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Woven hybrid Biocomposite: Mechanical properties of woven kenaf bast fibre/oil palm empty fruit bunches hybrid reinforced poly hydroxybutyrate biocomposite as non-structural building materials

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HIGHLIGHTS

- The polyhydroxybutyrate is targeted as matrix for green composite.
- The mechanical test of KBFw/EFB hybrid reinforced PHB biocomposite with 11 layers is determined that it has capability to replace with some wood and woody production.

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ABSTRACT

Green or Biocomposite materials encompass biopolymers and natural fibers (NFs) from renewable resources, which is helped to eliminate non-renewable waste, reduce raw material usage, and lessen greenhouse gas emissions. This paper aimed to assess and develop specific biocomposite in terms of mechanical properties, which prepared by lamination and compression molding method. The woven kenaf bast fibre (KBFw) is deliberated as reinforcement in this study due to the high tensile strength which was hybridized with oil palm empty fruit bunches (EFB) due to high toughness of EFB for covering the impact properties of biocomposite. The polyhydroxybutyrate (PHB) is a common biodegradable polymer that is targeted as matrix for green composite. The triethyl citrate (TEC) was chosen as plasticizer for improving flexibility and handling of PHB films. The scanning electron microscope was used to understand and investigate the tensile-fractured surface of different hybrid biocomposite. The results show that the tensile and flexural properties would be increase when NFs with higher tensile strength was used as skin fibre in term of hybrid composite. Conclusively, the flexural stiffness of biocomposite increase when the KBFw PHB biocomposite is hybrid with FEB reinforcement. The tensile and flexural test of KBFw/EFB hybrid reinforced PHB biocomposite with 11 layers (sample E) is determined that sample E has capability to replace with some wood and woody production.

1. Introduction

The construction industry consumes astonishing amount of materials, most of which derive from non-renewable resources or resources that require considerable time to be renewed [1]. Green or biocomposite materials from renewable resources encompass of a biopolymer and Natural Fibers (NFs) [2–4]. These materials are being investigated with the aim to decline impacts to environmental and human health from building materials [5,6]. The most research and development on biocomposites have been targeted in the packaging, automobile, medical, and interior design industries [7–9]. However, some important research has been accompanied on biocomposites [10–12] that have been considered in construction applications. In recent years, scholars [13–18] suggest the usage of different type of NFs and biocomposites in

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construction industry. Yan, L; and Chouw, N (2013) emphasized the potential of using NFs to achieve a sustainable construction with experimental investigation of a composite column consisting of flax fibre reinforced polymer (FFRP) and coir fibre reinforced concrete (CFRC) [13]. In 2014; Yan et al. experimentally examined various column parameters on axial compressive and flexural behavior of a new type of flax fibre reinforced polymer-confined concrete, which is termed as FFRP–CFRC [14]. They Confined concrete strength was predicted and compared with experimental results. Another research study in 2015 investigated the flexural behaviour of plain concrete (PC) and coir fibre reinforced concrete (CFRC) beams which externally strengthened by flax fabric reinforced epoxy polymer (FFRP) composites [15]. Regarding to use biocomposite as building materials; CoDyre et al (2016) explored the effect of foam core density on the behavior of sandwich panels with novel bio-composite unidirectional flax fibre-reinforced polymer skins, with a comparison to panels of conventional glass-FRP skins [16]. Mak et al (2015) researched on Structural sandwich panels with considering the potential for replacing conventional glass fiber-reinforced polymer (GFRP) skins with bio-based skins made of unidirectional flax fibers and a resin blend consisting of epoxidized pine oil [17]. And, Yan et al (2106) studied improvement Effect of alkali treatment on microstructure and mechanical properties of coir fibre reinforced-polymer composites and reinforced-cementitious composites as building materials [18].

Green composite is one existing class of materials and products which can improve the sustainability in composite science [19,20]. Sealy (2015) emphasized to use cellulose fibers as reinforcement in green composite that promise a sustainable and renewable term as alternative to petroleum-based plastics [21]. The use of renewable resources reduces the needs for petrochemicals and minerals, resulting in less natural resources depletion effect on the planet [22,23]. Inherently green or biocomposite made from renewable resources is biodegradable and change naturally by bacteria into substances without any harm to environment [24,25]. In fact, biocomposites and other green materials help eliminate non-renewable waste, reduce raw material usage, and cut fossil-fuel consumption [26]. In biocomposite, NFs are stronger and stiffer than polymeric matrix [27,28], but the important role for distributing stresses to fibers belongs to the binds between matrix and fibers. In biocomposite, biopolymer as matrix can play significant role as protection of fibers and total behaviors of biocomposite depend on: kinds of fibers, matrix, distribution of fibers on matrix, etc.

Biopolymers may be obtained from renewable resources, synthesized microbially, or synthesized from petroleum-based chemicals [29]. Polyhydroxybutyrate (PHB) is one of the most common biodegradable polymer and it will be studied as matrices for biocomposites in this research. The mechanical properties are reported to be equal or even better than traditional thermoplastics [30]. The PHB is an organic and biodegradable polymer [31] that is well known as a carbon and energy reserve produced by a variety of microorganisms, and its synthesis is favoured by environmental stresses such as nitrogen, phosphate or oxygen limitation [32,33]. There are a lot of inexpensive carbon sources and high productivity as basic feed stocks for PHB production. Among such substrates, molasses [34], starch [35], whey from the dairy industry [36], surplus glycerol from biodiesel production [37], xylose [38], and plant oils [39] are available. Fig. 1 shows closed carbon cycle in PHB production integrated in a sugar mill with ethanol [40].

Additionally, there are some research which highlighted regard to the successful replacement of synthetic fibres by bio-fibres [81,82]. Bast fibers, as majority of NFs; are proposed to compromise several advantages as replacements for synthetic fibers (e.g. glass) in composites [41] like giving the potential for reduced weights, and less damaging to machinery and personnel during the manufacturing process due to less abrasive than glass particles [42]. Kenaf bast fiber (KBF) has a great potential as a reinforcing fiber in composites due to high strength-to-weight/stiffness-to-weight ratio in comparison to other fibers. It has the highest carbon dioxide absorption of any plant (1 ton kenaf absorbs 1.5 tons of atmospheric CO_2), a valuable tool in the prevention of global warming and priority for choosing as Green materials [43]. Bast fibre as majority of NF is offered desirable characters specifically for hybrid composite based on mechanical properties and moderately high specific strength and stiffness. Table 1 shows properties of some bast fibres with oil palm EFB.

Furthermore, study of lignocellulose fibres has revealed that the properties of fibres can be better used in hybrid composites for using as an alternative to synthetic fibre composite [48,49]. Hybrid composites which contain two or more types of fibre and matrix could cover the lack in one fiber properties with another one [50,51]. The hybrid term is used to impart fancy effect, reduce cost of the end product, and find out suitable admixture of natural origin to mitigate the gap between demands and supply [52]. Among of the all NFs, Oil palm Empty Fruit Bunches (EFB) is hard and tough and found to be a potential reinforcement in composite applications [53]. The primary advantages of EFB hybrid composite are its low density, non-abrasiveness, and biodegradability. Hybridization of EFB with jute fibres [54,55], sisal [56,57], and glass [58,59] implied to enhance physical and mechanical properties of EFB hybrid composites to be used in various applications like construction industry. Based on the study of hybrid composite with bast fibres (like jute) and EFB [60,61], it has highlighted the promising material properties based on the high tensile strength of bast fibres (jute) and the toughness of EFB. Therefore, any hybrid composite of two fibres will exhibit the desirable properties of the individual constituents.

Tensile strength (TS) is one of the NF' mechanical property that defined the strength of material expressed as the greatest longitudinal stress it can bear without tearing apart. As can be seen from Table 1 TS (930 MPa) of kenaf fibers is higher than the TS of hemp (690 MPa). It can be used as reinforcing materials to make useful structural composites material with acceptable mechanical and physical properties in construction industry. However, the toughness of kenaf fiber is quite low and it leads to the low impact properties for composite. Therefore, in order to get composite with good tensile and toughness property, kenaf fibre need to be hybrid with other natural fibre such as EFB. EFB is oil palm fiber that has good toughness compare to other fibers.

The research aimed to assess and develop KBF_w/EFB hybrid reinforced PHB biocomposite as non-structural components for building material in terms of mechanical properties. The novelty of the study is hybridization of KBF_w and EFB fibres which would affect on tensile and flexural properties of KBF_w /EFB hybrid reinforced PHB biocomposite.

2. Materials and Methods

2.1. Materials

The woven KBF_w and EFB mats were obtained from Innovative Pultrusion Sdn Bhd, Malaysia. The properties of kenaf and EFB fibre are shown in Table 2. Polyhydroxybutyrate (PHB) granules was obtained from Goodfellow Cambridge Ltd in England. Table 3 shows the various properties of PHB, polypropylene (PP), and polyethylene (PE); and Table 3 shows similarities in the physical and mechanical properties of PHB, PP, and PE [84,85]. The others chemical materials included: ethanol used for alkaline treatment, 3-(triethoxysilyl) propylamine for silane coupling agent treatment, triethyl citrate used as plasticizer, and chloroform for mixing PHB biopolymer' granule with plasticizer were obtained from Mdigene Sdn Bhd, Malaysia.

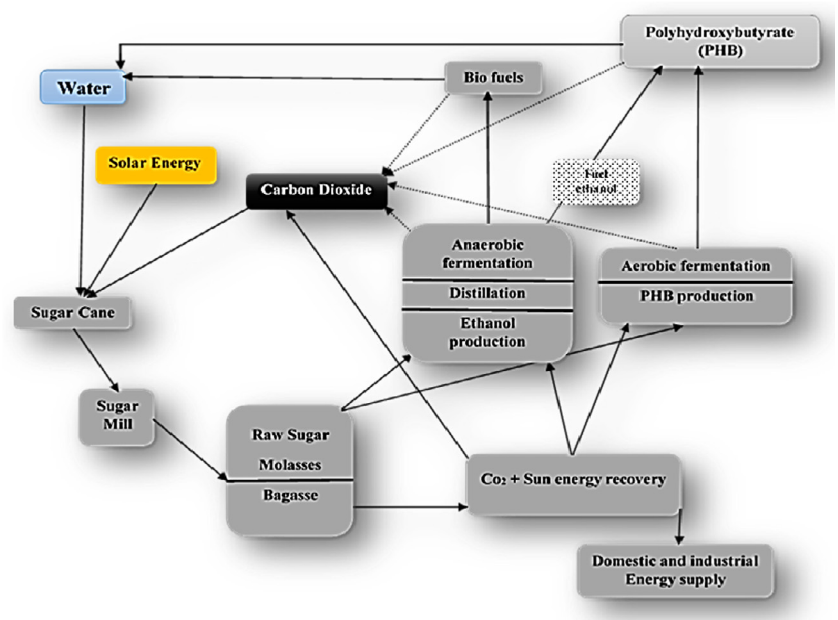

Fig. 1. Closed carbon cycle of PHB production from a sugar mill and ethanol [40].

Table 1
Typical properties of some bast fibres with oil palm EFB [44,45,46,47].

Properties	Fibres					
	E-glass	Flax	Hemp	Kenaf	Jute	OPF
Density g/cm3	2.5–2.6	1.4–1.5	1.4–1.5	1.4	1.3–1.49	0.7–1.55
E-modulus (GPa)	70–76	27.6–103	23.5–90	14.5–53	30	80–248
Tensile strength (MPa)	2000–3500	343–2000	270–900	223–930	320–800	150–500
Elongation at failure (%)	1.8–4.8	1.2–3.3	1–3.5	1.5–2.7	1–1.8	17–25
Moisture absorption (%)	–	7	8	–	12	10–15

Table 2
Typical properties KBFw, EFB and E-glass.

Properties	Density kg/m3	E-modulus (GPa)	Tensile strength (MPa)	Elongation at failure (%)	Moisture absorption (%)
KBF_w	1193	53	930	1.6	–
EFB	700–1550	3.2	248	2.5–18	10–15
E-GLASS	2500	70	2000–3500	2.5	–

Table 3
Goodfellow company information on the properties of PHB, PP, and PE.

Properties	PHB	pp	PE
Chemical Resistance			
Acids – dilute	Fair	Good-Fair	Good
Alcohols	Fair	Good	Good
Alkalis	Poor	Good	Good
Greases and Oils	Good	Good-Fair	Good-Fair
Mechanical Properties			
Elongation at break (%)	6	150–300	500
Izod impact strength (J m^{-1})	35–60	20–100	>1000
Tensile modulus (GPa)	3.5	0.9–1.5	0.2–1.2
Tensile strength (MPa)	40	25–40	20–40
Physical Properties			
Density (g cm^{-3})	1.25	0.9	0.94
Resistance to Ultra-violet	Fair	Poor	Poor
Thermal Properties			
Upper working temperature (C)	95	90–120	55–95
Biodegradability	Yes	No	No

2.1.1. Preparation of natural fibres mats and biopolymer films

The KBF_w/EFB hybrid reinforced PHB biocomposite was made from polymer films and kenaf together with EFB fabric by lamination and compression molding method. In term of hydrophilic problems of NFs, the alkaline treatment (mercerization) of KBF_w and EFB mat were carried out (Fig. 2-A) by soaking and immersing them with 5% sodium hydroxide (NaoH) for one hour. The amount of soaked NFs was based on: 200 g NFs with the solution of 5 g NaoH in 100 ml distilled water. After one hour, the NFs were washed thoroughly with water several times and finally washed with distilled water. Finally, air drying was applied at 70 °C for 8 h and vacuum drying at 60 °C for 2 h.

The PHB is stiff and brittle that would results in very poor mechanical properties [62]. Thus, triethyl citrate (TEC) was chosen as a plasticizer to improve flexibility and handling of PHB films [63,64]. The Plasticization mechanism in this study is based on the lubricity theory which the plasticizer acts as a lubricant to decrease friction and facilitates polymer chain mobility past one another, subsequently lowering deformation [83]. The PHB/Plasticizer was blended with (80/20 w/w) percentage. It was prepared by evaporating chloroform from polymer/plasticizer mixed solution (3% wt) with predetermined weight ratio. PHB films were prepared one at a time by compression molding on a hot press (Fig. 2-B). Every PHB film needs 25 g PHB, around 5 ml TEC and 2 ml chloroform. A magnetic stirrer or magnetic mixer was needed for the mixing.

Also, the silane coupling agent was chosen to improve interfacial adhesion between reinforcements and matrix of biocomposite to achieve good tensile and flexural properties [65]. In silane treatment process, the solution used was 2% triethoxysilyl propylamine in 95% alcohol and the duration of soaking was around 5 min. The treatment was followed by air drying of the fibers for 30 min which hydrolyzed the silane.

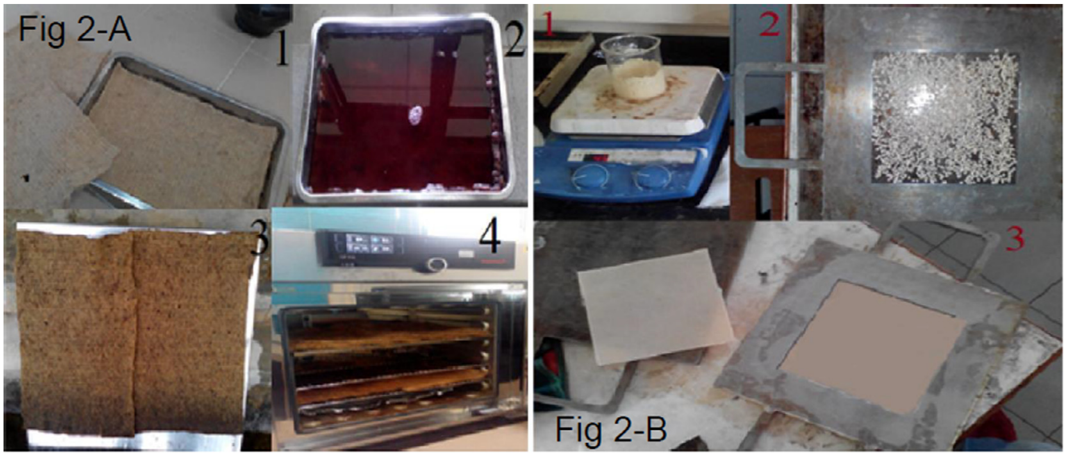

Fig. 2. The preparation of NFs mats (2-A) and PHB films (2-B).

Table 4
Samples arrangement of KBF_w/EFB hybrid reinforced PHB biocomposites.

	KBF_w: Layers (g)	EFB: Layers (g)	PHB: Layers (g)	Total Layers (g)
A				
Sample A	2(2 0 0)	1(50)	4(4 8 0)	7(7 3 0)
Sample B	1(1 0 0)	2(1 0 0)	4(4 8 0)	7(6 8 0)
Sample C	2(2 0 0)	2(1 0 0)	5(6 0 0)	9(9 0 0)
Sample D	2(2 0 0)	2(1 0 0)	5(6 0 0)	9(9 0 0)
Sample E	3(3 0 0)	2(1 0 0)	6(7 2 0)	11(1120)
B				
Sample S_1	1(1 0 0)	–	2(2 4 0)	3(3 4 0)
Sample S_2	–	1(50)	2(2 4 0)	3(2 9 0)
Sample S_3	1(1 0 0)	1(50)	3(3 6 0)	5(5 1 0)

2.1.2. The sample arrangement and the compression moulding of biocomposite

The goal of samples arrangement (Table 4-A) is to find the best arrangement for hybrid biocomposite. The different between samples C and D is the layout of the biocomposite. In sample C the EFB is placed at both side of the outer layer, but in sample D, the KBF_w is placed at both side of the outer layer. Also, it needed to develop and examine different samples to determine the effects of hybridization and role of EFB in biocomposite. In fact, the role of EFB in hybrid reinforcement composite is to increase the toughness. Therefore, another three samples were prepared to clarify the role of both NFs in hybrid composite (Table 4-B).

For the preparation of biocomposite, the compressing molding method was chosen with applying heat and pressure. The layup was sandwiched between aluminum plates and placed under a load of about 5 kN on a hot-press at 180 °C. The composite was hold at this temperature and load for 5 min to allow all of the films to melt. If the composite was too thick, (e.g. greater than 13 mm), the films at the center would not melt. After ten minutes, an additional 5 kN of force was applied to the composite to induce flow of the polymer. After about 5 min, the composite was removed from the hot press and cooled to room temperature under a slight pressure apply by a free weight (roughly 20 kg) covering the area of the plate. The free-weight pressure was applied to prevent curvature in the composite plate from differential cooling. After about one hour, the composite was removed from the plates. Fig. 3 shows samples arrangement of KBF_w/EFB hybrid reinforced PHB biocomposites in this research.

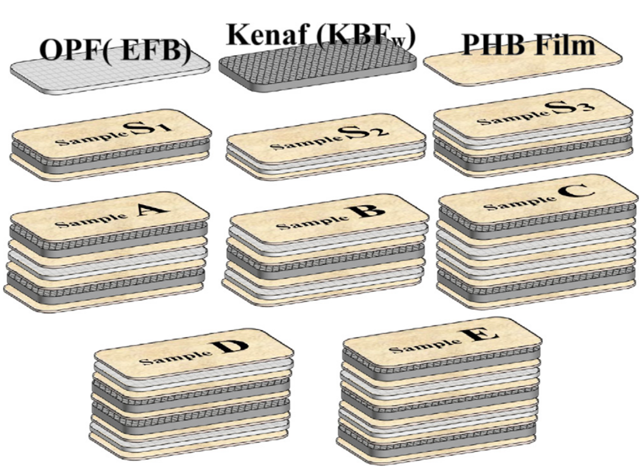

Fig. 3. Samples arrangement of KBF_w/EFB hybrid reinforced PHB biocomposite.

2.2. Characterization of KBF_w/EFB reinforced hybrid PHB biocomposite

2.2.1. Tensile test

Tensile testing was performed on KBF_w/EFB hybrid reinforced PHB biocomposite to determine the modulus of elasticity, tensile strength and percentage of elongation. Tests were conducted on both directions to characterize fully the natural fabric biocomposites. The tensile specimens test followed ASTM D638-10, "Standard Test Method for Tensile Properties of Plastics," [66], with a cross-head speed of 50 mm/min using universal testing machine (UTM) Instron 5567. In each sample, five specimens were tested and the average value was presented.

2.2.2. Flexural test

Flexural tests were performed on the materials to determine experimentally the flexural modulus and strength. Most structural materials with comparable properties to biocomposites such as wood, engineered wood products, and plastics are tested in flexure and flexural properties were reported rather than the pure tension and compression properties. The flexural specimens are tested in three-point bending according to ASTM D790, "Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials" [67]. Five specimens were tested from each composite plate.

2.2.3. Izod impact test

The Izod impact test was performed using a pendulum with impact energy of 5.54 Joule (J) at room temperature according to ASTM D256 [68]. The notched test specimens were used with near dimensions of 60 mm × 12.7 mm × 2 mm. The tests were repeated five times for each formulation and the mean with the standard deviation of the test were calculated.

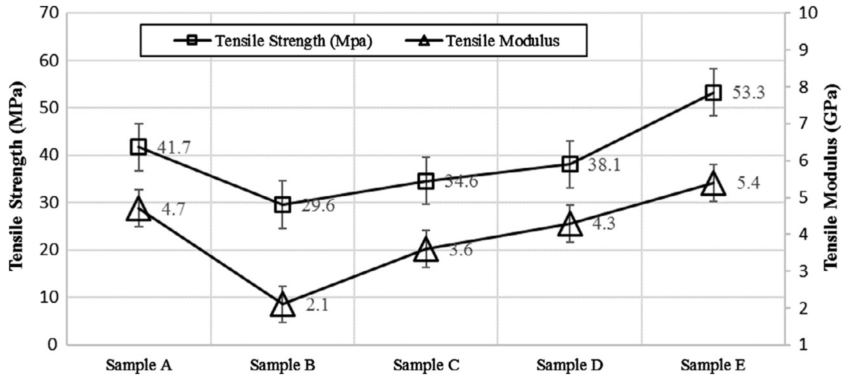

Fig. 4. Tensile Strength and Modulus for different samples from Table 4-A.

2.2.4. Scanning electron microscopy (SEM) of tensile fracture surface

Scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. In this study, the SEM was used to understand and investigate the tensile-fractured surface of different hybrid biocomposite. The micrograph samples were scanned at 200 magnifications because it gives the best overview of the composites surface.

3. Results and discussion

3.1. Tensile properties

The fibre–matrix interface plays an important role in determining the mechanical properties of composite materials especially tensile strength and modulus. Tensile strength (TS) of the composite is influenced by the strength and modulus of fibres [69]. Fig. 4 shows the TS and TM for different samples of KBF_w/EFB hybrid reinforced PHB biocomposite based on Table 4-A.

Tensile strength and modulus of the fabric reinforced is strongly related to the fabric structure as well as type, content and properties of the reinforcement [79,80]. Although the number of layers of sample A is lower than samples C and D, the TS and TM is higher than them. The tensile properties of sample A decrease with adding 1 layer EFB (sample C and D). In additions, the arrangement of the different components in hybrid laminated composite play significant role in influencing the mechanical properties of the hybrid composite [70,71]. The number of layers between sample C and D is the same, but the layout is different. The TS and TM increase from sample C to D when the high strength of fibre (KBF_w) is used as a skin and under the biocomposite. Based on Fig. 4, it is clear that the TS and TM of biocomposite increases with the number of layers. So, sample E with 11 layers shows higher TS (53.3 MPa) and TM (5.4 GPa) compare to other samples.

Fig. 5 shows the TM and TS of samples based on Table 4-B. The arrangement of sample was to determine the effect of hybridization and the role of EFB in biocomposite.

The tensile strength of kenaf fibre 930 MPa is higher than EFB (250 MPa). The aim of hybridization is to improve the weakness from one part with another part. So, the TS and TM of EFB PHB biocomposite (sample S_2) can be improved and increased with hybridization of EFB with KBF_w (sample S_3). On the other hands, if the reinforcement of biocomposite (sample S_1) hybrids by another reinforcement with lower tensile properties, its influenced to decline the TS and TM of new hybrid biocomposite (sample S_2).

3.1.1. Stress-strain characteristics under uniaxial tensile strength

The stress longitudinal strain curves of typical hybrid biocomposites are shown in Figs. 6 and 7. These graphs reveal a gradual increase in strain deformation of the 3 sample of hybrid biocomposite examined as the tensile load applied increased. All throughout the loading phase of the composite to its failure, a nonlinear and inelastic stress strain curve was displayed. This could be due to irreversible micro cracking. Each curve in Figs. 6 and 7 represents the average values obtained from four dog bone specimens of eight different hybrid biocomposites as described in Table 4.

Fig. 6 shows that the longitudinal strains of the KBFw PHB biocomposite (S1), EFB PHB biocomposite (S2), and KBFw EFB hybrid PHB biocomposite (S3) all see a marginal decrease from NFs reinforcement. With an applied stress of 25 MPa, the longitudinal

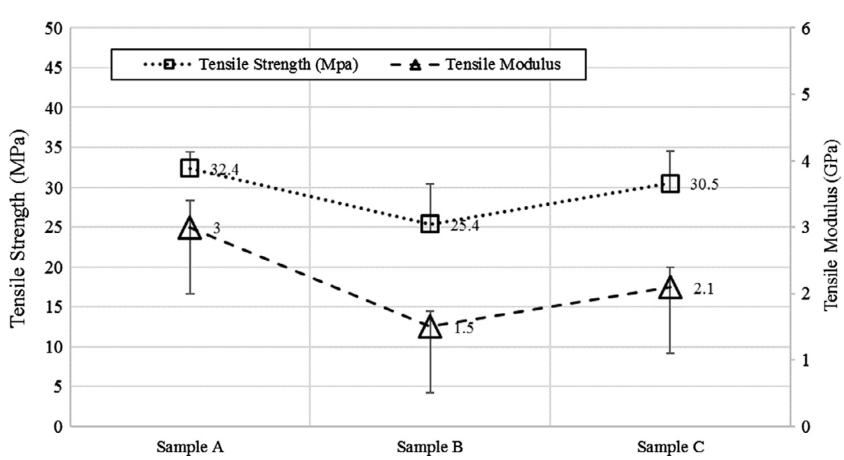

Fig. 5. Tensile Strength and Modulus for different samples from Table 4-B.

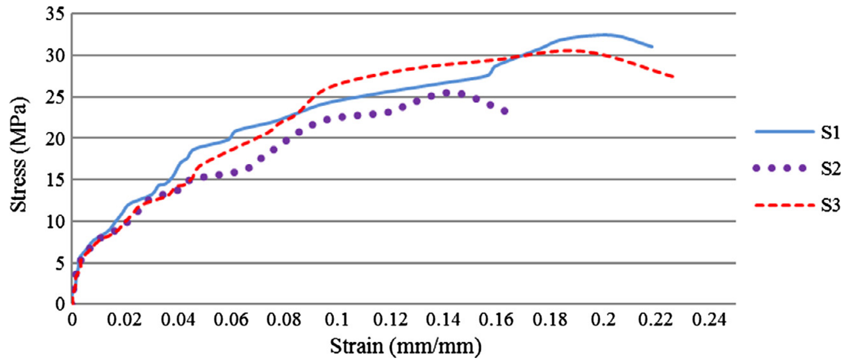

Fig. 6. Tensile stress-strain graph for different samples of hybrid biocomposites based on Table 4-B.

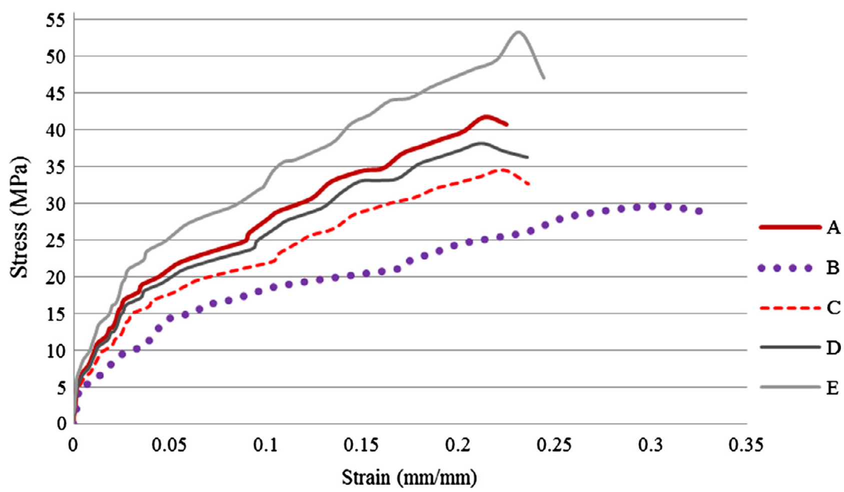

Fig. 7. Tensile stress-strain graph for different samples of hybrid biocomposite based on Table 4-A.

strains of KBFw PHB biocomposite (S1), EFB PHB biocomposite (S2), and KBFw EFB hybrid PHB biocomposite (S3) are 0.114, 0.144, and 0.091, respectively, as shown in Fig. 6. Fig. 7 shows the performance of A, B, C, D, and E with their strains of 0.091, 0.221, 0.123, 0.100, and 0.047, respectively under 25 MPa of stress. Based on the performance of the KBFw EFB hybrid reinforced PHB biocomposite specimen in the tensile stress strain diagrams, the following conclusion was drawn regarding the effect of NFs reinforcement on biocomposites: Sample E with 11 layers had the ability to sustain stress (53.30 MPa) before failure.

3.2. Morphological studies using scanning electron microscopy (SEM)

A Scanning Electron Microscope (SEM) in the analysis used fractured specimens from the tensile tests. The interaction and adhesion between the PHB matrix, KBFw, and EFB reinforcement was made implicit by the fracture surface micrographs of the tensile test samples. The NF reinforcement/matrix boundary plays a significant function in biocomposite properties. An acceptable interfacial bond between reinforcement and matrix is achieved with the employment of NF strength in the biocomposite for effective stress transmission from the matrix to the NF reinforcement. The composition of A, B, C, D, E, S1, S2, and S3 are shown in Figs. 8 and 9.

Fig. 8 demonstrates the SEM image of a tensile-fractured surface from different hybrid biocomposites samples at 200 times magnification based on Table 4-A. The difference between samples is the number of layers and the layout of the reinforcement. The porosity of sample B with one layer of KBFw and two layers of EFB is higher than sample A with two layers of KBFw and one layer of EFB as shown in Fig. 8. The composition has enhanced matrix bonding with a higher percentage of kenaf fibre in the hybrid reinforcement.

The comparison between the SEM of sample C and D in terms of mechanical properties shows the effects of different layouts. In previous studies on kenaf and bagasse reinforced biodegradable resin, the structure of the NF affected the properties of the biocomposites. The number of layers in sample C and D are same but the reinforcement layout is different. In sample C, the EFB layers are on the exterior of the sample, causing brittle fibre fractures. Fractures were soft and smooth when KBFw was the exterior layer. Based on results of the mechanical test, the best sample was sample E with 11 layers. The SEM of sample E shows low porosity and smooth fractures.

Fig. 9 shows the SEM images of samples tensile-fractured surfaces at 200 times magnification. The SEM of sample S2 with one layer of EFB fibre shows a higher porosity than sample S1 with one layer of KBFw fibre. High porosity caused decreased mechanical properties in the biocomposite. The SEM of sample S3 shows the proper dispersion both matrix and fibres and low porosity. This proper dispersion caused smooth and soft fractures on the surface of sample S3.

3.3. Flexural properties

The flexural strength (FS) represents the highest stress experienced within the material at its moment of rupture. The flexural stiffness is a criterion of measuring deformability in which the function is based upon two essential properties: the first is the elastic modulus (stress per unit strain) of the material that composes it; and the second is the moment of inertia, a function of

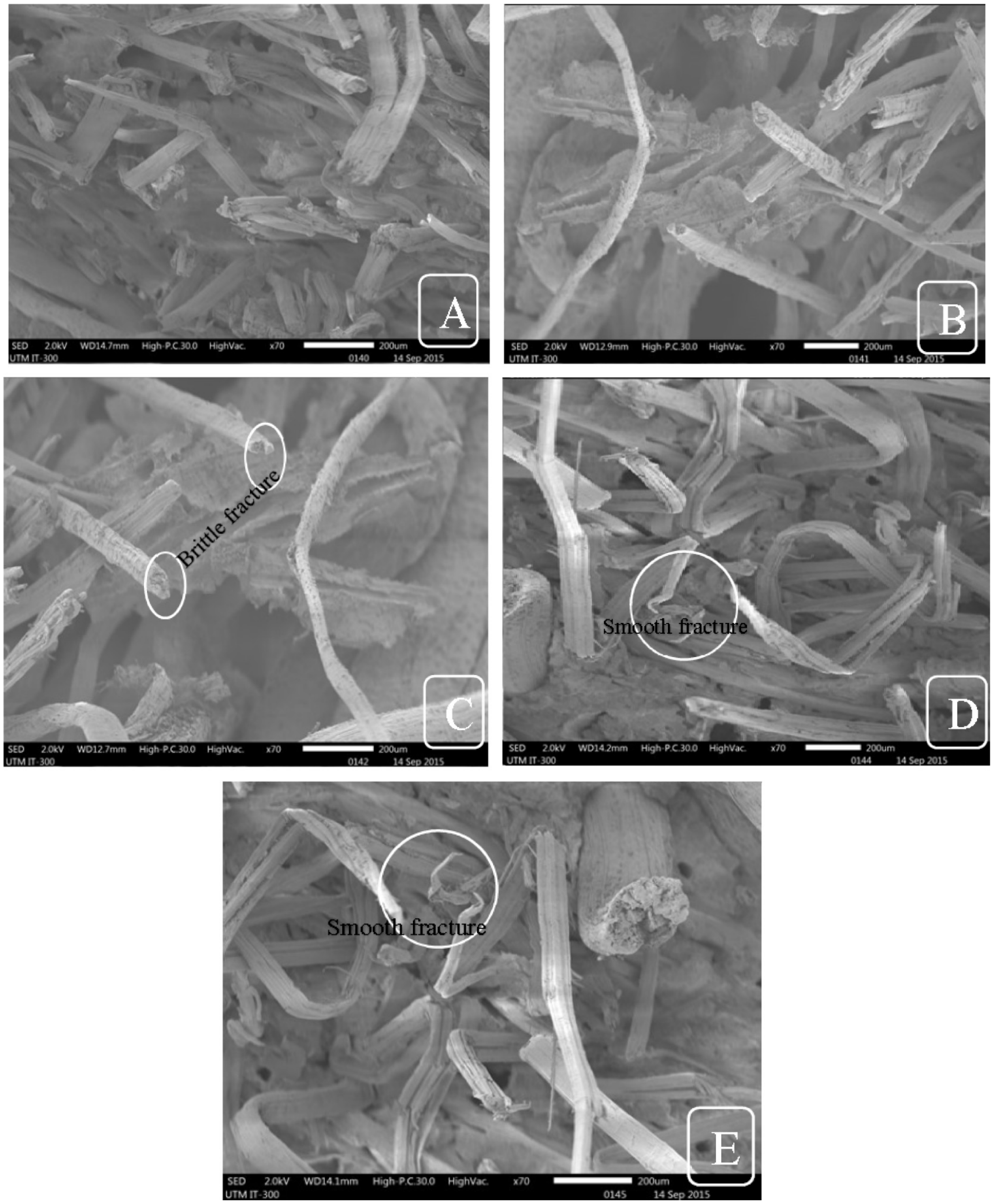

Fig. 8. Scanning electron micrograph of tensile fracture sample of A, B, C, D, and E.

the cross-sectional geometry. While, the flexural modulus (FM) or bending modulus is the ratio of stress to strain in flexural deformation, or the material affinity to bend. It is determined from the slope of a stress-strain curve produced by a flexural test (such as the ASTM D 790). Fig. 10 shows the FS and FM of different samples of KBFw/EFB hybrid reinforced PHB biocomposite based on Table 4-A. Evidently, it is clear that the FS and FM of biocomposite increases with the growth in a number of layer. And, sample E has higher FS and FM than the other samples of hybrid biocomposites.

The comparison between sample A and B is implied on higher FS and FM of KBF_w on EFB fibre. FS and FM of sample A is higher than B, with the same layers (7 layers). Also, the amount of composite layers between C and D is the same but the layout is different. The mounding arrangement of different components in hybrid laminated composite perform the significant role in influencing the mechanical properties of the hybrid composite [70,71]. The FS and FM of sample D is higher than sample because in the arrangement of sample D, the KBF_w layer with high tensile strength as skin and FEB with good toughness properties as core lead to improvement in flexural strength and modulus instead of sample C.

Fig. 11 shows the FM and FS of samples based on Table 4-B. The part B of sample arrangement (Table 4-B) is considered to determine hybridization and effect the role of EFB in biocomposite

The high cellulose content and high toughness value of EFBs mark it appropriate for application in composites [72–74]. It is clearly observed from Fig. 11 that hybridization of KBF_w with EFB fibre has resulted to increase FS and FM of hybrid biocomposite from sample S_1 to S_3.

3.3.1. Stress-strain characteristics under uniaxial flexural strength

The flexural stress versus strain curves of a typical hybrid biocomposite are shown in Figs. 12 and 13. These graphs reveal a gradual increase in strain deformation of the 3 sample of hybrid

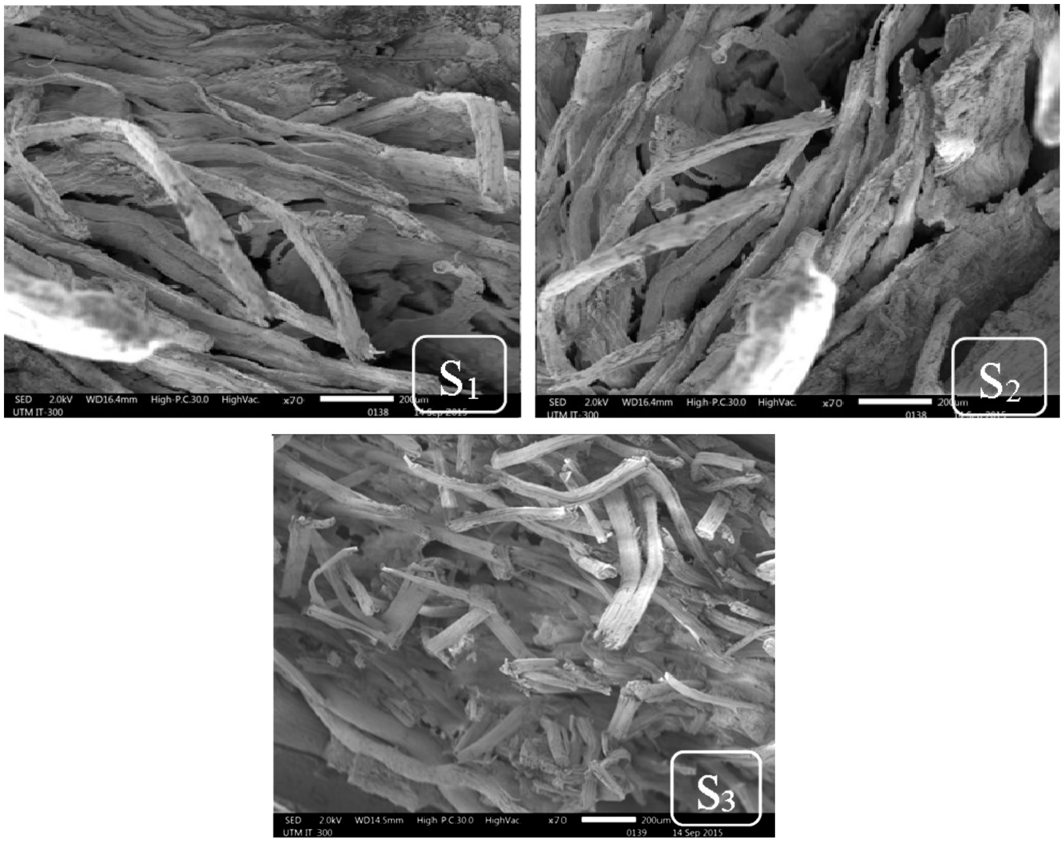

Fig. 9. The SEM of tensile fracture sample of S1, S2, and S3.

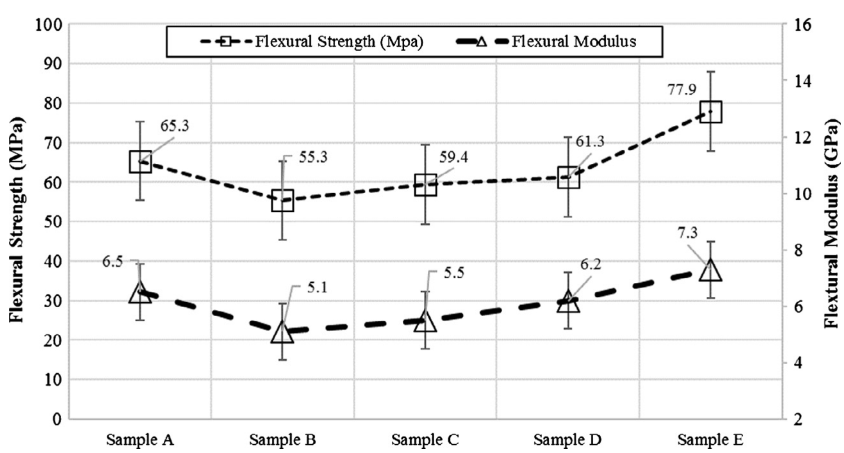

Fig. 10. Flexural Strength and Modulus for different samples from Table 4-A.

biocomposite examined as the flexural load applied increased. From the loading stage to failure, a nonlinear and inelastic stress strain curve was displayed due to micro cracking. Each curve in Figs. 12 and 13 represent the average values of five specimens for eight different hybrid biocomposites as described in Table 4.

It can be observed from Fig. 12 that the longitudinal strains of the KBFw PHB biocomposite (S1), EFB PHB biocomposite (S2), and KBFw EFB hybrid PHB biocomposite (S3) all marginally decreased because of NFs reinforcement. With an applied stress of 40 MPa, the longitudinal strains of the KBFw PHB biocomposite (S1), EFB PHB biocomposite (S2), and KBFw EFB hybrid PHB biocomposite (S3) are 0.187, 0.242, and 0.165, respectively, as seen in Fig. 10. Fig. 13 shows the performance of A, B, C, D, and E with strains of 0.056, 0.078, 0.078, 0.027, and 0.025, respectively when 40 MPa of stress was applied.

Based on the flexural stress strain diagram sample E had the greatest ability to sustain bending stress (77.90 MPa) before failure.

3.4. Impact strength

The notch Izod impact strength test measures the energy to spread an existing crack. Impact strength is the ability of a material to resist fracture under stress applied at high speed. Although the impact properties of composite are directly related to its overall toughness, it depends on several issues like fibre–matrix adhesion,

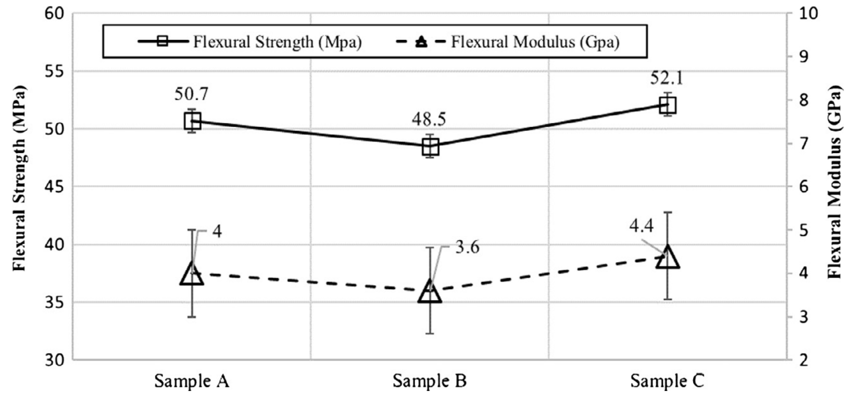

Fig. 11. Flexural Strength and Modulus for different samples from Table 4-B.

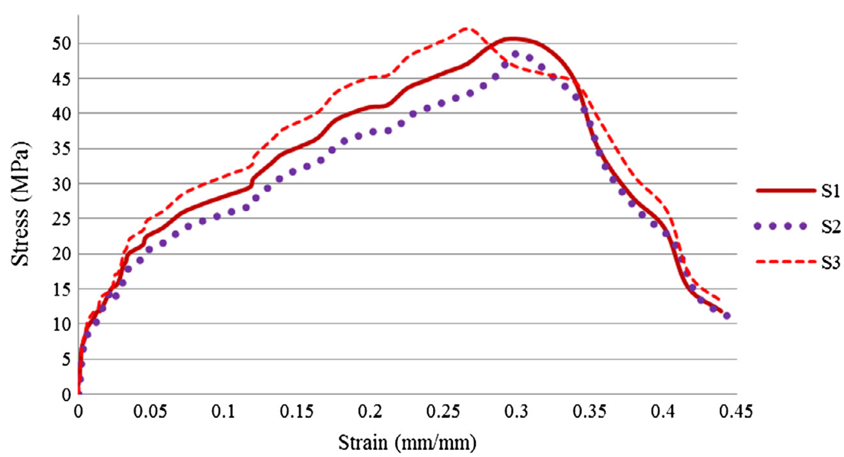

Fig. 12. Flexural stress-strain graph for different samples of hybrid biocomposites based on Table 4-B.

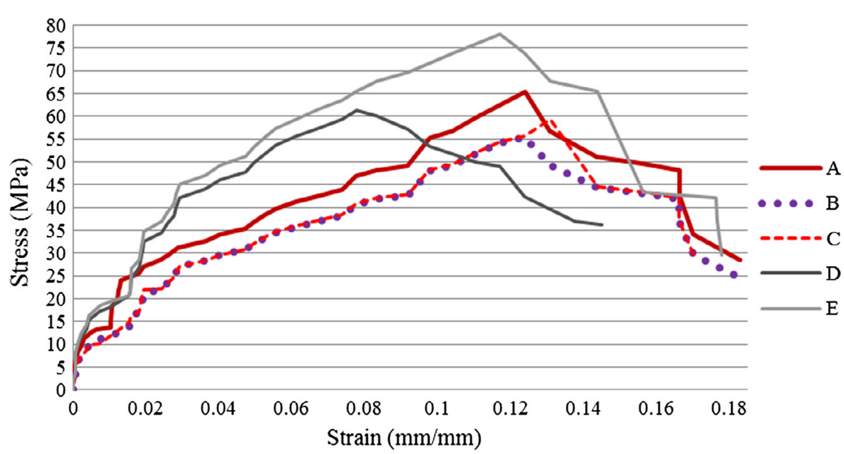

Fig. 13. Flexural stress-strain graph for different samples of hybrid biocomposites based on Table 4-A.

defects in the packing of fibre/matrix, toughness of the matrix and fibre, crystalline morphology, etc. [72,75,76].

Fig. 14 describes the notched Izod impact strength of all samples of biocomposite with PHB biopolymer. The impact strength of PHB is 35–60 J/m and it decreases with adding of KBF_w and EFB layers. The brittle character of the most bast fibres has affected on the impact strength of composite [77]. It can be seen that the impact strength of sample S2 (26.6 J/m) is higher than S1 due to the higher toughness character of EFB. The lowest impact strength observed in KBF_w reinforced PHB biocomposite (24.1 J/m). This impact strength of sample S2 smoothly declines from 26.6 J/m (sample S3) to 25.5 J/m (sample S3) because of the EFB hybrid with KBF_w in sample S3.

Although sample E has higher layers and fibre content among all samples, the impact strength of E is not higher than all. It is due to the lack of compatibility between the composite components [78]. Sample C shows highest impact strength (42.2 J/m) because EFB fibre which has high fracture toughness compared to kenaf bast woven fibre is present on one side of the biocomposite.

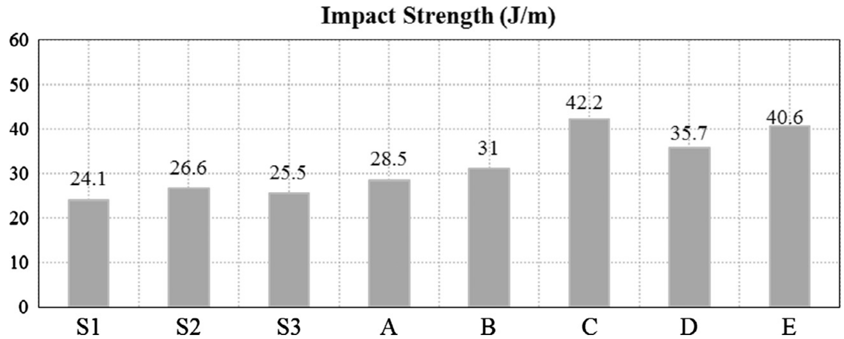

Fig. 14. Notch impact strength of different hybrid biocomposite samples.

Table 5
Summary of tensile, flexural, and impact test for all samples.

Test	Property	Samples							
		S1	S2	S3	A	B	C	D	E
Tensile Test	Modulus of Elasticity (GPa)	3.00	1.50	2.10	4.70	2.10	3.60	4.30	5.40
	Maximum Strength (MPa)	32.40	25.40	30.50	41.70	29.60	34.60	38.10	53.30
Flexural Test	Modulus of Elasticity (GPa)	4.00	3.60	4.40	6.50	5.10	5.50	6.20	7.30
	Maximum Strength (MPa)	50.70	48.50	52.10	65.30	55.30	59.40	61.30	77.90
Impact Test (J/m)		24.1	26.6	25.5	28.5	31	42.2	35.7	40.6

4. Conclusion

The tensile and flexural properties of a KBFw/EFB hybrid reinforced PHB biocomposite was studied using different layouts and different number of layers. Table 5 shows the results for the tensile, flexural, and impact test for all samples.

The KBFw/EFB hybrid reinforced PHB biocomposite with 11 layers (sample E) had the best tensile and flexural values (Table 5). Impact tests showed that hybridization improved composite toughness. The difference in impact values between sample C and E indicate incompatibility in the middle layers of sample E.

In terms of Tensile Strength (TS), the highest rate of TS belonged to a KBFw/EFB hybrid reinforced PHB biocomposite with 11 layers (sample E). The hybridization process has the potential to increase TF when NFs with a high TS (KBFw) are used.

For Flexural Strength (FS), the highest TS is belonged to KBFw/EFB hybrid reinforced PHB biocomposite with 11 layers (sample E). The flexural stiffness of the biocomposite increased for the KBFw PHB biocomposite hybrid with FEB reinforcement. Stiffness is directly related to Flexural Modulus (FM), and EFB fibres with high toughness have a positive effect on flexural modulus.

Besides, the impact property of composite is the capability of a biocomposite to resist fracture under stress applied at high speed. The impact strength of a KBFw PHB biocomposite increased due to the high toughness of oil palm fibres. The brittle character of bast fibres caused a decrease in impact strength.

A Scanning electron microscope (SEM) was used to analyze fractured specimens from the tensile test. The adhesion between PHB as a matrix, KBFw, and EFB was shown in the fracture surface micrographs of the tensile test samples. SEM showed tensile fractures that were smooth and soft fibres with high tensile strength were used as the skin of a hybrid biocomposite. The SEM of sample E with 11 layers had low porosity and smooth fractures.

These result (Table 5) are highlighted for using in some application which is needed the high rate of common mechanical test (tensile and flexural strength) such as some wood and woody production. Totally, the materials used in construction, such as wood, engineered wood products and short-fiber reinforced polymers composite have properties most similar to the biocomposite materials. While concrete, steel, and long-fiber reinforced polymers composite have significant negative environmental and human health impacts during their life cycle. Based on common mechanical tests (tensile and flexural test) of some wood and woody production; the average value of strength is between 50 and 100 MPa, and the average value of modulus elasticity is between 7 and 14 GPa (Fyfe, 2008).

So the result from tensile and flexural test of KBFw/EFB hybrid reinforced PHB biocomposite with 11 layers (sample E) is determined that sample E has capability to replace with some wood and woody production. Further research can be conducted for different biopolymers such as Polylactic acid (PLA). Our results provide a valuable reference for composite professionals who seek to advance composite science using with green composites.

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