A Review on the Perforated Impact Energy Absorption of Kenaf Fibres Reinforced Composites

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Abstract. This paper reviews the potential of mechanical energy absorption of natural fiber reinforced composites subjected to perforated impact. According to literature survey, several research works discussing on the impact performances on natural fiber reinforced composites are available. However, most of these composite fibers are randomly arranged. Due to high demand for sustainable materials, many researches give high attention to enhance the mechanical capability of natural fiber composites especially focused on the fiber architecture. Therefore, it is important to review the progress of impact energy absorption on woven fiber composite in order to identify the research opportunities in the future.

1. Introduction

Natural plant fibres can be economically and ecologically useful alternatives to reinforcement fibres in polymeric composites. Due to their low density and low cost in comparison to conventional fibres, natural fibre reinforced composites have great potential in engineering applications. A growing environmental awareness across the world has aroused interest in research and development of environmentally friendly and sustainable materials. Natural plant based fibres are used as reinforcements for composite materials and give various advantages as compared to conventional fibres.

In recent years, industries are attempting to reduce the dependence on petroleum based fuels and products due to the increasing of environmental consciousness. This leads to investigate environmentally friendly and sustainable materials to replace the synthetic fiber. The increasing of productions and consumption of plastics in every sector of our life and is lead to huge plastic wastes. Due to disposal problems, as well as strong regulations and criteria for cleaner and safer environment, have directed great part of the scientific research toward eco-composite materials. Among the different types of eco-composites, those which contain natural fibres (NF) and natural polymers have a key role to overcome a problem [1].

Few studies deal with structural based on natural reinforced composites. These studies are mainly oriented to the housing applications where structural panels and sandwich beams are manufactured out of natural fibres and used as roofs. Considering the high performance standard of composite materials in terms of durability, maintenance and cost effectiveness, the application of natural fibre reinforced
composites as construction material holds enormous potential and is critical for achieving sustainability. Due to their low density and their cellular structure, natural fibre possess very good acoustic and thermal insulation properties and demonstrate many advantageous properties over glass or rockwool fibre, for instance in example handling and disposal material [2]. Recently, some of studies have been carried out to determine the effects of various variables on energy absorption capability of composites material under compressive loading [3, 4].

![Figure 1. Comparison of specific modulus of kenaf fibre with several other fibres [5]](image)

One of the main important aspects of the behaviour of natural plant fibre reinforced polymeric composites is their response to an impact load and the capacity of the composites to withstand it during their service life. Such damage may be caused by bumps or crashes and falling objects and debris. Some of the reported work [4, 5] has suggested that natural fibre composites are very sensitive to impact loading. The major drawback is its low impact strength as compared to glass fibre reinforced thermoplastic and thermosets composites. In the broader context, assessing the impact resistance of a composite material is always difficult since the damage manifests itself in different forms such as delamination at the interface, fibre breakage, matrix cracking and fibre pulls out. Due to their complexity, many of their characteristics still remain unresolved.

In this work, it is started with the review of energy absorption of natural fiber, included advantages of kenaf fibre. Then, it is discussed on the characteristic between woven and non-woven of natural fibre which is focusing the strength of various numbers of layers and orientations.

2. Energy Absorption Factor in Natural Fiber

2.1 Advantages of kenaf fiber

Natural fibre is widely used in composite application, and has many advantages which is low cost, low density, have high specific properties, non-abrasive and less harmful during handling. In the research of kenaf natural fibre is increasingly interested among researchers [5, 6]. In summary, a comparative study of mechanical properties of kenaf fibre reinforced composites and other natural fibre are collected together. The characteristic strength of natural fibre is important to determine material ability, especially under extreme and critical condition, which is directly connected with engineering performance.

Figure 1 illustrates that kenaf composite have higher modulus as compared to other fibres. In this research, kenaf fibres are selected based on their capability of modulus strength [7]. The mechanical properties of the kenaf fibre can be seen in Table 1. Flexural properties were not available from the manufacture hence values for a similar product from another manufacture are used in their research.
Table 1 Properties of Kenaf Fibre [7]

| Property               | Unit  | Kenaf Fibre |
|------------------------|-------|-------------|
| Tensile strength       | MPa   | 350-600     |
| Elastic modulus        | MPa   | 40,000      |
| Elongation at break    | %     | 2.5-3.5     |
| Flexural strength      | MPa   | N/A         |
| Flexural modulus       | MPa   | N/A         |
| Density                | Kg/m3 | 1500        |

2.2 Characteristic of woven and non-woven

Woven composite are widely used on glass fiber [8-10], but glass fiber is very expensive and higher cost to manufacture. According Rizal et al., their research focus on the prediction of progressive failure in woven glass/epoxy composites. Most of the previous research, extensive used of plain weave on their fabric as shown in Figure 2. On the other hand, plain woven can absorb more energy, were perforated by higher force and their perforations were completed at higher deformation in comparison to other woven fabric during bursting strength and impact test.

![Figure 2: Types plain woven of natural fibre (a) Jute (b) Flax [12]](image)
According to some literature [13, 14], woven fibre is have good mechanical properties as compare to non-woven. Figure 3 shows the illustration image of unidirectional and woven of jute fabric. Table 2 shows the effect of NWJF (Non-Woven Jute Fabric) and WJF (Woven Jute Fabric) on impact strength of PLLA (Poly L-lactic Acid). The average impact strength of untreated WJF/PLLA composite in warp direction (16.4 kJ/m) is 85.9% higher than the impact strength of unreinforced PLLA. As a result, the strength of the WJF/PLLA fabric composite is greater than the strength in NWJF/PLLA. According to the result, it can be concluded that woven structure exhibited excellent mechanical behaviour under tensile, flexural, and impact loading as compare to non-woven composite. It also mentioned that, tensile, flexural and impact strength of WJF/PLLA composite is higher at warp direction as compared to weft direction.

![Figure 3 Image of (a) unidirectional jute, (b) plain woven jute fabric, (c) non-woven jute fabric composite and (d) plain woven jute fabric composite [14]](image)

2.3 Characteristics of impact tests for different number of layers
According to previous researcher, [15] using different layers to identify capability of fracture toughness. In their research focuses on fabricated composite using long kenaf fiber with woven glass hybrid laminated. In this way, the laminated on layer are not be used in natural fiber only, but also both hybrid on natural and glass fiber. From this research, it shows that by using combination hybrid also can improve of their properties. Figure 4 shows the variation in energy absorbed with different layers [16]. From the Figure 4, there is an increase in the amount of energy absorption by specimen.

![Figure 4 Absorb energy/time traces [16]](image)
hemp reinforced compared without reinforcement. It can be seen that energy absorbed by 1 and 2 layers is less than 3 and 4 layers. As can be seen from the result, 1, 4 and 5 layers of hemp reinforced samples was absorb total energies of 10.558 J and 10.528 J, respectively, which is have a small significant effect. The trend shows that by increasing at layer up to its threshold value the energy absorbed also increase.

2.4 Influence of treatment and untreated
Many of previous research doing comparison properties of composite with treatment and untreated [17-19]. Some of them using distilled water, rain water, sea water [15] and sodium hydroxide (NaOH) [18, 19] for treatment. Many investigations have focused on the treatment of fibres to improve the bonding with resin matrix. As shown in Figure 5, it observed that by using 6% of NaOH to the kenaf fiber was contributed to the better performance of treated compare to untreated. The modulus flexural are increase with 67% for untreated and 74% for treated it can be explained with the fact that the waxy layers on the fibre surface are removed with the assistance of NaOH solution which in turn enhance the interfacial adhesion of the fibre with the matrix. This lead to the carrying loading by the fibre during loading condition; the load is transferred to the fibre and the fibre are be able to carry some of the load.

2.5 Influence of different orientation
According to the research by Sikarwar et al., it can be seen that the energy absorbing capacity are increase with increasing of lamina tes thickness [20]. In their research, the laminates (0/90) lay-up laminates is much higher than other of lay-up laminates. The (0/90/30/-45) absorb more energy than the (0/90/30/-60) orientation. Thus, it is understood that energy absorption is dependent both on failure strain well as on Young’s Modulus. The result in their research can be seen as shown in Table 3.

2.6 Woven fragmentation with different densities
Research by Khalid et al., shows the woven fragmentation using difference densities and layers which is consist of Sample A,B,C and D [21]. Differences composite fragmentation pattern can be observed visually as shown in Table 4. Low speed impact causes fragmentation of the sample A(I) like a star and have fragmentation weft measuring over 20 mm where there is fragmentation fragment surrounding the point of impact on the composite panel. This occurs due to the occurrence of bending before failure on the composite panel. Significant difference can be seen with the fragmentation of the sample A(II) be round and have split weft measuring over 13 mm. Woven structure in high-density composite panels and balanced between warp yarns and weft yarns made of composite panel is fragile and will result in failure to make a full composite panel.
Table 2 Mechanical properties of jute fabrics/PLLA composite [14]

| Lay-up sequence | Thickness | Lay-up sequence | Thickness |
|-----------------|-----------|----------------|-----------|
| 0/90            | 1.5       | 27.09          | 27.73     |
|                 | 3.0       | 36.75          | 38.25     |
|                 | 4.0       | 66.63          | 65.34     |
|                 | 5.0       | 92.43          | 108.37    |
| 0/90/30/-60     | 1.5       | 22.23          | 22.81     |
|                 | 3.0       | 39.78          | 37.50     |
|                 | 4.0       | 57.19          | 49.59     |
|                 | 5.0       | 70.38          | 60.48     |
| 0/90/45/-45     | 1.5       | 23.40          | 21.66     |
|                 | 3.0       | 33.84          | 37.50     |
|                 | 4.0       | 46.20          | 49.59     |
|                 | 5.0       | 67.33          | 58.59     |
| 30/-60/60/-30   | 1.5       | 18.90          | 19.44     |
|                 | 3.0       | 30.37          | 31.74     |
|                 | 4.0       | 42.93          | 39.78     |
|                 | 5.0       | 54.00          | 47.04     |

Table 3 Experimental and theoretically predicted energy absorption capacity of the glass/epoxy laminates [20]

| Sample                      | Tensile Strength (MPa) | Tensile Modulus (GPa) | Strain (%) | Flexural Strength (MPa) | Flexural Modulus (GPa) | Impact Strength (kJ/m²) |
|-----------------------------|------------------------|-----------------------|------------|--------------------------|------------------------|-------------------------|
| 1. Unreinforced PLLA.       | 40 ± 6.3               | 0.36 ± 0.001          | 3.4        | 42 ± 9.7                 | 3.02 ± 0.8             | 8.82 ± 0.9              |
| 2. NWJF/PLLA composites.    | 55 ± 11.5              | 0.867 ± 0.02          | 6.0        | 67 ± 8.4                 | 2.83 ± 1.1             | 13 ± 1.1                |

At warp direction:

| 3. Untreated WJF/PLLA composites. | 81 ± 13.5 | 1.12 ± 0.034 | 3.8 | 82 ± 12.0 | 4.3 ± 0.10 | 16.4 ± 1.8 |
| 4. Treated WJF/PLLA.             | 87 ± 8.5  | 1.42 ± 0.047 | 5.1 | 121 ± 13.4| 5.3 ± 0.10 | 18.1 ± 2.3 |

At weft direction:

| 5. Untreated WJF/PLLA composite. | 71 ± 8.7  | 0.78 ± 0.063 | 4.1 | 81 ± 9.4  | 3.62 ± 0.08 | 14.3 ± 1.5 |
| 6. Treated WJF/PLLA              | 79.2 ± 9  | 0.91 ± 0.057 | 4.2 | 111 ± 8.1 | 4.72 ± 0.05 | 16.6 ± 1.8 |
Table 4 Visual fragmentation inspection [21]

| Type of Sample | Single Layer Composites (I) | Double Layer Composites (II) | Type of Sample | Single Layer Composites (I) | Double Layer Composites (II) |
|----------------|-----------------------------|-------------------------------|----------------|-----------------------------|-------------------------------|
| Sample A       |                               |                               | Sample C       |                               |                               |
| 20 mm          | 13 mm                        |                               | 35 mm          | 27 mm                        |                               |
| Sample B       | 28 mm                        | 23 mm                         | Sample D       | 37 mm                        | 38 mm                         |

Samples B(I), C(I) and D(I) show the effect of impact where the point of impact to be larger and elongated in the direction of the weft yarn has weft fragmentation during 28 mm, 35 mm and 37 mm. However, the sample B(II), C(II) and D(II) had the weft fragmentation during 23 mm, 27 mm and 38 mm. Damage is caused by decreases in tension warp yarns that support the weft yarns creating lacing effects more elongated in the direction weft yarns.

3. Research problem
In the latest years, there have been many researchers involved in this field of natural fibre reinforced plastics [22]. Most of them are based study on the mechanical properties of composites reinforced with short and non-woven fibres [18,23]. According to previous research [16], studied on low-velocity impact response of non-woven hemp fibre reinforced unsaturated polyester composites and only focus on low velocity impact of non-woven natural fibre using varying layers. Sikarwar et al., in their research focus on influence of fibre orientation and thickness on the response of glass/epoxy composites subjected to impact loading [20]. In experimental, glass/epoxy is laminated with orientation in order to determine the energy absorption capacity. Laminate with difference orientation [0/90], [0/90/30/-60], [0/90/45/-45], and [30/-60/60/-30] are used. Sas et al., also studied on orientation permeability of unidirectional fabric. In their study, the characterization of orientation is performed by using numerical analysis ANSYS software [24]. Although there has been research on orientation of material, but commonly uses a unidirectional.

4. Conclusion
Woven typed fiber orientation had not explored widely on kenaf natural fibre. Recently, most of the research focuses on tensile strength and flexural modulus of natural fibre [10, 25]. Energy absorption on woven natural fibre is better than non-woven were proved by previous researches on woven flax fibre has greater embodied energy than a glass fibre [26]. From the result, it can be summarized that woven on natural fiber are produced higher energy compared with non-woven. It is suggested, four layers are sufficient and comparable to the energy absorbed [14]. The effects of woven orientations are stronger than non-woven fibre. Dhakal et al., in their research, only focus on impact loading on fibre glass [16]. According to the author knowledge, lack of information on effect of orientation on impact loading by natural fibre from previous researcher and this field have opportunities in the future.
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