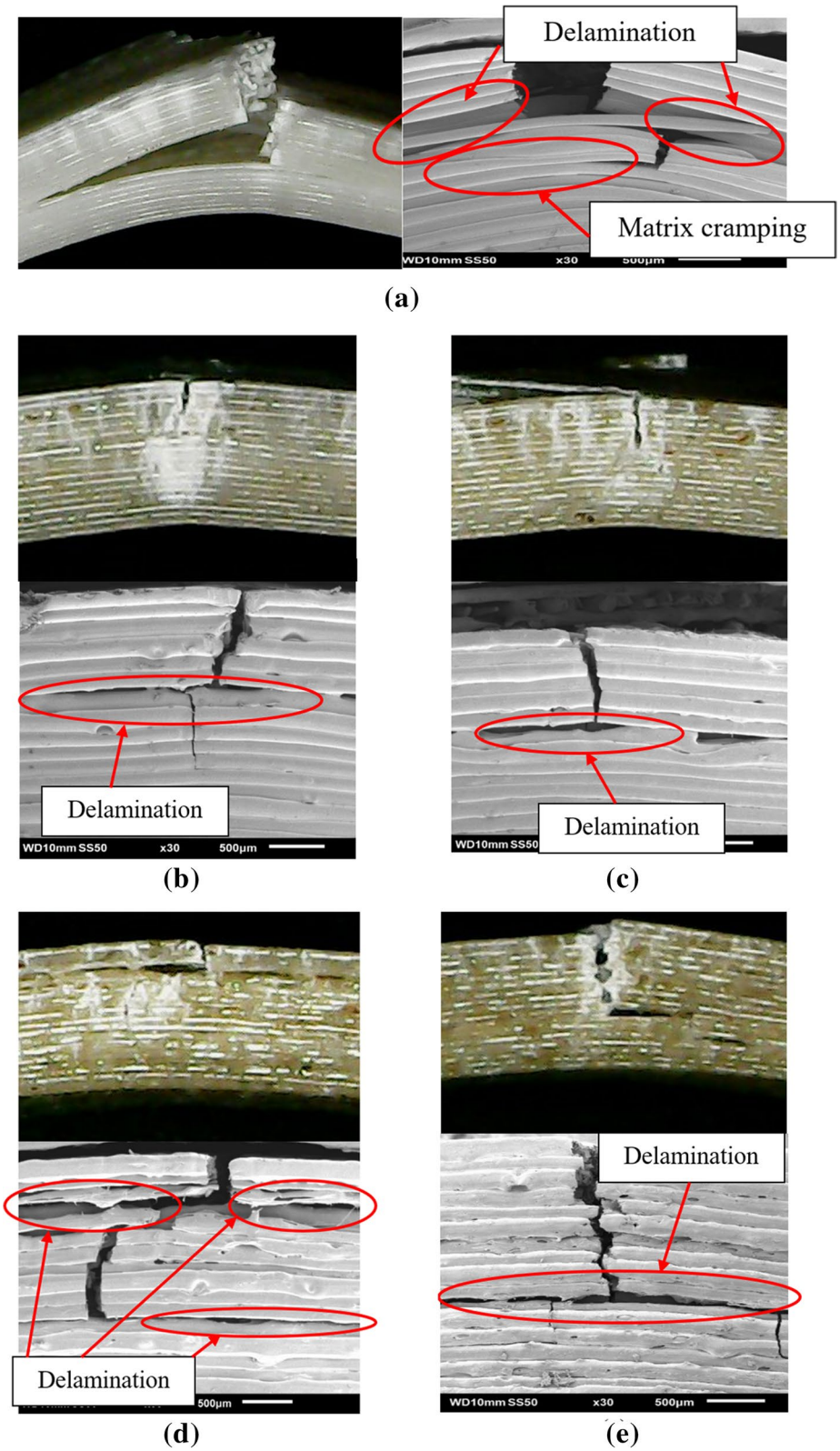

Fig. 9 Visual representation and SEM for flexural test. **a** 0% kenaf–ABS, **b** 2.5% kenaf–ABS, **c** 5% kenaf–ABS, **d** 7.5% kenaf–ABS, **e** 10% kenaf–ABS

resulted in delamination when subjected to external loads [30]. This happened due to untreated fibers consisting of impurities and unwanted elements on the surface of the fiber. Polymer molecules could not adequately bond with the surface of the fibers. The bonding condition of the surface of fibers with polymer molecules was poor and unable to transfer the external load evenly between the fibers and polymer molecules. Moreover, the weaker bonding would increase the potential of fiber to be pulled out, leaving empty holes in the matrix.

Conclusions

In the present work, the various volume percentages of kenaf fiber-reinforced ABS composites were compounded using twin-screw extruder machine, and 3D printer was used in producing samples. The samples underwent tensile and flexural properties testings and followed by morphological study. Based on the conducted analyses, the findings of this study can be explained as follows:

- Pure ABS resulted in 23.2 MPa for tensile strength and 328.17 MPa for tensile modulus. However, adding kenaf fiber decreased the tensile strength and modulus of composites fabricated through FDM. 2.5% kenaf–ABS gave the highest the maximum strength and modulus with 21.48 and 321.73 MPa, respectively, compared to 5, 7.5, and 10% of kenaf–ABS composites. The lowest tensile strength and modulus were exhibited by the 5% kenaf–ABS composite 11.48 and 184.48 MPa, respectively. Morphological analysis for tensile fractured revealed poor fiber-matrix interfacial adhesion, fiber pull-out, fiber breakage, and formation of porosities.
- Pure ABS demonstrated a flexural strength of 40.56 MPa and flexural modulus of 113.05 MPa. However, adding kenaf fiber decreased the flexural strength and modulus of composites. 2.5% kenaf–ABS resulted in the highest flexural strength with 33.02 MPa, while 10% kenaf–ABS revealed the highest flexural modulus of 88.46 MPa. The lowest flexural strength and modulus were exhibited by 5% kenaf–ABS composite. Morphological analysis for flexural side view fractured showed that the addition of kenaf fiber causes the formation of porosities and poor fiber-matrix interfacial adhesion, resulting in delamination phenomena.

Overall, the kenaf–ABS composite has the potential to be fabricated through FDM technology despite a slightly decrement in the tensile and flexural testing results of the kenaf–ABS composite in comparison with the pure ABS. This study has successfully confirmed the ability of kenaf fiber-reinforced ABS polymer composites filament for FDM machines based on tensile and flexural properties. Both properties are the important parameters in the material and design area, where the technical product performance target is mostly measured by these two properties. Therefore, there is a need to investigate these two properties. In composite, morphological analysis implies the results of mechanical properties where degradation of the mechanical properties is due to the lower interfacial bonding between the fiber and molecule of the polymer matrix shown by the scenario of fiber pull-out, porosity, and fiber breakage. In future works, a study on treating kenaf fiber with alkali and silane to enhance the interfacial adhesion between fiber and matrix will be conducted.

Abbreviations

3D	Three dimension
FDM	Fused deposition modeling
AM	Additive manufacturing
ABS	Acrylonitrile butadiene styrene
PLA	Polylactic acid
PC	Polycarbonate
PP	Polypropylene
PE	Polyethylene
HDPE	High-density polyethylene
NFRPC	Natural fiber reinforced polymer composites
SEM	Scanning electron microscopy

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Authors' contributions
SNMFH performed and interpreted the tensile test, flexural test, and morphological analysis. MMT confirmed the study conception and experimental design. MMR revised critically the writing and important intellectual content. RMAA approved the version to be submitted for publication. All the authors reviewed the results and approved the final version of the manuscript.

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Availability of data and materials
Raw data were generated at the Faculty of Mechanical Engineering large-scale facility. Derived data supporting the findings of this study are available from the corresponding author upon request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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