# Mechanical properties of natural fiber polyester composite sandwich panels

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**Abstract** In the current work, a novel kenaf fiber reinforced composite sandwich panel was developed and fabricated. The kenaf fiber composites as sandwich face sheets were prepared at 55% (by weight) fiber content. PVC foams were joined using epoxy resin adhesive to fabricate sandwich structures. A series of mechanical tests, such as tensile, three-point bending and double cantilever beam, were carried out to know the mechanical behaviors of sandwich panels. Fracture and failure modes were also reported and discussed. The results show kenaf fiber reinforced composite sandwich panels have potential application in engineering construction of buildings.

**Keywords** Natural fiber, Sandwich, Mechanical properties, Failure analysis

## 1. Introduction

In recent years, the use of sandwich structures continues to increase rapidly due to their advantages, such as high strength/weight and stiffness/weight ratios, excellent heat resistance and favorable energy-absorbing capacity. They have been widely used in the satellites, aircraft, ships, automobiles, rail cars, wind energy systems, and bridge and civil constructions [1]. Most sandwich specimens analyzed in the past studies were made of polymer foam cores with composite face sheets or with metal face sheets [2–4]. Additionally, more assembly techniques, such as screw fasteners, adhesively joints, or blazed bonding, can be applied for bonding the core material and the face sheet. These applications and novel manufacturing techniques increase the requirement for the mechanical strengths of the sandwich structures in practical designs.

Another question is that environmental protection becomes increasingly important. Thus, the use of natural fibers as reinforcements of polymer-based composites has been of great interest to many researchers [5–7]. Due to many advantages, such as low density, high specific strength and modulus, relative non-abrasiveness, ease of fiber surface treatment and wide availability. More important, they are renewable and biodegradable. In fact natural fibers are also much cheaper than synthetic fibers and could replace synthetics in many applications.

If according to the design concept of sandwich structures, the natural fibers are used to fabricate the sandwich panel, it is predictable that such a "sandwich structure" with lightweight, high strength, bio-degradable and environmental friendly properties could be obtained. However, few studies have addressed this aspect. The objective of this work was to develop a novel sandwich structure based on natural fiber and PVC foam materials. Fabrication method including sheet molding compound (SMC) and bonding technique was introduced. A series of mechanical tests, such as tensile, bending and fracture properties, were carried out to understand the mechanical behaviors.

## 2. Materials preparation

Kenaf bast fiber was supplied by Kengro Corp (Charleston, MS, USA). It was short fiber form and with a length of 5~8mm. The unsaturated polyester resin (UPR) was provided by Ashland Chemicals (AROPOL 6585) with density of 1.12 g/cm$^3$. The curing agent was obtained from Acros Orgaincs. The sandwich core was Divinycell H-grade H35 PVC foam (DIAB AB Group).

Kenaf fibers reinforced unsaturated polyester resin (UPR) composites were fabricated first as the face sheet of sandwich structure. Then polyesters, fibers, and curing agent were initially weighed to ensure the total fiber loading was 55 wt.%. Each mixture of sandwich face sheet was put into a steel mold and pressed at 5MPa for 2 min to form a mat. Then, the polyester resin with curing agent was poured into the mold and the mat was hot-pressed under a pressure of 5MPa and at a temperature of 150ºC for 2 hours. When the fabrication was accomplished, all the panel samples were put into a drier at room temperature for 48 hours for further investigation. The compliant PVC foam core were joined with the upper and lower kenaf fiber reinforced UPR composite panels using epoxy resin.

## 3. Mechanical properties of sandwich composites

3.1. Tensile test

Tensile specimens were cut from the composite panels. The tensile strength and modulus of the kenaf fiber composite panel were tested on the basis of three replicates with a MTS 810 universal testing system (USA) in accordance with the procedure described in ASTM D 638-10 [8]. The specimen dimensions were 100×20×1.60 mm$^3$ (Length × Width × Thickness). A tensile fixture was used, with a constant gauge of 60 mm and a crosshead speed of 0.50mm/min. An FEI Quanta Environmental Scanning Electron Microscope (ESEM; FEI Company, Oregon, USA) were used to examine the fracture morphology of the specimens.

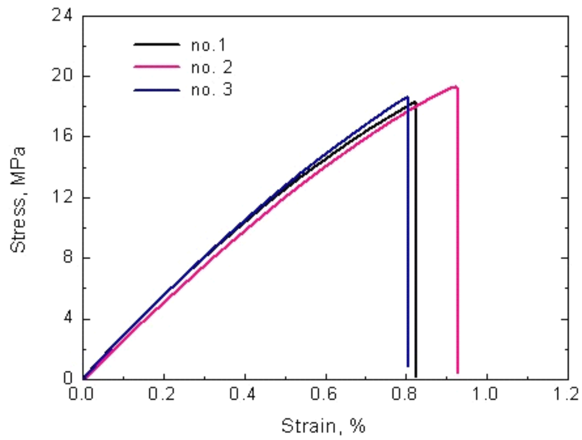


Figure 1. Tensile stress versus strain of kenaf fiber reinforced UPR composite panels

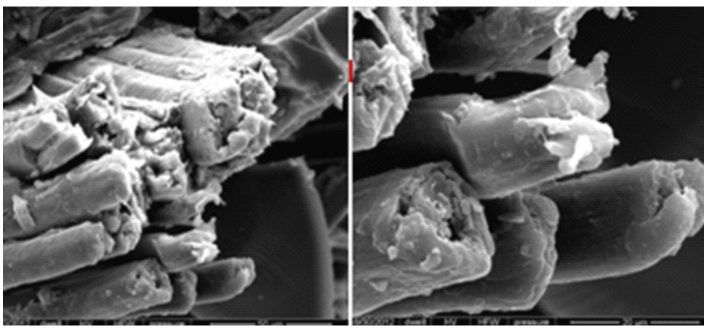

Figure 2. SEM micrographs of composites after tensile failure

In the present study, the tensile properties of the kenaf fiber reinforced UPR composites are displayed in Fig. 1 and summarized in Table 1 showing the peak load, tensile strength, strain at break and young's modulus. Among all tested specimens, kenaf fiber reinforced UPR composites exhibited relative high strength and stiffness characteristics. The tensile stress of sandwich specimens was about 18.21~19.32MPa. On the other hand, the failure strains was 0.81~0.92%. The young's modulus of sandwich panel was 2.05~2.39GPa. Fig. 2 shows the fracture micrograph of kenaf fiber reinforced UPR composites. Good interfacial adhesion of kenaf fiber with polyester resin can be found even though there are some local micro voids. Fiber breakage is the major failure mode.

Table 1. Tensile test results of kenaf fiber reinforced UPR composites

| Specimen | Peak load (N) | Max stress (MPa) | Strain at break (%) | Elastic modulus (GPa) |
|---|---|---|---|---|
| 1 | 582.72 | 18.21 | 0.82 | 2.22 |
| 2 | 621.39 | 19.32 | 0.81 | 2.39 |
| 3 | 594.28 | 18.86 | 0.92 | 2.05 |

3.2. Bending test

To investigate the characteristics of bending behavior of this novel sandwich panels and also to analyze the shear effects of PVC foam core, three point bending tests were carried out. Sandwich specimens for three-point bending test were cut from the whole sandwich panels. The bending load and deflection of the sandwich composites were tested on the basis of five replicates with a MTS 810 universal testing system (USA) in accordance with the procedure described in ASTM D 7264 [9]. The specimen dimensions were 140×28×28.80 $mm^3$ (Length × Width × Thickness). Three-point bending fixture was used, with a constant span of 110 mm and a crosshead speed of 2.0mm/min.

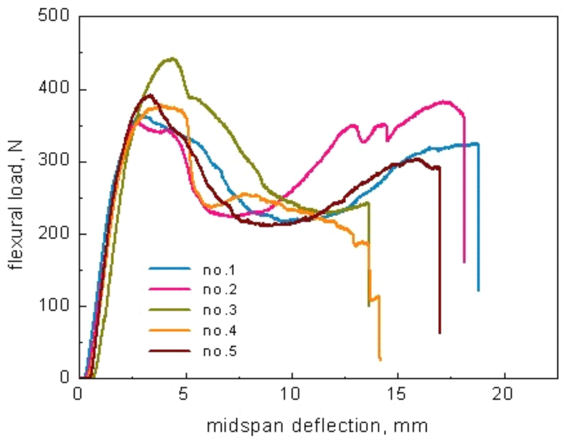


Figure 3. Flexural load versus mid-span deflection of sandwich composite specimens

Fig. 3 shows the flexural load and mid-span deflection of sandwich composite specimens. It could be seen that the whole three-point bending deformation tests included three similar stages for all of specimens. They were linear elastic stage, depressed region and final fracture. The bending properties of sandwich composites were also summarized in Table 2 showing the maximum load, deflection at break, bending stress of face sheet, shear stress in the core, local indentation stress and main failure modes. According to the analysis of [10] , bending stress in face sheet of all tested specimens were 7.79~9.45MPa. The maximum shear stress in the core was 0.29MPa. It was denoted that no shear failure initiated in the sandwich composites. Due to local concentration of loading at mid-span, the major failure mode was local indentation. In the present study, kenaf fiber was randomly distributed in the unsaturated polyester resin matrix. Bending strength was relative high at rich levels of fiber loading. Otherwise, at a relative low level of fiber loading, due to the limitation of resin strength, during the whole stress transfer process, fracture tended to occur in the voids between fiber and resin. Meanwhile those could be used to explain the low stress fracture in no.1 specimen of experimental results, shown in Fig. 4.

Table 3. Three-point bending test results of sandwich composites

| no. | Maximum load (N) | Max Deflection (mm) | $\sigma_f$ (MPa) | $\tau$ (MPa) | $\sigma_{lc}$ (MPa) | Failure modes |
|---|---|---|---|---|---|---|
| 1 | 365.30 | 18.82 | 7.79 | 0.24 | 1.37 | Upper skin fracture, local indentation |
| 2 | 381.13 | 18.17 | 8.13 | 0.25 | 1.43 | local indentation |
| 3 | 443.14 | 13.65 | 9.45 | 0.29 | 1.67 | local indentation |
| 4 | 378.92 | 14.19 | 8.08 | 0.25 | 1.42 | local indentation, crack in the core |
| 5 | 391.17 | 17.01 | 8.34 | 0.26 | 1.47 | local indentation |

*where,bending stress in the face sheet $\sigma_f$ , shear stress in the core $\tau$ and local indentation stress $\sigma_{lc}$ were as follows [10]:

$$\sigma_f = \frac{M_{\max}}{t_f hb} \tag{1}$$

$$\tau = \frac{V_{\max}}{hb} \tag{2}$$

$$\sigma_{lc} = \frac{P}{A} \tag{3}$$

$M_{\max}$ is the maximum moment, $t_f$ is the thickness of face sheet, h is the distance between centroids of the face sheets, and b is the specimen width, $V_{\max}$ is the maximum shear, $P$ is the applied load and $A$ is local crushing area.

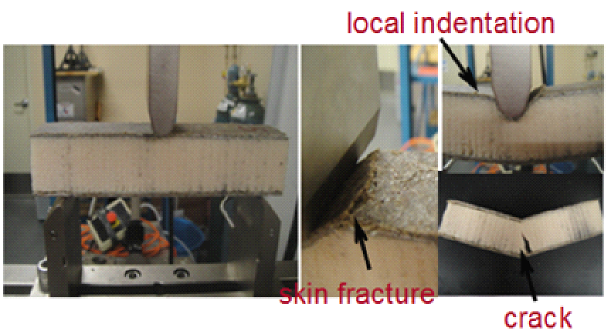


Figure 4. Three-point bending experiment set-up and main failure modes

3.3. Double cantilever beam test

The objective of this part experimental investigation was to understand the fracture behavior and performance of this novel sandwich composite. The double cantilever beam of the sandwich composites were tested on the basis of three replicates with a Shimadzu universal testing system (model SCG-5KNA, Japan) in accordance with the procedure described in ASTM D 5528 [11]. The specimen dimensions were 160×30×28.8 mm3 (Length × Width × Thickness) with a 25 mm pre-crack. A tensile fixture was used, with a piano hinge amounted on the upper and lower sandwich face sheet and a crosshead speed of 2.0mm/min, shown in Fig. 5. During the process of test, the digital camera was used to real-time record the fracture behavior of the pre-crack and also used to take pictures of the typical fracture behavior.

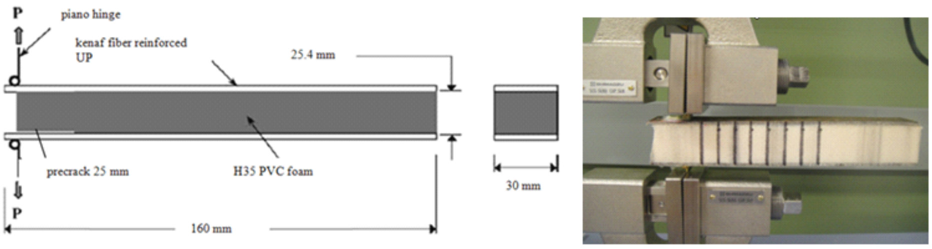


Figure 5. The dimension of double cantilever beam specimens and experiment set-up

A typical load against displacement curve of sandwich specimens during the DCB tests is shown in Fig. 6. The process of fracture can be approximately categorized into four stages based on the observation results and the characteristic load against displacement behavior at each stage, named as I, II, III and IV. In stage I, the load increased approximately linearly to the point A along with the increasing of the open displacement. From the point A to the point B (the stage II), the load against open displacement curve became non-linear. In this stage, the interlaminar delamination initiated between upper sandwich face sheet and PVC foam core and pre-crack developed stably. When stage II fracture completed, the load decreases rapidly from the point B to the point C (the stage III). In stage III, the interlaminar delamination propagated unstably. Beyond the point C, the interlaminar delamination propagation slowly went on. Due to the relative lower randomly distributed fibers in the upper face sheet, skin brittle fracture was found in no.2 specimen.

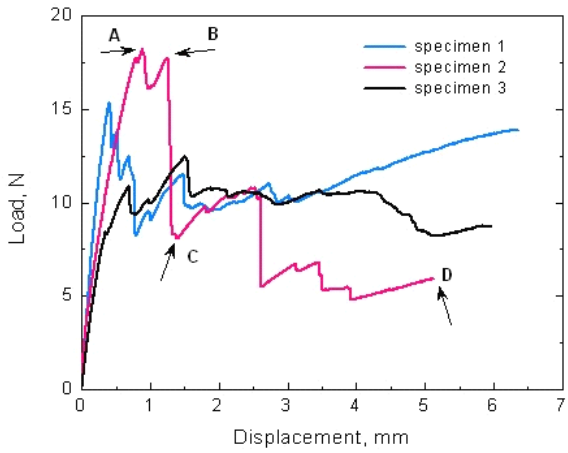


Figure 6. Load against open displacement curves for sandwich composite

According to [12], the strain energy release rate during crack propagation was calculated by,

$$G_c = \frac{\Delta U}{ba} \tag{4}$$

Where, $G_c$ is strain energy release rate, $b$ is the width of the specimen and $a$ is the incremental crack length during the process of test, the energy or work $\Delta U$, is equal to the area under load vs.

displacement curve. In order to calculate the work required to propagate the crack, for all of the specimens, load vs. open displacement of stage II were selected. Meanwhile, the DCB results were summarized in table 4 showing the peak load, open displacement and strain energy release rate Gc. Also compared with some published works, one was for honeycomb sandwich and another was for copper-epoxy interface, it was denoted that this novel sandwich structure exhibited better interlaminar fracture behaviors.

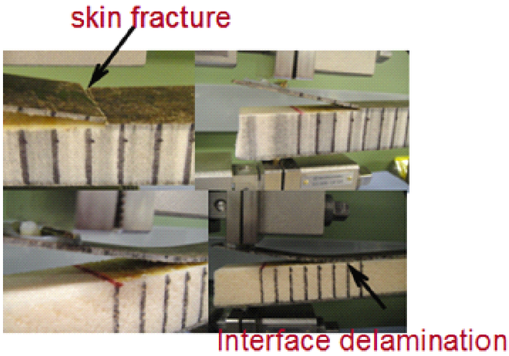


Figure 7. Fracture behavior and propagation of interlaminar delamination of sandwich composite

Table 4. Double cantilever beam test results of sandwich composites

| Specimen | Peak load (N) | Open displacement (mm) | Energy release rate (kJ/m$^2$) | Main failure mode |
|---|---|---|---|---|
| 1 | 15.37 | 0.41 | 0.476 | Interface delamination |
| 2 | 18.27 | 0.89 | 0.277 | upper skin fracture |
| 3 | 12.48 | 1.50 | 0.423 | Interface delamination |

## 4. Conclusions

The following results are obtained,
(1) A novel natural fiber reinforced UPR composite sandwich structure is developed and fabricated.
(2) Mechanical properties results show the elastic modulus of kenaf composite material is about 2.05~2.39GPa. Main failure mode in three-point bending tests is local indentation, while the equivalent flexural stiffness is about 1476~1592N/mm. Meanwhile failure mechanism analysis is accomplished by digital camera and SEM.
(3) Due to lightweight, relative high strength, high elastic modulus and absorb energy, this kind of sandwich structures can be potentially used in civil engineering constructions.

**Acknowledgements**

This research work was financially supported by the central university scientific research basic project (HEUCFZ1128) of China, National Science Foundation of USA (NSF-PFI 1114389 and NSF-CMMI 1031828). The authors thank Kengro, Inc. and DIAB group, for supplying the raw materials. Also show thanks to Dr. Wen Hu, Mr. Changlei Xia, Mr. Mangesh Nar and Dr. Kaiwen Liang for their help in experiments.

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