Tensile properties of hybrid kenaf/glass fiber reinforced epoxy composites with different stacking sequence using experimental and FEA simulation method

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Abstract. The conventional overhead transmission line insulators are usually made of glass and ceramics, but the materials are heavy and bulky. Therefore, kenaf fibre was chosen as partial replacement material to be reinforced with Glass/epoxy composite to reduce the weight and bulkiness of the composite structures. This study used Epoxy as matrix and kenaf/glass fibres to reinforce fillers to fabricate the composites in various stacking sequences. Finite Element Analysis (FEA) was carried out using LS-DYNA software to investigate the tensile properties of the hybrid composites. The results showed a significant improvement in tensile values of the modelled composite exhibited by the kenaf/glass fibre. The tensile strength of the hybrid composites was comparable with the Glass/Kenaf/Epoxy hybrid composites' experimental results. About 200% tensile strength improvement can be observed for both experimental and numerical for G/K/G/E sample than pure epoxy samples, thus making the new composite a potential substitute for insulator applications.

1. Introduction

The environmental issues, production cost and the decreasing of petroleum sources are the primary concern for the industrial sectors for the past three decades [1]. Extensive research has been deployed in renewability and sustainability to find a suitable material that can replace the existing conventional materials. This has resulted in an extensive growing interest in studying natural fibres where these natural fibres are used as a reinforcement in polymer matrix composites [2]. Researchers, scientist and polymer engineers are attracted towards natural fibre-based composites. Due to its environmental friendliness, lightweight, high durability, non-toxic and safer health and biodegradable properties. Natural Fibre is considered a potential substitute material that can be used in automotive, construction, furniture, and other mass-production industries [3]. Natural fibres are readily available fibres that can be extracted from animals, plants and mineral resources. Generally, plant-based natural fibres are
suitable for natural reinforcement materials in polymer composites [4]. The most common plant-based natural fibres used in applications are bast and core fibres such as flax, jute, hemp, ramie, sisal and kenaf [5]. Among all the plant-based natural fibres, kenaf is considered cheap renewable material, offering a reasonable choice to commercialize composite materials to advance high-performance engineering products [6]. Kenaf fibre belongs to species of *Hibiscus Cannabinus* derived from plants of the genus *Hibiscus*. Kenaf plants can grow up to more than 3m in height and a base diameter of 3 to 4 cm. Kenaf is ready to be harvested in 4-5 months and consists of 65% core and 35% bast fibres [7]. Kenaf fibre has superior tensile strength, flexural strength, and good impact strength and low density [8].

The tensile characterization of kenaf fibre reinforced polypropylene (PP) composite has been studied by Yuhazri et al. (2017). The author made 6 different samples through a hand lay-up method that consisted of one layer of kenaf fibre in a sample to 6 layers of kenaf fibre. The result showed that the sample consisted of 6 layers of kenaf fibre reinforced P.P. composites achieved 5.531kN and the lowest was performed by one layer of kenaf fibre reinforced P.P. composites (0.613kN) [9]. On a separate note, research was conducted by Kotresh et al. (2014) to study the tendon properties as a part of their study on tendons on the human body. Kenaf fibres were used with various weight percentages (10%, 20%, 30% and 40%) in polyester resin. The experiment resulted in 40 wt. % kenaf fibre reinforced polyester composites having the highest tensile strength, and it was proven that the addition of kenaf fibres led to an increase in tensile strength of the material [10]. Despite its advantages, kenaf fibre application alone will not achieve the required properties targeted for particular application because of the plant based natural fibres characteristics that are hydrophilic [11]. High moisture sensitivity of natural plant fibre can affect the durability of the resultant material [12]. Therefore, the research on hybridization between natural and synthetic fibres has increased as this class of composite material can resolve the drawbacks of single natural fibre reinforced composites. Hybrid composites are generally defined as a composite that consists of two or more types of fibres within a single matrix [13,14,15]. Recent studies have reported that several factors influence the performance of hybrid composites, including fibre orientation, fibre length, stacking sequence, configurations, the intermingling of the fibre and fibre-matrix bonding [16]. Glass fibre is a synthetic fibre commonly used in various applications. It is considered the cheapest among all synthetic fibres and imposed high temperature, non-corrosive, and possesses high tensile strength [17]. Several studies have been conducted to study the effect of hybridization on mechanical properties of composites. Zhafer et al. (2017) compared the flexural and impact strength between varying weight fraction utilized in kenaf/glass reinforced unsaturated polyester composite fabricated by hand lay-up method. The outcome revealed that flexural strength and impact increased with the increasing kenaf fibre and glass fibre loading until 20 wt.% kenaf/10 wt.% glass fibre composite [18].

Meanwhile, another finding by Nurshairatun et al. (2017) on the flexural properties and moisture resistance ability of non-woven kenaf/glass fibre mat reinforced unsaturated polyester (UPE) composites revealed that the existence of glass fibre at the outermost layer of the hybrid composite such as UPE/GF/KF/GF showed highest flexural properties. However, the results of water absorption showed that samples with kenaf fibre at the outermost layer had the highest water absorption due to kenaf fibre's hydrophilic nature [19]. Since the experimental work involves purchasing, preparing, fabricating and testing the material, the experimental works' time can be reduced by the introduction of numerical simulation methods where the experimental work will be conducted by using Finite Element Analysis (FEA) software. The FEA software can be utilized to obtain solutions to a large class of engineering problems involving stress analysis, heat transfer, electromagnetism and fluid flow. A previous research utilized ABAQUS simulation analysis and compared the results with the composites prepared using hand lay-up technique. The percentage of error was calculated to determine the simulation analysis's accuracy to the experimental result [20]. Another work was done on tensile properties of short glass fibre/reinforced polyamide composites (PA66-GF) and short carbon fibre reinforced polyamide composites (PA66-CF). The experimental sample was prepared using an injection moulding process at different orientations relative to the preferential fibre direction (0°,
45°, 90°). The numerical simulation was done by utilizing LS-DYNA software with 2D and 3D model designs. The results indicated that the 2D model design for both composites had better numerical-experimental correlation than the 3D model. The stress-strain curves from the 2D model for both composites retraced the experimental result [21].

In this paper, the tensile strength of hybrid kenaf/glass fibre reinforced epoxy composites with different stacking sequences was examined through FEA using LS-DYNA software and compared with data from the authors' previous experimental work [22]. For experimental analyses, ASTM D3039 was adopted for the specimen dimensions, and six different stacking sequences of composite layers were investigated viz. E, K/E, G/K/G/E, G/K/E, K/G/K/E, K/G/K/G/E and G/E as explained in our preliminary study [22].

2. Finite Element Modelling Details

2.1. Finite Element Discretization and Element Type

The geometry of the specimen with the appropriate dimensions was generated and meshed with LS-Prepost. Auto Mesher tool was used to discretize the geometry into shell elements with an average size of 0.5 mm, which yields to a total number 6480 element per composite layer. Both ends of the specimen have coarse mesh and were modelled as rigid bodies. These portions of the specimen were firmly gripped in the experimental work, and thus their deformation was negligible. Each composite layer has the same mesh scheme as it was duplicated from the first layer using Translate command with the Copy Elements option. The specimen having the stacking sequence of K/G/K/G is shown in Fig. 1. The default shell element type (Belytshko-Tsay formulation) was used with two integration points through-thickness and a recommended shear factor of 0.833. This element formulation was selected due to its computational efficiency. The layers' cohesiveness was modelled with tiebreak contact (TIEBREAK_SURFACE_TO_SURFACE), and hourglass control was adopted to prevent hourglass modes.

![Figure 1. 3D model of the tensile specimen: (a) Isometric View showing the stacking of different layers: K/G/K/G specimen (b) Top view showing the meshing scheme.](image)

2.2. Material Model

The assignment of material properties was implemented by selecting the appropriate material model. While LS-DYNA provides a massive library of material models, the enhanced composite damage material model (MAT054) is widely used in modelling composite structures due to its versatility and robustness [23-28]. The material properties can be defined along with three orthogonal directions, and
brittle failure can be incorporated. When undamaged, the material behaves linearly whereas a nonlinearity option is available through damage parameters. The mechanical properties and the damage parameters of the composite layers are listed in Table 1. These properties are adopted from previous studies [29-32] and calibrated to obtain the experimental results’ stress-strain curves [22]. The pure epoxy specimen was modelled with the piecewise linear plasticity material model (MAT024) with an Elastic modulus of 266 MPa, a tensile strength of 26.5 MPa, which was defined using MAT_ADD_EROSION. The nonlinear plastic behaviour was captured by adopting the experimental stress-strain curve into the material model. Similar approach of modelling plastics is reported in [33].

Table 1: Mechanical Properties of the Composite Laminate (MAT054).

| Non-woven kenaf fibre reinforced with epoxy matrix | Value | Units | Value | Units |
|-------------------------------------------------|-------|-------|-------|-------|
| EA                                              | 0.9   | GPa   | GAB   | 0.335 | GPa   |
| EB                                              | 0.9   | GPa   | GBC   | 0.335 | GPa   |
| EC                                              | 0.072 | GPa   | GCA   | 0.335 | GPa   |
| PRBA                                            | 0.340 | -     | RO    | 1300  | kg/m^3 |
| PRCA                                            | 0.0193| -     | XC    | 5.769 | MPa   |
| PRCB                                            | 0.0193| -     | XT    | 25.00 | MPa   |
| EFS                                             | 0.135 | -     | YC    | 2.692 | MPa   |
| SC                                              | 1.154 | MPa   | YT    | 0.577 | MPa   |

| Non-woven glass fibre reinforced with epoxy matrix | Value | Units | Value | Units |
|--------------------------------------------------|-------|-------|-------|-------|
| EA                                              | 38.50 | GPa   | GAB   | 4.20  | GPa   |
| EB                                              | 38.50 | GPa   | GBC   | 4.20  | GPa   |
| EC                                              | 32.98 | GPa   | GCA   | 2.60  | GPa   |
| PRBA                                            | 0.0787| -     | RO    | 1174  | kg/m^3 |
| PRCA                                            | 0.0787| -     | XC    | 29.31 | MPa   |
| PRCB                                            | 0.4206| -     | XT    | 90    | MPa   |
| EFS                                             | 0.0152| -     | YC    | 85    | MPa   |
| SC                                              | 7.41  | MPa   | YT    | 27.68 | MPa   |

*Abbreviation: E.A.: E_a, Young’s Modulus in a-direction, E.B.: E_b, Young’s Modulus in b-direction, E.C.: E_c, Young’s Modulus in c-direction, PRBA: ν_ba, Poisson Ratio, ba, PRCA: ν_ca, Poisson ratio, ca, PRCB: ν_cb, Poisson ratio, cb, EFS: Effective failure strain, SC: Shear Strength in A.B. plane.*

2.3. Boundary Conditions

One end of the specimen is fixed in all degrees of freedom via the constraints option in MAT_RIGID card definition, whereas the other end is allowed to translate only along the direction of force (x-axis). PRESCRIBED_MOTION_RIGID keyword is used to impose the displacement on the moving end at a
constant rate of 5 mm/min. Due to the slow speed of the test, mass-scaling is adopted to expedite the simulation run time.

3. Results and Discussion

A comparison between the FEA simulation and experimental results' stress-strain curves is shown in Fig. 2 and Fig. 3. Comparison between the two figures showed that there were good agreements between experimental and numerical results. The numerical model was found to be very accurate in reproducing the mechanical behaviour of the samples. Indeed, the stress-strain curves obtained from the simulations retraced the experimental ones up to the fracture of the samples.

![Figure 2. Simulation results of stress strain of E, K/E, G/K/G/E, K/G/K/E, K/G/K/G/E and G/E.](image)

![Figure 3. Experimental test results of stress-strain of E, K/E, G/K/G/E, K/G/K/E, K/G/K/G/E and G/E composite [22].](image)

The G/K/G/E specimen had the maximum tensile strength among the hybrid Kenaf composites with a value reaching 49.0 MPa and the second-highest fracture strain of 6.6%. It was observed that the K/G/K/G/E hybrid composite had the highest value of fracture strain at 7.25%. Nevertheless, it was the weakest in terms of tensile strength while compared to the other specimen. Therefore, in this case, it can be seen that adding another layer of kenaf on top of G/K/G/E resulted in a considerable reduction of the tensile strength. This could be due to poor interfacial bonding between kenaf and
glass fibre and the ineffectiveness of Kenaf fibre to transfer stress to the hybrid composite compared to specimens with glass fibre surfaces that finally resulted in such failure.

The K/G/K/E hybrid composite performance was slightly different, with a tensile strength of 33.2 MPa and fractured strain at 6.2%. Both K/G/K/E and K/G/K/G/E had lower tensile strength than G/K/G/E. It can be concluded that having glass fibre on the surface side of the composite is the better option regarding the high tensile property of glass fibre. It is worth noting that the tensile strength would be more significant when the excessive strength material is used as the surface, which is the primary load-bearing component in tensile strength calculation. This indicated that glass fibre on the surface was able to withstand the tensile stress. The kenaf core was bearing the pressure and distributed them consistently along with the hybrid composite.

Consequently, this shows that the stacking sequence plays a significant role in the performance of hybrid composites. Besides, a natural fibre hybrid composite's strength is highly dependent on the failure strain of the individual fibres [34]. Epoxy matrix has plastic behaviour and should display large plastic deformation, but the plastic zone was hardly observed in all hybrid samples. This could be due to the inefficiency of the surface quality of the composites and resulted in stiff samples. Plastic deformation is the permanent distortion occurring when a material is subjected to stresses that exceed its yield strength and finally cause it to elongate or bend before it eventually ruptures. The tensile strength (MPa) values and strain (%) for both experimental and simulation samples were tabulated in Table 2. The values were taken at four points along with the graph at 25%, 50%, 75% and 100%, i.e. when the sample breaks.

**Table 2:** Tensile strength (MPa) and strain (%) for experimental and simulation samples of kenaf/epoxy hybrid composites.

| Sample ID | % increase in the stress-strain curve | Experimental | Simulation |
|-----------|--------------------------------------|--------------|------------|
|           |                                      | Tensile Strength (MPa) | Strain (%) | Tensile Strength (MPa) | Strain (%) |
| K/E       | 25%                                  | 5             | 1.6        | 5             | 1.3        |
|           | 50%                                  | 13            | 2.6        | 11            | 2.5        |
|           | 75%                                  | 16            | 3.8        | 17            | 3.7        |
|           | 100%                                 | 22            | 5.2        | 21            | 5.1        |
| G/K/G/E   | 25%                                  | 5             | 1.6        | 7             | 1.7        |
|           | 50%                                  | 15            | 3.3        | 18            | 3.6        |
|           | 75%                                  | 31            | 4.8        | 27            | 4.7        |
|           | 100%                                 | 49            | 6.5        | 50            | 6.6        |
| K/G/K/E   | 25%                                  | 4             | 1.7        | 4             | 1.6        |
|           | 50%                                  | 12            | 3.2        | 11            | 3.2        |
|           | 75%                                  | 22            | 4.6        | 23            | 4.8        |
|           | 100%                                 | 34            | 6.2        | 35            | 6.3        |
| K/G/K/G/E | 25%                                  | 2             | 1.8        | 3             | 1.8        |
|           | 50%                                  | 6             | 3.7        | 7             | 3.7        |
|           | 75%                                  | 13            | 5.5        | 13            | 5.6        |
|           | 100%                                 | 21            | 7.4        | 20            | 7.4        |
| G/E       | 25%                                  | 2             | 0.2        | 8             | 0.1        |
|           | 50%                                  | 20            | 0.3        | 32            | 0.3        |
|           | 75%                                  | 55            | 0.4        | 70            | 0.4        |
It can be seen that the values of experimental and simulation for tensile strength and strain were 95% accurate, and hence the model is said to be reliable for such analysis. Nonlinearity behaviour was observed in the hybrid composites and the G/E composites, which is due to the micro failure of the glass fibres. The G/E and E had the lowest strain and was very brittle compared to the samples with the addition of Kenaf fibre. As natural fibre is flexible, it contributes to the elongation of the hybrid composite before it finally ruptured. In contrast, the K/E composite demonstrated perfect linear response. The sample G/K/G/E had the highest tensile strength value than other kenaf hybrid composites which was 49 MPa. The simulation sample result showed a value of 50 MPa, which was very close to the actual value. The same trend was also observed for the strain value, which was 6.5% and 6.6% for experimental and simulation, respectively. The FEA also showed high accuracy at 50% stress/strain curve of the same sample, where the value of tensile strength was 15 MPa (experimental) and 18 MPa (simulation). In comparison, strain was 3.3% (experimental) and 3.6% (simulation). The overall comparison between experimental and simulation results for each graph's four points showed good agreement except for sample G/E at 50% stress/strain curve. The simulation result showed tensile stress's value to be 32 MPa, but the actual value was 20 MPa. There was some deviation of the simulation value compared to the experimental result.

4. Conclusion and Future Work

In the present study, the numerical simulations of the tensile test of the hybrid composite were successfully performed using the nonlinear finite element software LS-DYNA. The numerical simulations details were presented, and an orthotropic material model with damage was adopted for modeling the behaviour of the composite specimens. The material properties were adopted from previous studies, and the model was calibrated to obtain satisfactory results compared to the experimental data. The model was capable of reproducing the experimental stress-strain curve, and the brittle failure mode was captured. Micro damage of the material was observed through the nonlinearity of the stress-strain curve, and the influence of the stacking sequence was highlighted. About 200% improvement was observed in the hybrid composite in comparison with pure epoxy composite. Stacking sequences had proven that it could affect the properties of hybrid composites as portrayed by both experimental and numerical results. There were 2% of deviation errors between experimental and simulation findings, thus highlighting the reliability of the numerical model.

Author’s contribution

M.N.M.Ansari1,* - Idea & concept generation, suggestion and advice on the simulation studies, suggestion on interpretation of the data, supervision of the project and manuscript editing. 
K.S.Vinoth2: first draft and manuscript writing, experimental data collection, analyses of data. Noor Afeefah Nordin1 - project management, suggestion and advice on the analyses, manuscript editing and revision. Alaseel Bassam - simulation and interpretation of the data, manuscript editing. Ameen Topa3 - simulation and analytical tools application, simulation results and interpretations, manuscript editing.
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