Correlation of manufacturing defects and impact behaviors of kenaf fiber reinforced hybrid fiberglass/Kevlar polyester composite

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Abstract: In this study, the impact properties of kenaf fibre reinforced hybrid fiberglass/Kevlar polymeric composite was investigated. In this study, a new fiber arrangement based on kenaf bast fiber as reinforcement to the hybrid fiberglass/Kevlar fiber and polyester as matrix used to fabricate the hybrid polymeric composite. Five different types of samples with different of kenaf fiber content based on volume fraction (0, 15, 45, 60 and 75%) to hybrid fiberglass/Kevlar polymer composites were manufactured. 0% of kenaf fiber has been used as control sample. The results showed that hybridization has improved the impact properties. These results were further supported through SEM micrograph of the manufacturing defects of the polymer composite. Based on literature work, manufacturing defects that occurs in composite system reduced the mechanical properties of the material. Therefore, in this research the correlation of impact behaviors and manufacturing defects of kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite has been successfully done. As conclusion, the highest manufacturing defects determined in the composites during the fabrication significantly lowest the results of impact behavior.

Keywords: hybrid composites, manufacturing defects, materials selections, natural fiber composites, scanning electron microscopy.

Korelacja defektów produkcyjnych i odporności na uderzenie poliestrowego kompozytu hybrydowego włókno szklane/Kevlar wzmocnionego włóknem kenaf

Streszczenie: Zbadano udarność hybrydowego kompozytu polimerowego na osnowie żywicy poliestrowej napełnionej włóknami szklanymi i kevlarowymi wzmocnionego włóknem łykowym kenaf. Wytworzono pięć próbek różniących się zawartością włókien kenafu (0, 15, 45, 60 i 75% obj.) Próbkę kontrolną stanowił kompozyt z 0% obj. udziałem włókien kenaf (0%). Wykazano, że hybrydyzacja wpłynęła na poprawę właściwości udarowych wyjściowego kompozytu. Wyniki potwierdzono analizą SEM defektów produkcyjnych otrzymanego kompozytu. Stwierdzono, że zachodzi korelacja między wytrzymałością na uderzenie a wadami produkcyjnymi badanego hybrydowego kompozytu poliestrowego wzmocnionego włóknami kenaf. Powstałe podczas produkcji wady produkcyjne w istotnym stopniu pogarszają właściwości udarowe kompozytów.

Słowa kluczowe: kompozyty hybrydowe, wady produkcyjne, dobór materiałów, kompozyty z włókien naturalnych, skaningowa mikroskopia elektronowa.

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Generally, most of the research published related to composite materials concern on developing and redesigning with the aim to improve and to adapt traditional products and introduce new products in a sustainable and responsible way [1]. In the last few years, there have been a stringent consumer's awareness towards new products from renewable sources. Green marketing, new directives on recycling, social influence and change of cognitive values has led the consumer towards environmentally friendly products [2–4]. In Malaysia, kenaf fiber is recently commercially used in the natural fiber composite industries due to their low density, no health risk, high specific strength and modulus and renewability. Besides all the advantages stated above, natural fibers composites also have a few disadvantages such as low mechanical properties, low impact strength, poor moisture resistance, poor microbial and fire resistance, and low durability properties. In order to enhance the capabilities of these natural composite materials several researchers have tried combining two or more different fibers to attain a new material called hybrid composite with new and upgraded performance properties.

Hybrid material is a combination of two or more materials to harvest new material properties with improved strength and stress. Hybrid composite material usually produces improved properties than non-hybrid composite. In other hand, as has been published previously, the main factor affecting mechanical performance of natural fiber reinforced composites are fiber selection, matrix selection, interfacial strength, fiber dispersion, fiber orientation, composite manufacturing process and porosity [5]. Also has been reported by Oqla and Salit [6], the performance of the natural fiber composites depends directly on the fibers counting, length, shape, arrangement, and the interfacial adhesion with the matrix.

Nowadays, the application of natural fiber (NF) reinforced hybrid composite has been widely used for engineering application in a various field including maritime especially in composite boat construction. In this study, the new application of natural fiber reinforced hybrid composite materials is performed. Impact behavior were studied. Also, correlation between impact behaviors and manufacturing defects analyzed.

Manufacturing defects are typically occurred during the commercial production of composites. It can be caused by batch-to-batch variations in the prepreg and sometimes by the manual construction known as a lay-up. Manufacturing effects variability could arise from differences in the prepreg tack level during lay-up because of variable resin content. The composites can contain several defects introduced during manufacturing, which can considerably increase the likelihood of composite failure. The defects are classified as voids, resin-rich zones, pocket of undispersed cross-linker, misaligned fibers, and region where resin has poorly wetted the fibers [7, 8].

EXPERIMENTAL PART

Materials

A treated kenaf bast fiber with density of 1.16 g/cm^3 provided by the Institute of Tropical and Forest Product (INTROP), UPM, Serdang, meanwhile fiberglass and Kevlar with 23 cm length were provided by MSET Inflatable Composit Corporation Sdn. Bhd. used in this study as the reinforcement to fabricate the hybrid composite. The raw kenaf bast fibers were combed to disrupt and untangle the strong bonds between individual fibers. Bernard *et al*. [9] reported that combed fiber exhibits stronger mechanical properties than uncombed fiber. The kenaf bast fibers with the diameters of 3 to 5 cm approximately were cut to a length of 23 cm using scissors. Polyester resin used were produced by MPI Polyester Sdn. Bhd located in Shah Alam, Malaysia. The density of polyester resin used as a matrix material stated as 1.12 g/cm^3.

Fabrication of hybrid polymer composite

The hybrid polymeric composite samples were prepared by using kenaf fiber reinforced hybrid fiberglass/Kevlar and polyester resin as a matrix. The samples were fabricated using a hand lay-up process in a mold steel. As has been published by previous researcher, one of the main obstacles that need to be addressed in the fabrication of kenaf fiber reinforced composites is the uneven fiber distribution in the composite system and Zampaloni *et al*. [10] pointed out, kenaf fibers are difficult to manually separate and visually disperse evenly during manufacturing. All the samples have been finished with a roller to roll it on the hybrid composite surfaces to avoid some voids and bubbles in the samples. Rolling the surface helps the matrix that exceed toward the area being rolled consequently pushing the air and bubbles out from the samples. Then, the mold with the composite sample, compressed using the composite hotpress compressing machine at a temperature of 70°C and a pressure of 5 MPa. The samples were prepared in different percentage of volume fraction (vol %) of kenaf fiber to hybrid fiberglass/Kevlar polymeric composite as 0%, 15%, 45%, 60% and 75% based on volume fraction. 0% of Kenaf fiber to polyester matrix composite has been used as a control sample.

Methods of testing

Impact test

The kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite samples were cut using into the dimension of 15 × 10 (cm^2) at thickness 0.5 cm according to the ASTM E23 [11] for the Charpy low velocity impact test. In the Charpy low velocity impact test, a pendulum with a defined mass attached to a rotating arm connected to machine body. Pendulum falls from a high with the angle of 131° and hit the test samples and the sample absorbs part of pendulum kinetic energy. The absorbed impact energy and impact strength of material were calculated by the equation (1) and (2) as follow:

$$E = E_1 - E_2 \tag{1}$$

$$U = E/(bh) \tag{2}$$

where: E – determined as the absorbed energy after impact, U – the impact strength, E_1, E_2 – initial and final potential energies, b, h – width and thickness of the specimen, respectively.

Scanning electron micrograph

Scanning electron micrograph on kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite sample is carried out using Scanning Electron Microscope (SEM) model Hitachi S-3400N. SEM was used to determine the manufacturing defects of kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite before the impact test and to verify the results of impact properties obtained from impact test. The dimensions for SEM specimens were 0.5 × 1.5 (cm^2) prepared at same thicknesses of 0.5 cm. All specimens were cut using an electrical handsaw. The surfaces of the specimens were coated with a mixture of 80% gold and 20% palladium.

RESULTS AND DISCUSSION

Impact behaviors

The energy absorption and impact strength of kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite were investigated by the Charpy low velocity impact test. In this study, the unnotched specimen were subjected to same energy level which are the impact load of 30.25 kg and the angle is 131° at room temperature. Durability of kenaf fiber plays a vital role in controlling the serviceability for a long term. Figure 1 shows the comparison of energy absorbed capability at the different kenaf fiber content in the composites under the same impact energies. Hence, the Charpy low velocity impact energy absorbed of the different kenaf fiber content shows that almost the same behavior when tested under the same energy level. Figure 1 depicts the energy absorbed values of specimens with respect to kenaf fiber contents.

It observed, there is an increment in the total energy absorption by the samples up to 60% and at the 75%, it shows the decrement. The energy absorption of the samples: 0% (control sample), 15%, 45%, 60% and 75% are 3.05, 3.97, 5.57, 8.71 and 5.00 J, respectively. The level of the maximum energy absorbed reached for the 60% of kenaf fiber content is the highest value under the same energy level. There are no significant differences in the energy absorbed that can be observed in control sample.

The energy absorbed tend to decrease at 75% fiber content, due to the lower percentage of the polyester resin to the kenaf fiber reinforced hybrid fiberglass/Kevlar polymer composite.

This may cause uneven polyester resin distributes to fibers or poor-wetting resin area, weak interfacial adhesion between the fibers (reinforcement) and resin (matrix), delamination affect the total absorption of energy values as has been also claimed by Hyseni, De Paola, Minak and Fragassa [12]. However, the amount and the type of failure mechanism depend on the impact energy level and mechanical properties of the fiber and matrix [13]. Figure 2 depicts the result of impact strength of kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite after the low velocity impact test with respect to different kenaf fiber content.

As has been reported by Joffe and Anderson [14], it could be attributed to the increases of the stiffness of the composite by increases of fiber content to reinforced thermosetting plastics. It was clear that, for the composite sample with 60% kenaf fiber content, higher values of impact strength record compared to other samples.

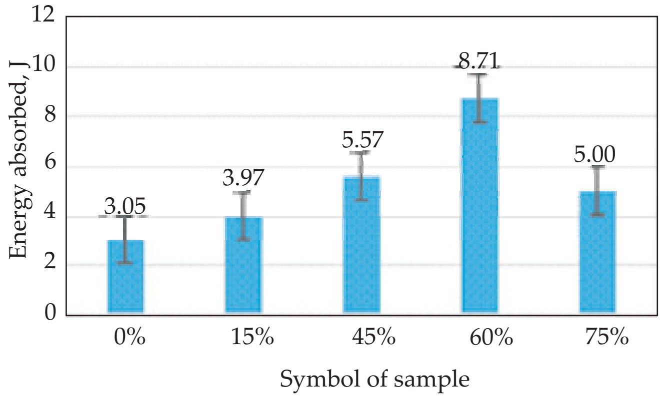

Fig. 1. Energy absorbs of kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite with respect to kenaf fiber content

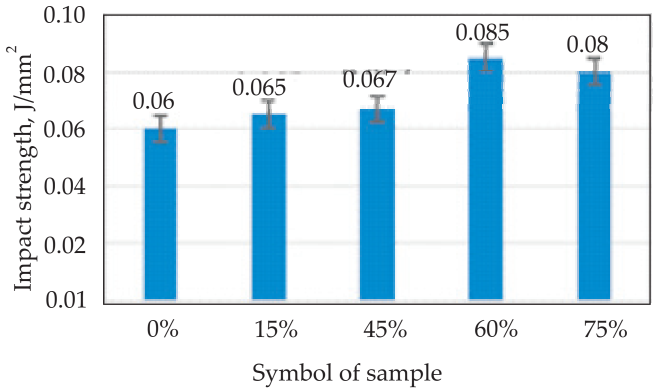

Fig. 2. Impact strength of kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite with respect to kenaf fiber content

T a b l e 1. Impact strength kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite

Symbol of sample	Energy absorbed J	Width mm	Height mm	Area mm^2	Impact strength J/mm^2
0%	3.05	10	2.50	25.0	0.060
15%	3.97	10	6.10	61.0	0.065
45%	5.57	10	8.31	83.1	0.067
60%	8.71	10	10.21	102.1	0.085
75%	5.00	10	10.48	104.8	0.048

This is attributed to the fact that the increase of fiber content above 60% causes the lack of energy absorption. It is because the kenaf fiber content of 75% has reaches beyond the threshold value.

In general, the impact energy strongly depends on the percentage of the fiber content. Furthermore, low interfacial shear stress between natural fiber and polymer resin might contribute to the increase in the composite strength. In other facts, the incorporation of lignocellulosic fibers offers the challenges to the propagation of an initial crack longitudinally through the interface following the specimen length direction.

Indirectly, as depicts in the Fig. 2 and tabulates in Table 1, we can conclude that the Charpy low velocity impact toughness seems to have the same impact energy and impact strength behaviors. It is clearly seen that the composite material with 60% kenaf fibers content have the greatest impact toughness value of 0.085 J/mm^2. As the research study has been reported, both fiber content and properties of the polymer are accountable for deciding the impact toughness [13, 14]. This implies that both effect of interlaminar delamination and interfacial adhesion between fiber and matrix highly decide impact properties [15].

Determination of manufacturing defects

Surface characterization by SEM micrograph was performed to understand more about the correlation between manufacturing defects and impact behaviors of the 75% kenaf fiber reinforced hybrid fiberglass/Kevlar polymer composite. The SEM micrograph verify the results of the Charpy low velocity impact test.

Figure 3 depicts a weak interfacial adhesion between the fiber and matrix in the region where resin has poorly wetted the fibers. There is a gap clearly observed in between fiber and matrix.

In the Fig. 4, voids can be clearly observed on the sample surface of 75% of kenaf fiber reinforced hybrid fiberglass/Kevlar polymer composite. Voids are usually defined as air bubbles trapped in the matrix during composite fabrication, but voids can be caused by many factors. Voids will affect mechanical properties indirectly by enhancing the moisture pick-up and degradation of the interfacial adhesion of the fiber matrix [16, 17].

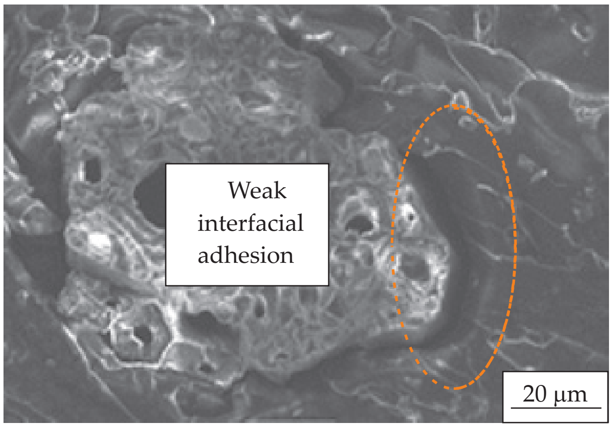

Fig. 3. Weak interfacial adhesion between fiber and matrix of 75 vol % kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite

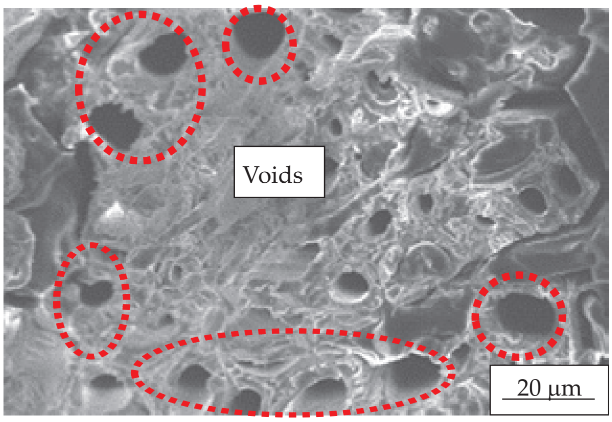

Fig. 4. Voids clearly observed in 75 vol % kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite

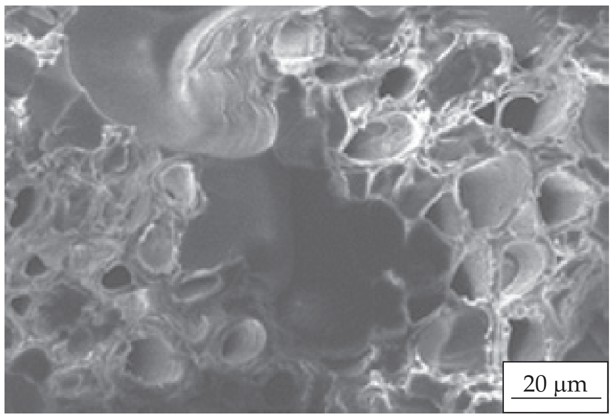

Fig. 5. Fiber pull-out in 75 vol % kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite

Figure 5 depicts SEM micrograph of fiber pull-out in 75 vol % kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite system during the fabrication process. Fiber pull-out mainly occurred due to the resin that not distributed well through the fiber surface. Therefore, these phenomena consequently affected the interfacial between fiber and matrix as well as fiber pull-out.

Correlation of impact properties due to manufacturing defects

The amount of energy and impact strength are correlated directly and both of absorbed energy and impact strength are influenced due to manufacturing defects. As report by Scheirs [7], the manufacturing defects such as voids, resin-rich zones, pocket of undispersed cross-linker, misaligned fibers, and region where resin has poorly wetted the fibers found in composite during the fabrication. Figures 3, 4, 5 depict the SEM micrograph of 75 vol % of kenaf Fiber reinforced hybrid fiberglass/Kevlar polymeric composite observed manufacturing defects. In this study, the impact strength and energy absorbed tend to decrease at 75% of kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite when the load is applied to the surface during the impact test. This is happened due to weak interfacial adhesion between fiber and matrix as depicts in Fig. 3, affected the load distributed unevenly. Consequently, will caused the sample experiencing fracture mechanism and failure. This is also claimed by Shaari *et al*. [17], in their study of impact behavior of Kevlar reinforced hybrid polymer composite.

In the Fig. 4, voids can be clearly observed on the sample surface of 75% of kenaf fiber reinforced hybrid fiberglass/Kevlar polymer composite. Voids, as mentioned before, are usually defined as air bubbles trapped in the matrix during composite fabrication, but voids can be caused by many factors. Voids can also occur owing to the presence of impurities in the commercial epoxy resins used for the fiber-reinforced composites, which can lead to a significant impact on the cure behavior of the resin. Therefore, voids occurred in the samples of 75 vol % kenaf fiber reinforced hybrid fiberglass/Kevlar polymeric composite significantly affected both of impact strength and energy absorption. During the fabrication process, the sample with the high ratio fiber content to matrix may having the area which is poorly wetted with resin. The area with poorly wetted with resin experienced the fiber pull-out and when load is applied to the composite surface, it will significantly be promoted to composite failure [18, 19]. Therefore, it is important to determine the optimum ratio of fiber to matrix in fabricating the composite samples. The phenomena of fiber pull-out in the composite system may affect the low performance of mechanical properties and it has been reported in the literature by Li *et al*. [20].

CONCLUSION

It can be concluded, the energy absorbed and impact strength of kenaf fiber reinforced fiberglass/Kevlar hybrid polymeric composite increases with the increasing of kenaf fiber content from 15, 45 and 60 vol %. The energy absorption and impact strength of 75 vol % of kenaf fiber reinforced fiberglass/Kevlar hybrid polymeric composite decreased at 75% due to manufacturing defects as weak interfacial adhesion, voids, and fiber pull-out. Therefore, kenaf fiber reinforced fiberglass/Kevlar hybrid polymeric composite shows the highest value of energy absorbed and impacts strength at 8.71 J and 0.085 J/mm^2, respectively. The manufacturing defects as weak interfacial adhesion, voids and fiber pull-out had directly influenced the performance of impact behaviors of kenaf fiber reinforced fiberglass/Kevlar hybrid polymer composite. In addition, the manufacturing defects that occurred in the composite must be considered seriously because it is significantly reduced the mechanical properties of the composites. The good composite is mainly consisting of the least of manufacturing defects. The highest manufacturing defects determined in the composites during the fabrication significantly lowest the results of impact behavior.

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