Low Energy Impact on the Short Kenaf Fibre Reinforced Epoxy Composites: Effect to the Residual Strength and Modulus

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ABSTRACT

In this investigation, the effect of low energy impact to the residual strength and modulus of short kenaf fibre reinforced epoxy composites were investigated. The composites were made from hand lay-out technique and subjected to low impact energy at the 20%, 25% and 30% of impact failure values. The load-time curve exhibited the damage states of unreinforced epoxy specimens and short kenaf fibre reinforced epoxy composites. The research found that the low energy impacts were affecting the residual strength and residual stiffness which indicated the short kenaf fibre reinforced epoxy composites were extremely sensitive to the impact loads. The damages were manifest by the visible observation of cracks on the specimens

Keywords: *Kenaf, Polymer composites, Low energy impact*

Introduction

Natural fibres have been emerging as the potential reinforcement material for composites because of their applicable benefits. It offers great versatility such as low density, renewable, biodegradability and environmentally harmless. Therefore, this natural product has a potential for use in engineering application while remain in cheap and affordable [1]-[3]. Kenaf (Hibiscus cannabinus, L.) is one of those abundance natural fibres that gains attraction by many researchers around the world. The fast growing plant, rising height to 4-5 m in within 4-5 months would give the opportunity to produce products similar to that material of wood [4]. It has been reported the uses of natural fibre composites could offer acceptable performances and various advantages as compared to man-made fibres [5-6].

Apart from the continuous fibre composites that has been established in both thermosetting and thermoplastic matrix, short fibre composites are one of the considerations for the engineers in designing the components. The short fibre composites are often required for the low performances and less demanding application, or when the manufacturing aspect and cost evaluation are unlikely to be achieved as for the continuous fibre. Being reinforcement in composites material, short natural fibre must endure and survive on various impacts loading in different environments during its service life. Impact damage can occur during production process, maintenance (i.e. dropped tools) or flying scrap that crashes to the composite body. Impact damage is a catastrophic failure that can be visibly noticed by engineers. In contrast, low impact energy is even complicated and the damages are always harder to detect. The low impact energy creates major influences on the impact responses of the material and the structural integrity of the component.

The studies of the impact properties on fibre reinforced in polymer composites are increasing over the time. It has been well documented in the literatures by many scholars. Some of the authors presented the experimental and numerical analysis of the low energy impact of glass fibre and carbon fibre reinforced in polymeric composites [7]-[9]. The studies of impact properties natural fibres are growing fast [10]-[12], with positive outcomes but still insufficient to warrant the short natural fibre as reinforcement in polymer composites. It appears that natural fibres polymer composites are sensitive to the impact loading [13] and also, the complexity of lignocelluloses fiber itself that affects to the strength of composites, are less understood.

In this investigation, the short kenaf fibre reinforced epoxy composite were initially subjected to impact test for determining its impact failure. Subsequently, the data was used to characterize the post impact behaviour under varies low impact energy by using a falling weight impact tester. The evaluation of composites damages was manifest by the residual strength and residual stiffness that were measured under tensile tests. The data obtained from the study could be beneficial into the study of natural fibre polymer composites.

Methodology

In order to characterize the residual strength and stiffness (measured from tensile testing) of the specimens, the composites undergone a series of low velocity impact test (3 selected values of low energy impact) to accumulate the degree of damages. The undamaged specimens and unreinforced specimens were used as references. The breakage specimens from impact and tensile test were examined using SEM for microstructure evaluation while the photograph of impacted specimens was useful to propound any further evidence.

Materials Preparation

In this work, the short kenaf fibre with length varied up to $3x10^{-3}$ m as shown in Figure 1 below were supplied by Malaysian Agricultural Research and Development Institute (MARDI), Malaysia. The density of raw kenaf provided by MARDI is 1120 kg/m^3. Meanwhile, the epoxy resin and hardener were used as the matrix for the composite samples. The recommended ratio of the epoxy resin and hardener mixture is at 3:1 parts by weight and the curing process should bedone at least 8 hours at room temperature for satisfactory results.

Figure 1: A close-up view of the short kenaf fibre

Fabrication of Composites

The fabrications of the composites employed a hand lay-up technique. The percentage of weight fraction was 25%, clean short kenaf fibre constitutes of 0.04006 kg were required whereas the remaining of 75% in liquid (approximately 0.1305 kg) was needed for epoxy resins. The fabrication began with the short kenaf were randomly aligned into a mould cavity (dimensions of 0.230 m x 0.210 m x 0.003 m). The mixture of epoxy and hardener were then poured into the mould before the assembly was tightly closed using the upper mould plate. 1 kN load of cold compression was applied on the mould assembly, ensuring uniform of matrix distribution among the fibres and to remove the air bubbles. The use of mould release agent coated on the mould surfaces was significantly benefits to prevent samples from sticking onto the mould after curing process. The assembly was left overnight at room temperature for curing process before harvested. The dimension of specimens was in accordance to the BS EN ISO 527 standard for tensile and impact evaluations, shown in Figure 2. The specimens were machined cut from the plaque using a diamond cutter to the required standard dimensions. The edges of the specimens were bonded with aluminium tab to minimize any chance of slippage during impact and tensile loadings.

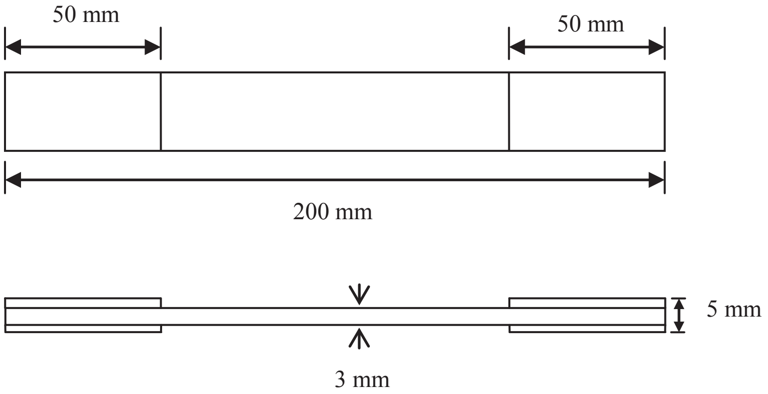


Figure 2: Standard dimension according to BS EN ISO 527 (1997)

Impact Testing

In present investigation, the specimens were initially undergone fully destructive impact test in order to characterize the low velocity impact test. The impact levels of specimens used were 20%, 25% and 30% from its failure impact energy value. The test was performed by using Mini falling weight impact tester with types of steel weight as shown in both Figure 3(a) and Figure 3(b). The specimens were clamped between two steel plates having 0.023 m diameter hole at the centre. Steel weights were added on the impactor.The steel weight was varied according to the required impact energy. The impact energy was calculated as given by the equation below.

$$E = mgh \tag{1}$$

where:

E = Impact energy (J)
m = the mass of the impactor plus any mass added on,
g = acceleration due to the gravity (9.81 m/s^2)
h = the height of impactor from the specimen.

For this test, the height of the impactor was fixed at 0.3 m. The head of the impactor was a hemispherical steel nose with a diameter of 0.127 m. This is the standard shape and size of impactor used in most low velocity impact tests. The impactor was held and released manually.

(a) (b)

Figure 3: Low energy impact equipment consists of (a) Mini Falling Weight impact tester and (b) types of steel weight

Tensile Test

The tensile properties of specimens were determined using a servo-hydraulic testing machine with a 25kN load cell. The lower end of the specimen was first hydraulically gripped with pressure of about 2 kPa. The upper jaw was slowly positioned before the upper end of the specimen was gripped using the same pressure at about 2 kPa. Tensile load was then applied gradually at a displacement rate of 1 mm/min until fracture. All tensile tests were carried out at room temperature of 23^{o}C and 20 specimens were repeated for each sample type. All the data were recorded via the built-in data acquisition system.

Scanning Electron Microscopy

The scanning electron microscopy observations were carried out by using Mini Scanning Electron Microscope utilizing SMARTSEM software. Fractured specimens from all tests were first cut into 0.01 m height in order to fit on top of the stub surface area. It was then coated by thin layer of gold with thickness of 100 μm in order to promote conductivity. Specimens were then observed with varied magnification until desired clear images were obtained.

Results and Discussion

Destructive Impact Test Results

Impact test is one of the techniques to determine the toughness properties when a material subjected to shock loadings. The obtained impact data is used to characterize the post impact test set up. Table 1 showed the summary of the impact test for the epoxy and its kenaf reinforced epoxy composites. Physical observation showed that all the fractured specimens exhibit a clean breakage, a sign of brittle failure.

According to the data, the composites had better impact properties as compared to the unreinforced specimen. The Failure Force improved from 141.64 N to 248.81 N. The similar trend was also observed to the Failure Deformation, it increased from 2.74 mm to 7.44 mm respectively. The impact test estimated the amount of the energy absorbed during fracture of the specimens. In this experiment, the composites absorbed the impact energy at average of 5.32 J, while the epoxy specimens shattered at low level energy of 0.97 J, a rise about 548% with addition of 25% fibre volume ratios in the composite system.

The presented data suggests that short kenaf fibre composites showed significant improvement in impact properties. Impact properties are somehow related to the stiffness, by influences of the good interfacial bond strength between matrix and fibre in composites material [14]. The principal of polymer composite material emphasize that the role of polymer matrix are to hold the fibres in its location and also transmitting the loads to the individual reinforcing fibres within the composites, resulting material with improved impact properties compared to the unreinforced epoxy matrix material. Most of the epoxy exhibits low tensile strain and they are considered as a brittle by nature. These brittle properties often show low level of impact properties [7]. The effect of integrating of ductile matrix combined with short kenaf fibre volume ratios could be another interesting topic to be explored.

Table 1: Summary of the falling weight impact test

Sample type	Epoxy		Composite	
	Mean	SD	Mean	SD
Failure Force (N)	141.64	65.02	248.81	25.23
Failure Deformation (mm)	2.74	0.76	7.44	1.15
Failure Energy (J)	0.97	0.19	5.32	0.41

Many investigations in the past concluded that the failures of composites were attributed to combination of matrix cracking, fibre de-bonding, delamination and fibre breakage [15]. Some of these failures were depicted on the fracture specimens scanning under SEM shown in Figure 4. The fibre pull-out and fibre breakages were typically found in the fracture specimens. There were matrix voids however, those were minimal.

Many authors proposed the first damage in composites occurs due to matrix cracking before subsequent fibre breakages, fibre pull-out and fibre matrix debonding by examining its mechanical behaviour under fatigue and tensile loading [9][16-17]. The damages are gradually developed or happened in stages. In contrast, the impact test is a rapid destruction process and determining which type of damages came first is always complicated.

Referring to the research published by Dhakal and co-worker [12], the load-time curve could explain the damage stages in current investigation.Figure 5 showed the responses of the specimens when it was subjected to impact loading. In contrast to the unreinforced specimens, the curves of the composites peaked at the highest load, followed a rapid fall afterwards. Here, the damage stated of the epoxy and its composites can be understood clearly. At point 1, the impactor hit the specimens and it sustained the progressive loads up to the point 2. The point 2 showed the highest peaks of epoxy specimens, that may resulted from matrix crackings initiation before it fractured suddenly. Due to the reinforcement of short kenaf fibre, the composites sustained even further loads up to point 3 but the matrix cracking were remained exist and grew up to point 3. The size and extent of matrix cracking at point 4 in epoxy specimens caused severe fibre matrix debonding and fibre fractures in composites material until the specimens were completely fractured at point 5.

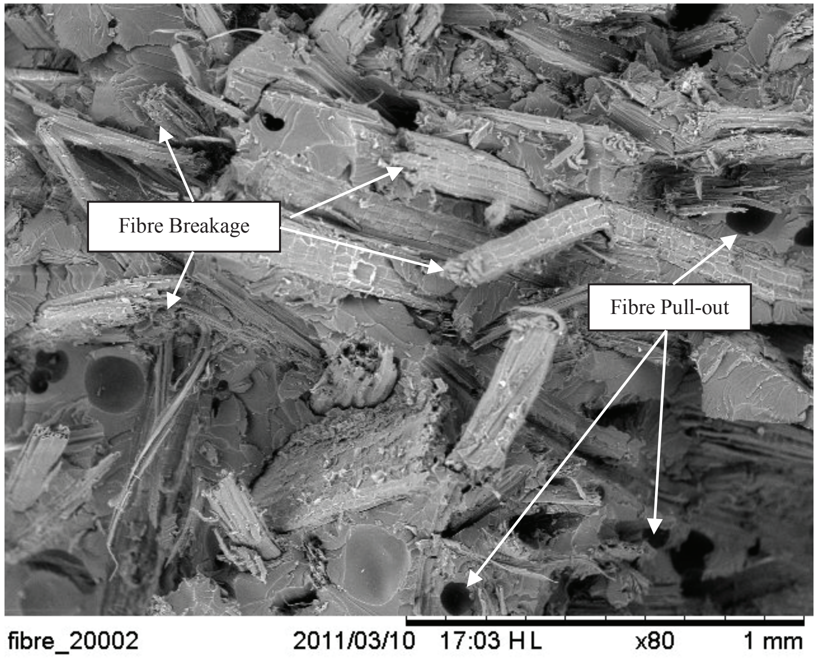


Figure 4: SEM micrographs of impacted surface of composites. The evidence of fibre pull-out and fibre breakages can be observed

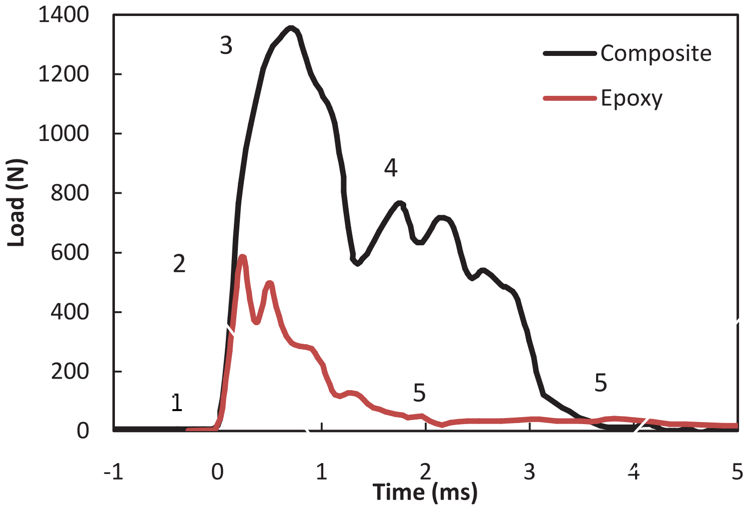


Figure 5: Typical load-time curve of epoxy and composite

Effect of Low Velocity Impact

The residual strength and residual stiffness results after low energy impact test were tabulated in Table 2. The data showed that the tensile strength of the specimens reduced to 15.1 MPa, 9.9 MPa and 4.9 MPa respectively after the specimens were impacted at 1J, 1.3J and 1.6J impact level compared to the undamaged specimens (22 MPa). Similar trend were observed to the residual stiffness, it fell to 2.7 GPa, 2.1 GPa and 1.2 GPa respectively. The undamaged specimen was recorded at 2.9 GPa.

The results agreed with the previous testing reported by Tong Yuanjian and co-worker [10] as the increment of impact energy resulted in reduction of the tensile strength at all impact energies up to 25J in glass fibre reinforced polyester resin composites. In present investigation, the low energy impacts were affecting the residual strength and residual stiffness of short kenaf fibre reinforced epoxy composites. The toughness resistance was significantly reduced by increased of the impact energy level.

Table 2: Residual strength and Residual Stiffness

Impact Energy (J)	**Undamaged**		**1**		**1.3**		**1.6**	
	Mean	**SD.**	**Mean**	**SD.**	**Mean**	**SD**	**Mean**	**SD**
Residual Strength (MPa)	22.0	2.485	15.1	2.137	9.9	1.406	4.9	1.641
Residual Stiffness (GPa)	2.9	0.080	2.7	0.096	2.1	0.086	1.2	0.370

The impact damage tolerance of composites can be understood by normalizing the residual strength or residual stiffness values with the increasing impact energy. The normalized was obtained by dividing residual strength or residual stiffness values at each impact energy level by undamaged respective values of the composite. In Figure 6, the composites lost about 30% of their residual strength and 10% of their residual stiffness at 1.0J impact energy level. These amounts reduced to 55% for the residual strength and 30% for the residual stiffness when the impact energy increased up to 1.3J. However, the final 1.6J impacted specimens showed a significant finding. While the residual stiffness only reduced to 60%, the residual strength on the other hand lost about 80% of its life although it was impacted 30% from its failure impact energy of 5.32J. The data indicates that the residual strength was the most affected when compared to the residual stiffness.

Therefore, the used of short kenaf fibres reinforced epoxy composites would give benefits by enhancing its impact properties as compared to the unreinforced brittle specimens. However, the short kenaf fibre reinforced epoxy composites suffer large amount of damages due to low energy impact, were evidenced by the low amount of the residual tensile strength and residual stiffness. The data obtained from this research have a good agreement with previous research [10,13].

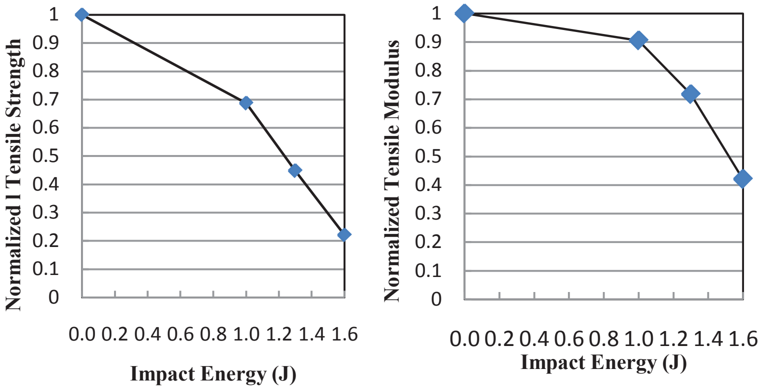
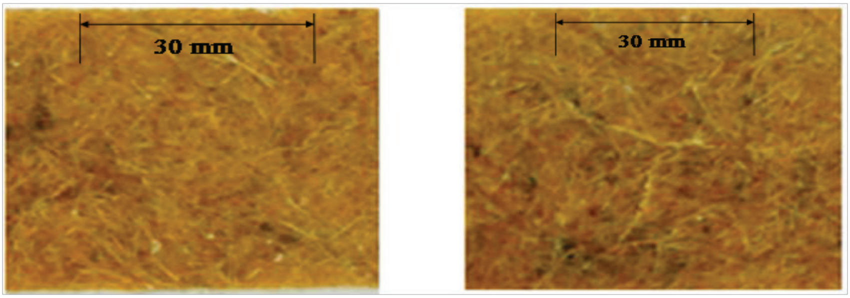


Figure 6: Effect of impact energy on residual: (a) tensile strength of composites and (b) tensile modulus

Using a digital camera to photograph images of the specimens after low energy impact test, any degree of damages can be described. The impacted specimens were examined in faces which were front face and back face respectively. It showed that the damage effect of impact forces were more severe on the back faces of the specimens compared to the front faces. It was barely visible effect in the front face specimens of 1.0J impact energy as shown in Figure 7(a). However, there was a presence of visible crack on the back faces of 1.0J impact energy specimens shown in Figure 7(b). The small amount of impact energy was able to initiate cracks on the surfaces of the specimens.

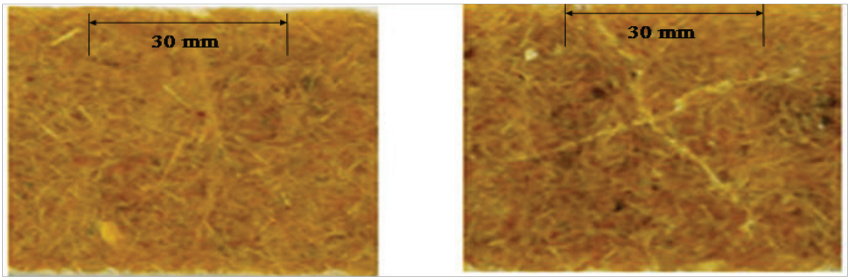
Increasing the impact energy to 1.3J had resulted in more deterioration on the surfaces area of the specimens as shown in Figure7(c) and Figure 7(d). Visible crack were noticed even on the front face of the 1.3J impact energy specimens whereas larger and noticeable area of crack were observed on the back face of the specimens. On the other hand, Figure 7(e) and Figure 7(f) showed the dented surfaces that were impacted by 1.6J impact energy. Increasing the impact energy to 1.6J had resulted in more severe damages as compared to other types of specimens with noticeable larger crack propagation areas. It was noted that cracks were visible in both front and back faces of the specimens.

All images indicated similar fashion of the cracks that attributed to matrix cracking. Referring to the impact responses at point 2 in Figure 5, the cracks could be explained. This is where the matrix started to crack on particular impact energy.The matrix cracking might subsequently followed by other damages; fibre breakages and fibre pull-out.



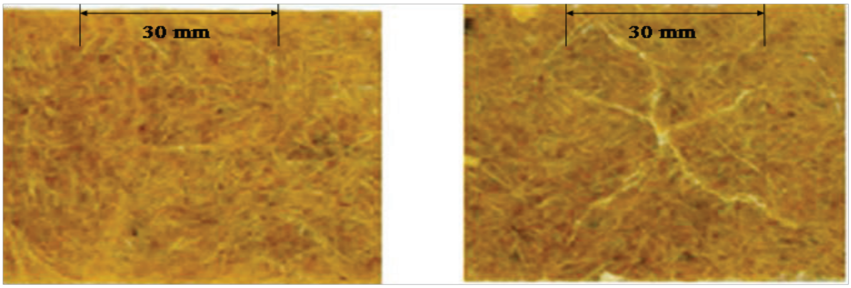
(a) Front face of 1J Impacted Composite

(b) Back face of 1J Impacted Composite



(c) Front face of 1.3J Impacted Composite

(d) Back face of 1.3J Impacted Composite



(e) Front face of 1.6J Impacted Composite

(f) Back face of 1.6J Impacted Composite

Figure 7: The photographed of impacted specimens subjected to 1J, 1.3J and 1.6J manifest by front face and back face

Conclusion

Low energy impact tests were conducted on randomly short kenaf fibre composite materials to evaluate the degree of damages in term of residual strength and stiffness. A twenty five percent of fibre volume composites were fabricated using hand layout technique. The result indicates the composites have better impact properties as compared to the unreinforced specimen. It was observed in this work that the highest impact energy up to 30% was affecting residual strength the most as compared to residual stiffness. The impacted specimens were photographed on the front and back faces. Visible cracks could be noticed and grew as the impact energy increased. Therefore, it appears from this study that the matrix cracking was corresponding to the initial damage of composite.

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