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# INVESTIGATION OF GLASS FIBER INFLUENCE ON MECHANICAL CHARACTERISTICS OF NATURAL FIBER REINFORCED POLYESTER COMPOSITES: AN EXPERIMENTAL AND NUMERICAL APPROACH

**In the past few decades, natural fiber reinforced polymeric composites have gained significant importance for various structural applications in different sectors like the automotive, aerospace, sports and building construction industries. However, hybridizations make the composite more versatile in term of strength, weight and its processing for many engineering applications. In the current study, a polyester resin matrix was reinforced with two different natural fibers, namely kenaf and palmyra palm leaf stalk (PPLS) and hybridized with glass fiber. Four layers of two different fiber mats, kenaf/glass and PPLS/glass with different stacking sequences were employed to fabricated laminates by the hand lay-up technique. In this case, an attempt was made using the numerical approach to investigate the influence of glass fiber on the mechanical characteristics of the laminates. To substantiate the results of the numerical approach, experiments were conducted. Enhancement of both the tensile and flexural strength was observed due to hybridization of both the kenaf and PPLS fiber with glass fiber. The tensile and flexural strength improved by 68.91 and 37.63% respectively when the kenaf fiber was hybridized with glass fiber. Similarly, enhancement of 54.42% of the tensile strength and 15.92% of the flexural strength were noticed when the PPLS fiber was hybridized with glass fiber. Through the use of ANSYS software, finite element analysis (FEA) was employed as a simulation method to examine the tensile and flexural strength. The numerical findings were found to be quite close to the experimental results, with a variation of less than 3%.**

**Keywords:** **glass fiber, kenaf fiber, palmyra palm leaf stalk fiber, mechanical strength, ANSYS**

## INTRODUCTION

Over past few years, natural fiber-reinforced composites (NFRCs) have proven to be emerging materials in different manufacturing sectors owing to their inherent properties like high strength-to-weight ratio and biodegradable nature [1, 2]. Despite the several advantages of synthetic fibers, natural fibers like pineapple, jute, abaca, coir, sisal, cotton, bamboo, banana, hemp, kenaf, palmyra palm leaf stalk, etc. have been found to be a suitable alterative in composite manufacturing [3]. To address the limit of NFRC use in structural components due to its lower mechanical strength, the hybridization of natural and synthetic fiber has been found to be one of the promising solutions.

Rassmann et al. [4] evaluated the mechanical and physical properties of kenaf fiber with different resins. Epoxy, vinyl ester and polyester resin were used as the matrices and laminates were fabricated with volume fractions of 15, 22.5 and 30%. They found that the epoxy laminates exhibited good strength values, while high modulus and impact properties were seen in the polyester resin, and the vinyl ester laminates reported excellent water absorption. Mahjoub et al. [5] studied the tensile properties of kenaf fiber with volume fractions of 10, 30 and 40%. It was noticed that the tensile properties are increased at the 40% volume fraction of fiber and the Poisson's ratio was reduced.

Sivakumar et al. [6] investigated the mechanical properties of a palmyra fiber reinforced polyester composite. They found that chemical treatment of the palmyra fiber displayed a tensile strength of 48 MPa and flexural strength 64 MPa. Velmurugan and Manikandan [7] investigated samples of different fiber length with variation of fiber weight content percentage reinforced in a roof-lite resin matrix. The study reported that enhanced mechanical properties were obtained at a 55% weight fraction of reinforcement with a fiber length of 50 mm. Shanmugam et al. [8] developed a polyester matrix composite reinforced with jute-palmyra palm leaf stalk fibers with varied fiber content. They reported that the flexural and tensile properties rose with an increase in jute fiber when compared with treated palmyra palm leaf stalk fiber. Nevertheless, the impact energy of the palm fiber composite was more than the palm/jute hybrid composite.

Glass fibers are produced from glass strands that are incredibly fine and hydrophobic in nature. They are light in weight and have great strength and flexibility. The hybridization of natural fiber with glass fiber enhances the mechanical properties, thermal strength and hydrophobic nature of composites [9, 10]. Yuvraj et al. [11] studied the impact and tensile strength of sisal/glass epoxy composites taking constant a matrix--fiber ratio at 50:50 and varying the percentage of reinforcement of sisal and glass fibers. They found that the impact and tensile strength of the composites increased by 110.47 and 34.9%, respectively, at the sisal-to-glass fiber ratio of 30:70. Jayabal et al. [12] determined the mechanical characteristics of coir/polyester composites with glass fiber hybridization. A GGC laminate with two layers of woven glass (G) on one side and one layer of coir (C) on the other side demonstrated higher flexural, tensile and impact strength than GCG and CGG laminates. In another study, Arthanarieswaran et al. [13] reported that the hybridization of sisal and banana fiber with glass fiber enhances the mechanical properties. The addition of two layers of glass fiber to banana (GBG), sisal (GSG) and banana-sisal (GBSG) composites improved the flexural and tensile strength by 135, 160 and 209% and 119, 126 and 165%, respectively. Sanjay et al. [14] studied the effect of hybridization on jute/kenaf/glass epoxy composites. They reported that the microhardness, flexural and tensile strength of the composites with the stacking order glass/kenaf/jute/kenaf/glass improved by 3.99, 1.16 and 27.46% in comparison to the composite with the stacking order glass/kenaf/kenaf/kenaf/glass.

Finite element analysis is a key tool widely used in different engineering fields and is employed to analyze composite materials. In FEA, different types of complex 3D problems are solved by means of ANSYS software [15-17]. Sing et al. [18] studied the flexural properties of a glass fiber reinforced polymer (GFRP) composite. The glass fiber/epoxy composite was modeled in ANSYS mechanical APDL 14.5. The material properties for simulation were evaluated under static load conditions. The SHELL281 element was chosen to simulate the flexural strength. It was found that the error between the simulation and experimental results was less than 10%. Jeyasekaran et al. [19] tested and calculated experimentally and numerically the tensile characteristics of a banana/glass fabric reinforced epoxy composite. It was observed that the tensile strength was increased due to the hybridization of banana fiber with glass fiber. Shell elements were used to simulate the tensile stress and strain. From both the experimental investigations and the numerical simulation using ANSYS, it was found that the numerical results were higher than the experimental results. Sudheer et al. [20] evaluated the Poisson's ratio, modulus of elasticity and shear modulus with the Halpin-Tsai model, Nielsen elastic model, the Chamis micromechanical model and the rule of mixtures. These elastic values were also calculated by means of the finite element method (FEM).

In this paper, the main objective is to evaluate the tensile strength of composites containing kenaf, palmyra palm leaf stalk fiber and their hybridization with glass fiber. The simulation results of these hybrid composites are validated by means of finite element analysis software ANSYS R19.0.

## MATERIALS AND METHODS

### Materials used

Bidirectional woven glass, kenaf and palmyra palm leaf stalk fiber mats were procured from Nirmala industries, Hyderabad, India. The matrix material was prepared by mixing methyl ethyl ketone peroxide (catalyst), unsaturated polyester resin, and cobalt naphthenate (accelerator). They were purchased from Abanti Enterprises, Odisha, India. The properties of the materials are listed in Table 1.

TABLE 1. **Properties of fibers and polyester resin [21-24]**

| Property | Poisson's ratio | Young's modulus [GPa] | Shear modulus [GPa] | Density [g/cm$^3$] | Mat thickness [mm] |
|---|---|---|---|---|---|
| Glass fiber | 0.21-0.23 | 72-85 | 30-36 | 2.55-2.66 | 0.25 |
| Kenaf fiber | 0.342 | 53 | 7.3 | 1.45 | 0.50 |
| Palmyra palm leaf stalk fiber | 0.4896 | 3.774 | 12.5 | 1.45 | 0.80 |
| Polyester resin | 0.316 | 2 | 1.2 | 1.1 | - |

### Fabrication of composites

The fiber reinforced composites were made in a mold by hand lay-up at laboratory temperature. Before proceeding with the fabrication, the kenaf fiber, palm fiber and glass fiber mats were cut according to the mold size (180 × 150 × 5 mm). The mold was cleaned and After Heavy Duty silicone spray (grade-8082) was applied to all sides of the mold for easy removal of the composite after curing. Appropriate amounts of unsaturated polyester resin and catalyst were mixed in a ratio of 10:1 with 2% accelerator to prepare the matrix. Then the mixture was stirred thoroughly to ensure homogenous mixing and the mixed resin was spread over the mold with a brush. The fiber mats were dipped into the resin mix and placed layer upon layer in sequential manner to obtain the desired stacking sequence as presented in Table 2. A roller was used for uniform spreading of the resin on the fiber mats and also to squeeze out any air gaps present between the layers. The samples were left to cure up to 48 hours at room temperature. After curing, specimens were cut from the prepared composite samples for the various tests.

TABLE 2. **Sample scheme with weight percentage**

| S. no. | Composite | Laminate orders | GF [wt.%] | KF [wt.%] | PF [wt.%] | Matrix [wt.%] |
|---|---|---|---|---|---|---|
| 1 | Kenaf fiber (KF) | KKKK | 0 | 31.32 | 0 | 68.68 |
| 2 | Kenaf/glass fiber (KF/GF) | KGGK | 13.67 | 16.51 | 0 | 69.82 |
| 3 | Palmyra palm leaf stalk fiber (PF) | PPPP | 0 | 0 | 31.66 | 68.34 |
| 4 | Palmyra palm leaf stalk/glass fiber (PF/GF) | PGGP | 13.52 | 0 | 15.83 | 70.65 |

## Mechanical testing

- **Tensile testing**

Tensile specimens were tested according to the ASTM D 638 standard using a universal testing machine (UTM – model INSTRON 3382) with a maximum load capacity of 100 KN [25]. The crosshead speed for testing was 2 mm/min and the gauge length was set at 50 mm. The dimensions of the dumbbell-shaped specimens were 165 × 19 mm. The tensile test specimens are shown in Figure 1 before being tested. The average values were derived after testing five samples of each laminate.

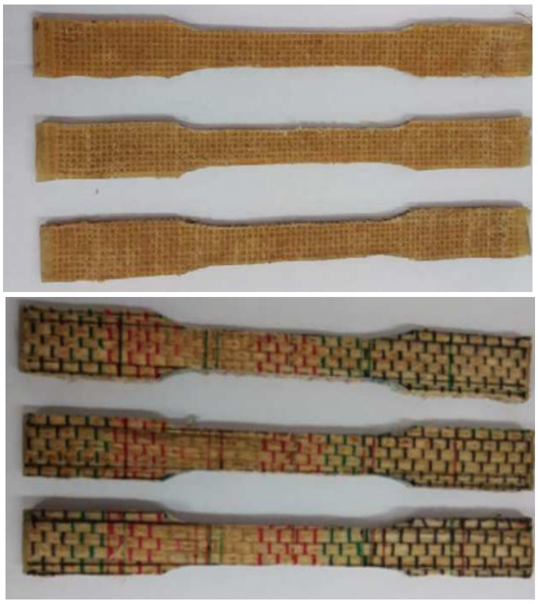
a)
b)


Fig. 1. Tensile test specimens of kenaf/glass (a) and palmyra/glass laminates (b)

- **Flexural testing**

Flexural tests were performed in accordance with ASTM D790 using a universal testing machine (UTM – model: INSTRON 3382) [26]. The crosshead speed was set at 2 mm/min. The size of the specimens was 130 × 13 mm with a span length of 100 mm. Figure 2 presents the flexural test specimens before testing. The average values were found after testing five specimens of each laminate.

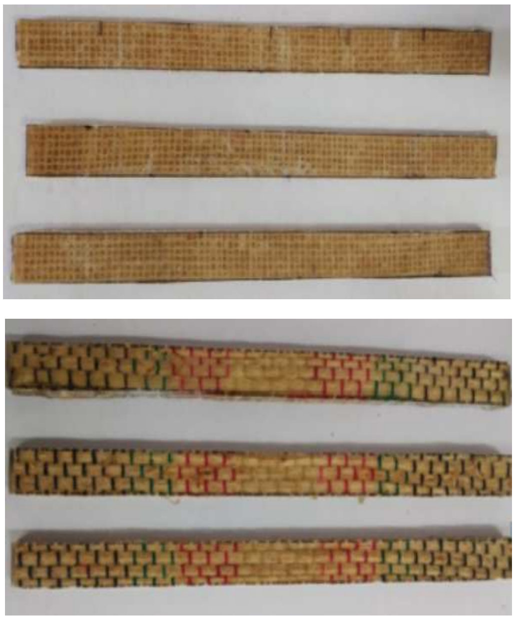
a)
b)


Fig. 2. Flexural test specimens of kenaf/glass (a) and palmyra/glass laminates (b)

# NUMERICAL ANALYSIS

## Finite element analysis using ANSYS Workbench

Using the ANSYS (version R19.0) Space-Claim modeler, discretization of a three-dimensional tensile test specimen (ASTM D638) model was performed with finite element SOLID185 having 8 nodes as shown in Figure 3.

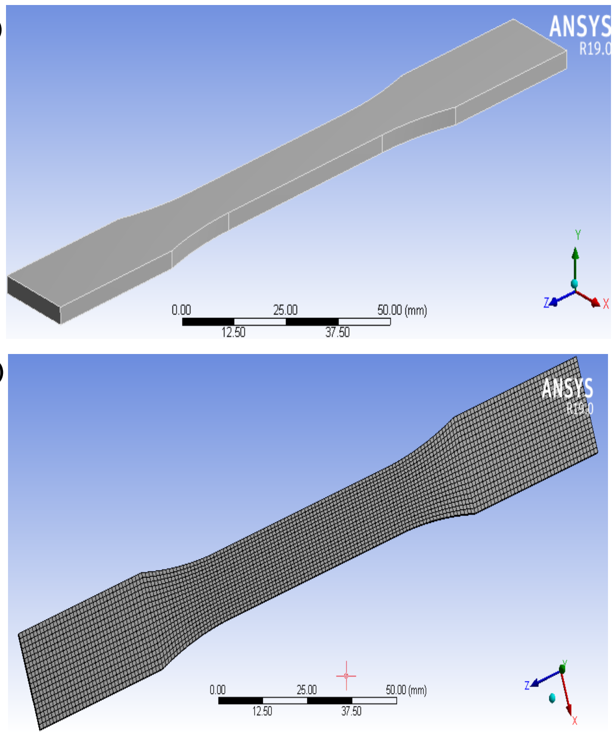
a)
b)



Fig. 3. 3D modeling (a) and meshing of tensile CAD model (b)

The material properties were determined by the rule of mixtures (ROM) [20] on considering each ply as orthotropic in nature. As the plies have a woven structure, $E_x$ is assumed to be equal to $E_z$. Considering the above assumption, the material properties listed in Table 3 were adopted for the simulation. The laminate lay-up was built in ANSYS Composite Prepost (ACP). In ACP, the thickness of 0.4 mm was considered for the glass/polyester ply, whereas the thickness of the kenaf/polyester and palmyra palm leaf stalk/polyester plies were determined by subtracting the total glass/polyester thickness from the laminated thickness, as listed in Table 4. Regarding the static analysis, appropriate boundary conditions were adopted for different loading conditions. Then in the post process, the stress, strain, deflection, etc. were evaluated at the required points.

TABLE 3. **Material properties for simulation**

| Property | Kenaf/ polyester ply | Glass/ polyester ply | Palmyra palm leaf stalk/ polyester ply | Source |
|---|---|---|---|---|
| $E_X = E_Z$ [MPa] | 11500 | 10590 | 2301.6 | Experimental |
| $E_Y$ [MPa] | 4910 | 4397.8 | 2173.7 | Analytical (ROM) |
| $\mu_{XY}$ | 0.08 | 0.03 | 0.07 | Experimental |
| $\mu_{YZ} = \mu_{XZ}$ | 0.32 | 0.305 | 0.345 | Analytical (ROM) |
| $G_{XY} = G_{YZ} = G_{XZ}$ [MPa] | 1830 | 1760.5 | 1417.9 | Analytical (ROM) |
| Density [kg/m$^3$] | 1234 | 1348.5 | 1159.5 | Experimentally |

TABLE 3. **Specimen dimensions**

| S. no. | Laminate orders | Tensile test specimen | | Flexural test specimen | | Thickness [mm] |
|---|---|---|---|---|---|---|
| | | Gauge length [mm] | Average width [mm] | Span length [mm] | Average width [mm] | |
| 1 | KKKK | 50 | 13 | 100 | 12.7 | 3.21 |
| 2 | KGGK | 50 | 13 | 100 | 12.7 | 2.76 |
| 3 | PPPP | 50 | 13 | 100 | 12.7 | 5.00 |
| 4 | PGGP | 50 | 13 | 100 | 12.7 | 3.62 |

## RESULTS AND DISCUSSIONS

### Tensile test

Figure 4 presents the experimental results of the tensile strength and load of the fiber reinforced polymer composites. The tensile strength of KF, KF/GF, PF and PF/GF were found to be 34.86, 60.36, 32.55 and 46.81 MPa, respectively. Hybridization of KF and PF with glass fiber increases the strength of the composites 73.14 and 43.80%, respectively, as compared to the composites reinforced only with KF and PF. The study shows improvement in the strength of the natural fiber composites when combined with the glass fiber. The kenaf/glass fiber composite achieved the highest strength because of the higher strength and tensile modulus of the kenaf than the palmyra palm leaf stalk fiber. A similar increasing trend of the tensile properties was also reported by several researchers [26, 27].

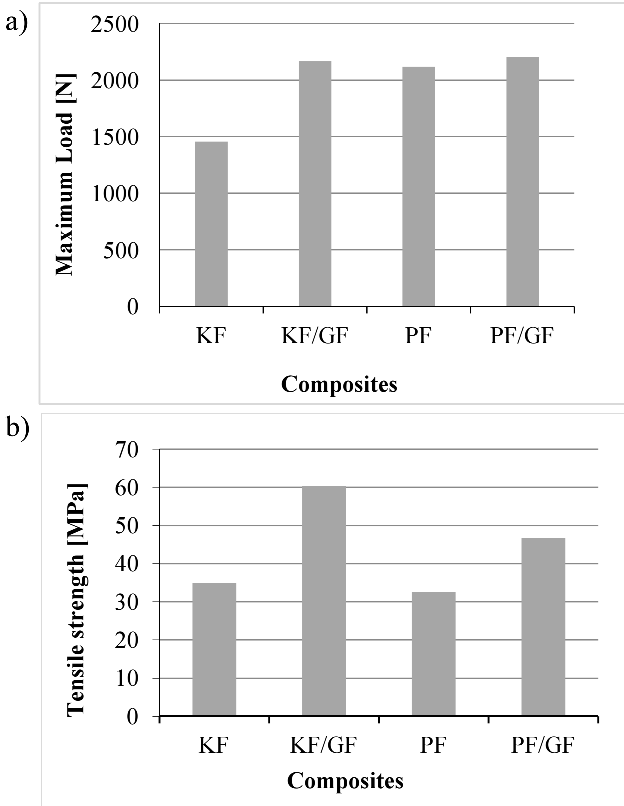



Fig. 4. Tensile test results: a) maximum load and b) tensile strength of composites

### Tensile simulation

Figure 5 illustrates the equivalent stress distribution of the composites. The equivalent stress (von Mises) of KF and PF was found to be 35.717 and 33.428 MPa, respectively. Nonetheless, owing to their hybridization with glass fiber, the KF/GF and PF/GF composites achieved tensile strength of 61.467 and 47.704 MPa, respectively. It is clearly noticed that the KF/GF reinforced composite achieves higher strength than the laminates containing only kenaf or palmyra palm leaf stalk fiber.

A comparative study of the tensile stress between the experimental and numerical results is shown in Figure 6. The highest error of 2.68% was found for the PF laminates, whereas the lowest error of 1.83% was found for the KF/GF laminates, presented in Table 5. The formation of micro-voids and improper distribution of the matrix may be the reason for the above mentioned deviation [28].

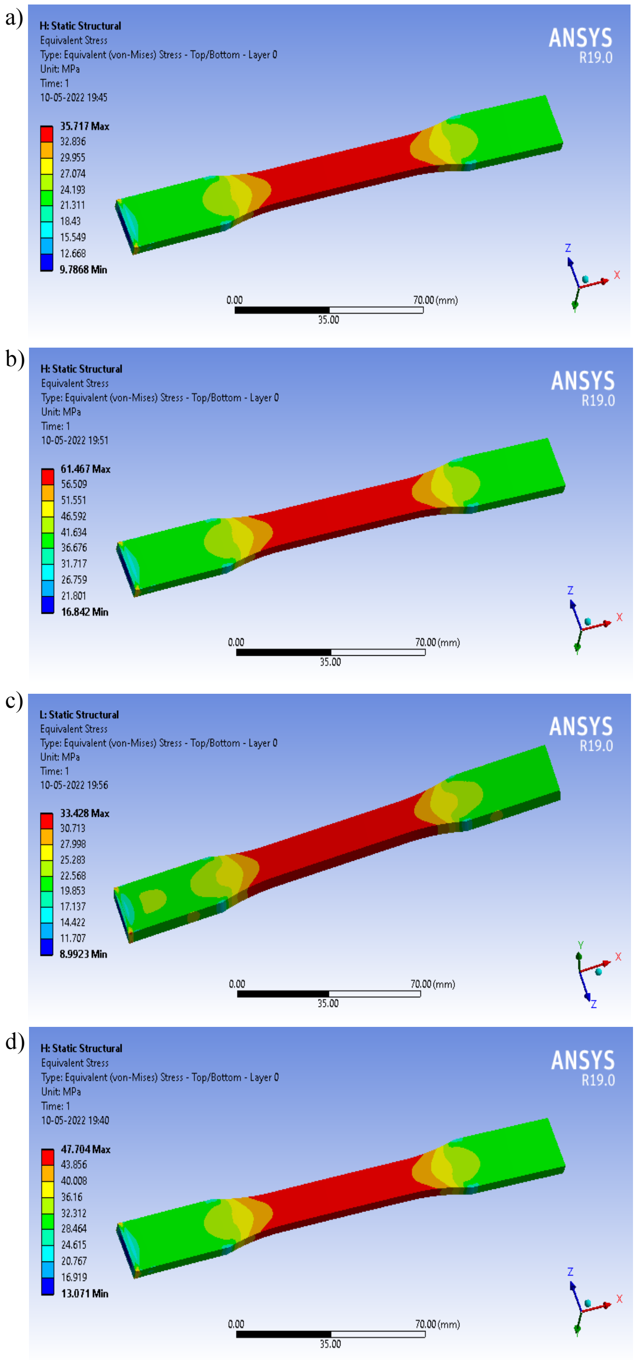



Fig. 5. Von Mises stress distributions of composite samples: a) KF, b) KF/GF, c) PF and d) PF/GF under tensile simulation

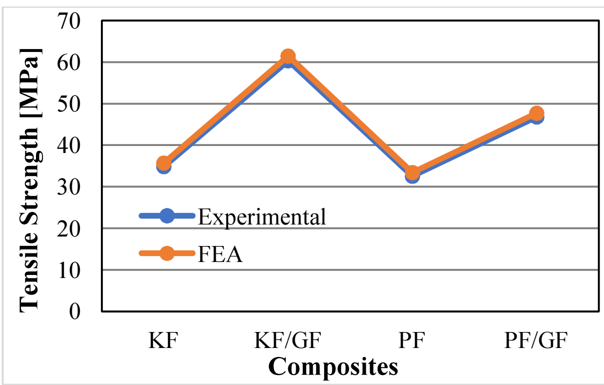



Fig. 6. Comparison of tensile strength results

TABLE 5. **Comparison between experimental and numerical results of tensile strength**

| Composite specimens | Experimental tensile strength [MPa] | Numerical tensile strength [MPa] | Error in tensile strength [%] |
|---|---|---|---|
| KF | 34.86 | 35.717 | 2.45 |
| KF/GF | 60.36 | 61.467 | 1.83 |
| PF | 32.55 | 33.428 | 2.68 |
| PF/GF | 46.81 | 47.704 | 1.91 |

## Flexural test

The experimental results for the flexural strength and load of the fiber reinforced composites are shown in Figure 7. The flexural strength of the KF, KF/GF, PF and PF/GF laminates were found to be 50.43, 38.76, 45.35 and 37.85 MPa, respectively. The addition of glass fiber to the kenaf and palmyra palm fiber decreases the flexural strength by 23.14% and 16.53%, respectively, as compared to only kenaf or palmyra palm leaf stalk fiber. The KF/GF composite achieved a higher flexural strength of 2.40% than the PF/GF composites, which may be due to the high strength and modulus of kenaf fiber in comparison with the palmyra fiber [29, 30].

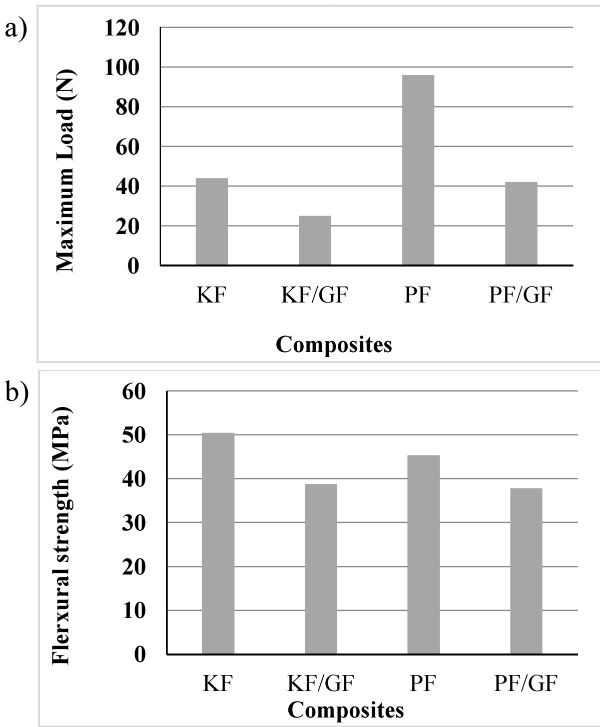



Fig. 7. Flexural strength test results: a) maximum load of composites and b) flexural strength

## Flexural simulation

The stress distribution of the composite specimens is presented in Figure 8. During the simulation, von Mises stresses of 51.755, 39.427, 46.684 and 38.588 MPa were reported for the KF, KF/GF, PF and PF/GF specimens, respectively.

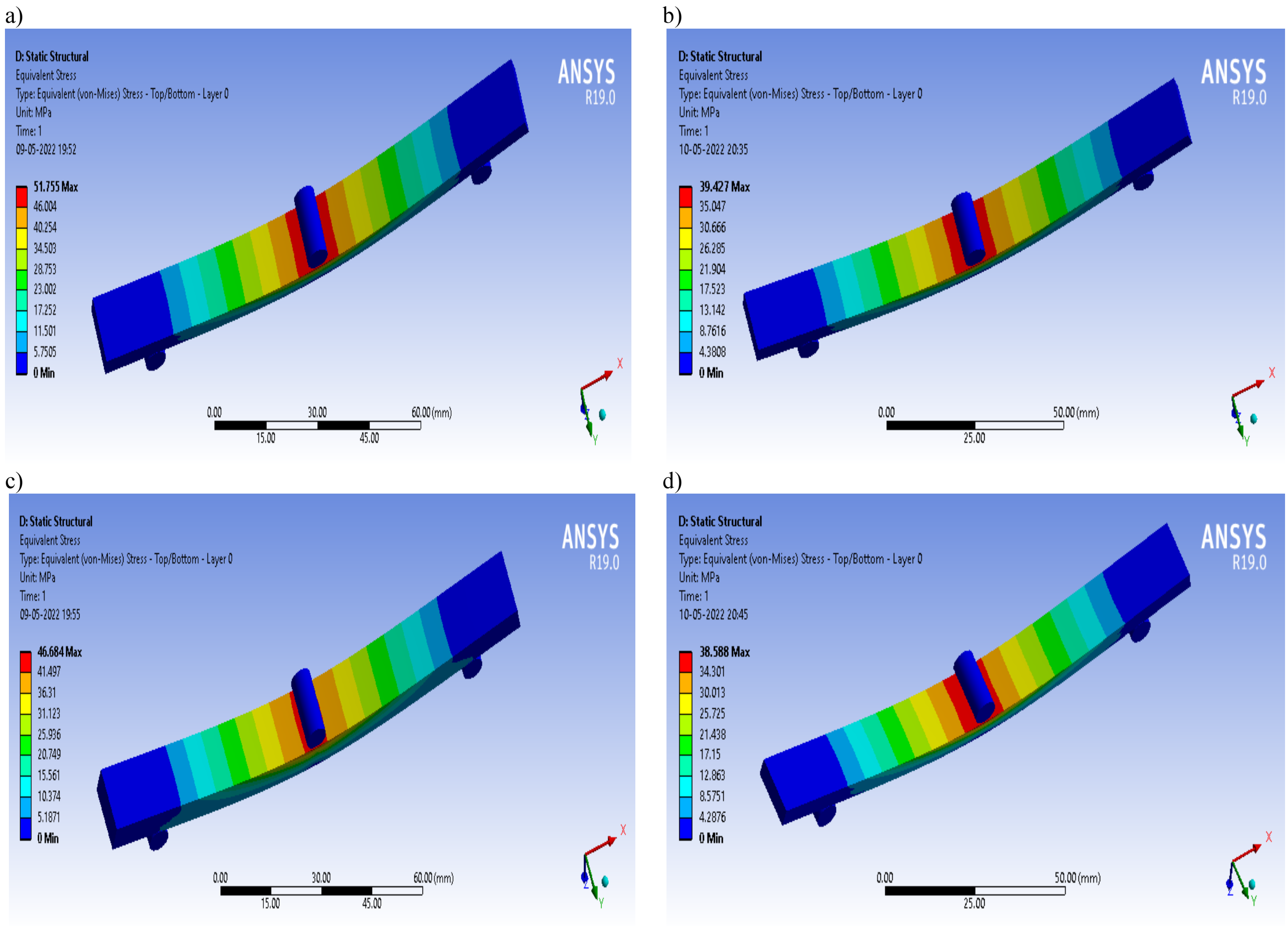



Fig. 8. Von Mises stress distributions of composite samples: a) KF, b) KF/GF, c) PF and d) PF/GF under flexural simulation

Figure 9 shows the comparison of the flexural stress between the experimental and numerical results. The numerical results were found to be parallel to the experimental ones with at the highest deviation of 2.94% for the PF laminates, whereas the lowest deviation of 1.72% was found for the KF/GF laminates, as illustrated in Table 6. This deviation in the results is due to the waviness of the fiber and voids present in the specimens during sample preparation by the hand lay-up technique.

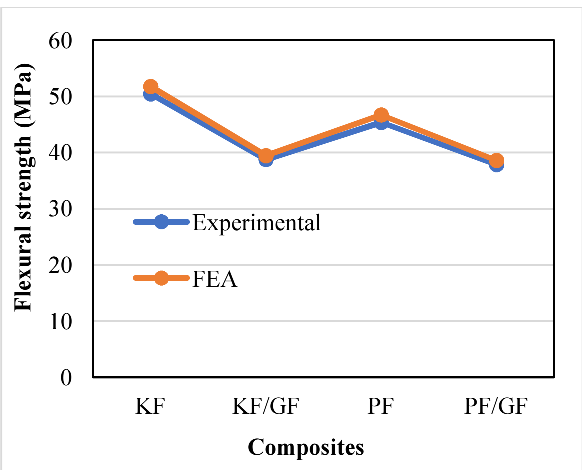



Fig. 9. Comparison of flexural strength results

TABLE 6. **Comparison between experimental and numerical results of flexural strength**

| Composite specimen | Experimental flexural strength [MPa] | Numerical flexural strength [MPa] | Error in flexural strength [%] |
|---|---|---|---|
| KF | 50.43 | 51.755 | 2.62 |
| KF/GF | 38.76 | 39.427 | 1.72 |
| PF | 45.35 | 46.684 | 2.94 |
| PF/GF | 37.85 | 38.588 | 1.95 |

## CONCLUSIONS

In this work, kenaf and palmyra palm leaf stalk fibers were used as reinforcement, hybridized with glass fiber to prepare composite laminates. The hand lay-up method was employed to prepare the laminate composites. Experimental and numerical techniques were used to investigate the tensile and flexural characteristics of the hybrid composites. The following findings have been drawn from the above study:

- The addition of glass fiber to kenaf and palmyra palm leaf stalk fibers improves the tensile strength of the composite laminates by 73.14 and 43.80%, respectively.

- A reduction in the flexural strength was observed due to the hybridization of kenaf and palmyra palm fiber with glass fiber.
- The results of the numerical simulation of the tensile and flexural tests are in good agreement with the experimental results, which demonstrates the capability of the simulation technique to predict the tensile and flexural behavior. Thus, the numerical simulation results have a good scope in automotive and aerospace industries, especially to predict tensile and flexural properties.

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