

# *Mechanical Performance of Kenaf / Wheat Straw Bio-composite Panels Bonded with Urea Formaldehyde*

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## ABSTRACT

The pursuit of sustainable construction materials requires exploring bio-composites as alternative to conventional particle board used in green buildings. This study has evaluated the mechanical properties of bio-composite panels made from a mixture of "*kenaf fibers: wheat straw fibers*" with urea-formaldehyde (UF) resin as a sustainable alternative to conventional particle board. Two types of panels were analyzed: standard specimen (S) and specimen (A) (kenaf: wheat straw) (50:50). Key properties, which were assessed, included tensile strength, stress, strain, modulus of rupture (MOR), modulus of elasticity (MOE), density, internal bond (IB) and young's modules. Specimen (A) exhibited a tensile strength of (22.2) MPA, compared with specimen (S), which had the value of 23.4 MPA. Specimen (A) exhibited a stress of (20.4) MPA, compared with specimen (S), which had the value of 22.3 MPA. Specimen (A), also, showed a strain of (0.8 %) compared with the specimen (S), which exhibited the value of 1.2%. It also displayed MOR of (20.6) MPA, compared with the specimen (S), which had the value of 21 MPA. Specimen (A) also manifested MOE of (2.2) GPA, compared with the specimen (S), which showed the value of 2.6 GPA. It also recorder a density of (0.58)  $\text{g/cm}^3$  compared with the specimen (S), which had the value of 0.6  $\text{g/cm}^3$ . Further, specimen (A) showed IB of (0.63) MPA, compared with the specimen (S), which had the value of 0.9 MPA. It also exhibited young's modules of (2550) MPA, compared with specimen (S), which showed the value of 2500 MPA. This study has concluded that specimen (A) showed mechanical properties which were **very close** to standard specimen (S). The tensile strength, MOR, MOE, young's modulus and strain obtained were excellent, and the stiffness was **very good**, but it showed lower flexibility and slight decrease in internal bonding. It can be **concluded**, according to the findings of this study, that specimen (A) could be used for **interior panels and furniture** in green buildings. The study **recommends** using additional proportions of kenaf fibers, improving the mechanical properties of specimens by increasing the fiber proportions, and increasing the resin content. Furthermore, applying higher mold pressure and increasing density, both, enhance the MOR, MOE and IB values and make specimens more suitable for industrial applications and green building construction.

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## 1. Introduction

### Background

**Fiber** is a category of materials that are continuous filaments or are in discrete elongated pieces, similar to lengths of thread (Khaliq and Zulifqar 2020). They are very essential in the biological systems of both plants and animals, for holding tissues together (Reeves, Tripathi et al. 2022). Human uses of fibers are diverse. They can be spun into filaments, strings, or ropes, used as a component of composite materials, or matted into sheets to make products such as paper or felt. Natural fibers are extracted from natural sources such as plants and animals, whereas synthetic fibers are either made up of chemicals or produced by processing natural fibers to create new fiber structures or properties (Jagadeesh, Puttegowda et al. 2021).

Natural fibers are environmentally friendly, and easily available; they have a low production cost and good definite strength and modulus (Rajeshkumar, Seshadri et al. 2021). Natural fibers are

extracted from different parts of the plant such as stems, leaves, bark and fruits, and they are classified accordingly. The most extensively used plant fibers are sisal kenaf, banana, coir and hemp (AS Singha,2008) and (Shesan, Stephen et al. 2019). Natural fibers are cheap and locally available in several countries. So their use as a construction material for increasing properties of composites costs very little (almost nothing when compared to the total cost of the composites) (Rangappa, Siengchin et al. 2022).

Another benefit may also include the easy usage/ handling of fibers due to their flexibility. But this property can cause a problem when a great amount of fibers is used, as in case of steel fibers. Thus, for using a very high proportion of fibers, there is a need to invent a methodology for casting. '**Fiber volume fraction**' and '**fiber content**' are two terminologies used for expressing the quantities of fibers in a given composite, which can be used for many civil engineering applications,

counting roofing tiles, corrugated slabs, simple slab panels, boards, and mortar etc. (Reeves, Tripathi et al. 2022)

The bio-composite is a composite material formed by a polymeric matrix and a reinforcement of natural fibers like, banana and bagasse jute, coir, sisal, pineapple, ramie, bamboo, etc. These types of materials often mimic the structure of the biomaterials involved in the process, keeping the strengthening properties of the matrix being used, and always providing biocompatibility (Iannace, Bravo-Moncayo et al. 2019). The interest in bio-composites is rapidly growing in terms of industrial applications (such as aerospace, military applications, construction, automobiles, railway trains and packaging), and fundamental research due to their great benefits (they are renewable, cheap, recyclable, and biodegradable). Bio-composites can be used separately or as a complement to standard materials such as carbon fiber (Balaji, Karthikeyan et al. 2018).

Green composites are kinds of bio-composites where both matrix and/or reinforcement are based on cellulose. In addition to their bio-degradability, the benefit of these composites is the chemical similarity of the matrix and the reinforcement, whereby they are able to overcome the problem of poor fiber-matrix adhesion, which is common in bio-composites. Because of increasing ecological effect, natural fibers have been widely recognized as alternatives to synthetic fibers as reinforcements in composites for decades (Choudhury and Debnath 2021).

The utilization of natural fiber reinforces green composites in many applications, and broad research has proved that it has excellent properties such as low density, great strength, handling adaptability, high stiffness, and so forth. A report by (Mahmud, Hasan et al. 2021) has proved that composites based on natural fiber have picked up a significance importance as a reinforcing component in composites.

Green building is the practice of creating structures, adopting processes that are environmentally responsible and resource efficient throughout the building's lifecycle: from planning to design, construction, operation, maintenance, renovation, and deconstruction.

Historically, kenaf fiber was first used as cordage. In industry, exploring the use of kenaf in paper making and non-woven textiles is very common. Like most kenaf, composite products exploit the long part ratio of kenaf fibers and fiber bundles. One method to do this is to form kenaf into a non-woven textile mat that can be used for erosion control, **seedling mulches**, or oil spill absorbents. After a matrix is added to the kenaf mat, they can be compressed into flat panels or molded forms, such as interior car door substrates. Furthermore, low density particle board based on kenaf pith is produced into other parts of the world for animal bedding and other absorbent applications. (Ramesh, Durga Prasad et al. 2018).

The interest in natural fiber-reinforced bio-composites has been growing speedily recently, driven by improved environmental and health concerns, more supportable methods of manufacture and reduced energy consumption. Natural fibers such as cotton, flax, and hemp have been used as reinforcements in bio-composites. Waste generation are a significant burden on the environment. Most food and forestry industry actions result in large amounts of by-products that are often treated as waste and sent to land-fill. One of them is wheat straw. As an inexpensive and more quickly renewable source of cellulose-rich fiber, wheat straw has a great potential of being used as reinforcement in bio-composites (Zhang & Xu, 2021).

The objectives of this study is to reduce the agricultural waste by using it to manufacture bio-composites for ecofriendly building panels and green buildings. The study also aims to manufacture panels for buildings (such as partition board, preformed roofing, flooring materials, windows and doors) with low cost and high durability, to ensure the availability of such buildings, to prove the easy construction and reconstruction of different building parts, and to benefit from such buildings and houses in disasters such as seasonal floods or earthquakes.

**2. Material and methods:**

**2.1 Material**

Kenaf fibers and wheat straw were used as a source of fibers for this research work. Kenaf fibers, and wheat straw were collected from the Blue Nile State.



Fig (2.1): Kenaf fibers

Fig (2.2): Wheat straw

**Table 1: Physical properties of kenaf fibers**

NO	Property	Typical value range
1	Density	1.2-1.45 g/cm <sup>3</sup>
2	Tensile strength	295-930 mpa
3	Young's modules	14-60 Gpa
4	Elongation at break	2.7-1.5%
5	Moisture absorption	13-8%
6	Degradation temperature	200-250 °c
7	Cellulose content	45-57%
8	Hemicellulose	25-50%
9	Lignin	15-20%
10	Ash content	8-15%
11	Fiber eength	2-4mm
12	Fiber diameter	10-30 micrometer

Pickering, K.L, Efendy, M .A, &Le, T.M (2023)

**Table (2.2): The physical and mechanical properties of wheat straw fibers**

NO	Property	Typical value range
1	Density	1.1-1.4 g/cm <sup>3</sup>
2	Tensile strength	150-350 mpa
3	Young's modules	3-15 Gpa
4	Elongation at break	2.5-1.5%
5	Moisture absorption	14-8%
6	Degradation temperature	220-260 °c
7	Cellulose content	40-33%
8	Hemicelluloses	25-20%
9	Lignin	20-15%
10	Ash content	15-8%
11	Fiber length	3.5-2.1mm
12	Fiber diameter	26-12 micrometer

Zhang, Y .Liu ,Wang H,(2023)



**Fig (2.4): Kenaf fibers particles**



**Fig (2.5): Wheat straw particles**



**Fig (2.6): Grinding machine**

**2.1.2 Binding**

Commercial urea-formaldehyde (UF) resin was imported from China with a concentration of 60% and formic acid was also added to urea-formaldehyde resin as a hardener. The properties of urea-formaldehyde are shown in table (2.3).



**Fig (2.3): Urea-formaldehyde adhesive**

**Table (2.3): Properties of the UF adhesive**

Properties	UF adhesive
Appearance	white powder free from foreign matter
PH	7.8-8.8
Solid content (3h\120°C)	60 +_ 2%
Viscosity@20°C	350-450cpc
Gel time@100°C	65-90sec
Specific gravity@20°C	1.25 approx
Free formaldehyde	0.5 max
Shelf@20°C	1 month

**2.2 Methods**

**2.2.1 Composite fabrication:**

**2.2.1.1 Improving the absorbency of kenaf fibers:**

Kenaf fibers and wheat straw were immersed in caustic soda solution concentrically 2% for 45 minutes at 70c. They were washed with hot water for 5 minutes, and then washed with water and soap at 80c for 5 minutes. Finally the fibers were washed with water and soap at room temperature.

**2.2.1.2 Particles preparation**

Kenaf fibers were placed under sun to dry, and were then cut with scissors. Wheat straw was also dried under sun. Kenaf and wheat straw were ground using a Christu grinding machine to achieve a suitable particle size and were then screened.

**2.2.1.3 Manufacture of panels:**

The panels were designed and one specimen was produced using raw materials, the one variables' specimen was as follow: A (Kenaf: Wheat straw) (50:50); the ratio taken from adhesive was one layer panel. The mold was prepared using film to prevent the adhesion of the composites; the dimensions of mold were 40cm x 30cm x3cm, representing length, width, and height, respectively, and the mold was prepared under the sunlight while mixing the particles for one minute

120g of kenaf fiber was taken alongside with 120g of wheat straw and placed on the metallic plate, then mixed carefully. Then the resin of urea-formaldehyde powder was added as a binding material and mixed with other mixture components. In addition, one litter of water was added gradually with continuous stirring. Finally, 5mm of formic acid was added to the mixture as a hardener material and mixed with other components of the mixture. After that, the ingredients were poured in the mold. The mold was put into the oven at 100c° for 1 hour at the pressure of 1.9\*10<sup>-5</sup> bar. It was then removed from the oven and exposed to cold air at 20c° for 30 mins and the mold was left for 24hr. Finally, the specimen was removed from the mold and the tests were carried out

**2.2.1.4 Explanation of fiber-resin interaction**

fiber-resin interaction refers to the bonding mechanism at the interface between the reinforcing fiber and the polymer resin in composite material. This interaction is essential because it allows efficient stress transfer from the resin to the fiber, which carries most of the mechanical load. A strong interfacial bond improves tensile strength, stiffness, and internal bonding of the composite.

**Table (2.4): The percentages and weights of panel specimen (kenaf: wheat straw)(50:50)**

Specimen	(Kenaf: Wheat straw) (50:50)
Weights of fibers/g	120:120
Weights of resin/g	70
Amount of hardener/ml	5
Amount of water/liter	1



**Fig (2.7): Fibers and UF weighting**



**Fig (2.8): Preparation of panels**



**Fig (2.9): Preparation of the moulds**

### 2.3 Panel tests:

The panels were tested on a 100KN capacity universal testing machine UTM (Lishi-Shanghai Instruments Co. Ltd, China), using an ASTM D3039 stander.

### Introduction to the universal testing machine (UTM):

A universal testing machine (UTM) is a mechanical testing device used to determine the mechanical properties of materials under different types of loading. It is called "universal because it can perform many tests such as:

- Compression test
- Bending test(flexural)
- Shear test
- Internal bond test



**Fig (2.10): Manufactured panels**

### The main components of A UTM:

- Load frame, the main structure holding all parts.
- **Cross head;** moves up/ down for applying force.
- **Load cell;** measures the applied force (load value).
- Grips / fixtures, hold the specimen.
- Extensometer / displacement.
- Sensor-measures (extension value).
- Control system & software, record load, extension, stress, strain; and draw curves.

### Specimen preparation:

(According to ASTM standards, especially ASTM D1037,EN 310, EN319 for tension proper specimen preparation is essential for accurate results.

#### 1. Cutting the specimen:

The specimen was cut into rectangular strips. The standard dimensions for composite tension test were:

Total length: 250 mm Gauge length: 150 mm  
Width: 25mm

Thickness: depended on the material (eg 3-5mm).

#### 2. Measuring the dimensions:

The dimensions were measured by using caliper to measure: width (b), thickness (t), and gauge length (lo); these values were recorded for stress and strain calculations.

#### 3. Edge finishing:

Smoothing the edges by using fine sand paper, ensuring that the specimen was straight and flat without cracks or voids.

**4. Adding tabs (optional for composites):**

For panels (natural fiber reinforced composites) the tabs were added at both ends to prevent gripping damage. Tab length: 30-40mm, epoxy adhesive was used carefully.

**5. Making gauge length:**

The marks were drawn to define the gauge section where the strain would be measured.

**Test procedure :( How to perform the tensile test)**

- **Mounting the specimen:**
  1. The specimen was placed between the upper and lower grips.
  2. The grips were tightened carefully to avoid slippage.
  3. We made sure that the specimen was aligned vertically and not twisted,
- **Test settings:**

The specimen was tested by using the UTM software. To select tensile test, the specimen dimensions were entered: the width, thickness, gauge length. The cross head speed was adjusted (commonly 2mm/min for composites), zero the load cell and extensometer.

- **Starting the test:**

Once the start was pressed, the cross head was moved upwards, the specimen was beginning to stretch. The machine recorded the load values in N, extension values in mm. These values were shown continuously . The extension was plotted by the software.

- **Test end**

The test was stopped when the specimen fractured; the peak load (maximum force), total extension, stress-strain curve ,ultimate tensile strength, tensile modulus (E), strain at break were all provided by the machine. Extension value (Extend value): Extension value is the measured increase in the specimen's length during the test.

It represents how much the material elongates as the load is applied.

**What is a measure?**

- Change in length ( $\Delta L$ )
- Unit: mm

Use in calculations:

**Strain= Extension/ Lo**

Extension = ( $\Delta L$ )

Gauge length = Lo

**Applied load value:**

Applied load value is the force applied to the specimen by the testing machine during the test

**Definition of stress:**

Stress is the load applied divided by the cross sectional area.

**Formula**

$\sigma = P/A$

$\sigma$  = Stress (MPa)

P value = applied load (N) & taken from applied load

A ( $\text{mm}^2$ ) = cross sectional area & width x thickness

To convert to mega:

1MPa = 1 N/ $\text{mm}^2$

**Strain:**

Strain is the change in length of specimen divided by gauge length.

**Formula**

$\epsilon = \Delta L / L_0$

Where:

$\epsilon$  = strain

$\Delta L$  value = extension taken from extent value

$L_0$  = gauge length

**Definition of ultimate tensile strength:**

Tensile strength is the maximum stress a material can withstand while being stretched before breaking. It represents the maximum load carrying capacity of the material in tension.

**Formula**

$UTS = P_{max}/A$

$P_{max}$  = maximum Applied load before fracture (N)

A= cross sectional area of specimen

A ( $\text{mm}^2$ ) = cross sectional area & width x thickness

**Definition of Young's modulus:**

Young's modulus measures the stiffness of material, how much it resists deformation under load.

**Formula**

E= Young's modulus (MPa)

$E = \Delta \sigma / \Delta \epsilon$

Where

E= Young's modulus (MPa)

$\Delta \sigma$ =change in stress in the liner region

$\Delta \epsilon$ = change in strain in the liner region

**MOE-Modulus of elasticity:**

MOE-Modulus of elasticity is the slope of the linear (elastic) part of the load deflection or stress-strain curve. It measures the stiffness of material.

Formula (bending)

$MOE = L^3 \Delta P / 4bt^3 \Delta \sigma$

Where

L = Span length (mm)

b = width (mm)

t= thickness (mm)

$MOE = \Delta P / \Delta \sigma$

**MOR Modulus of rupture:**

MOR is the maximum bending stress a material can withstand before failure.

**Formula:**

$MOR = 3 P_{max} L / 2 b t^3$

$P_{max}$  =maximum load before fracture

L = span length

t= thickness

Unit = MPa

**Internal bond (IB):**

It is the tensile strength perpendicular to the board surface, measuring the internal bonding quality between fibers and particles.

**Formula**

$IB = P_{max} / A$

$P_{max}$  =eak load at failure

A = bonded area ( $\text{mm}^2$ )

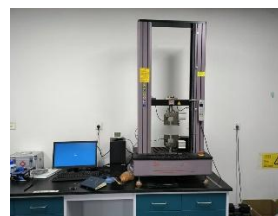




Fig (2.11): Universal testing machine (UTM)

The standard dimensions of A UTM:

- The length: 250mm
- Gauge length: 150mm
- Width: 25mm
- Thickness: 3mm

From the A UTM the applied and extended values are taken.

**Density:**

Density is the mass of material per unit volume.

**Formula:**

$$\text{Density} = \frac{\text{mass (g)}}{\text{volume (mm}^3\text{)}}$$

$$\text{Volume} = b \times d \times L$$

d= thickness (mm)

b= width (mm)

L= length (mm)

**Applied value definition:**

It is a practical benefit obtained from using the universal testing machine to measure the actual mechanical performance of materials under real loading conditions.

**Extended value definition:**

It is an additional value gained beyond the basic test results, such as predicting future behavior of materials, comparing the different composites, or extending the results to wider engineering applications.

There was one specimen A (kenaf fibers and wheat straw fibers reinforced urea-formaldehyde resin)

, tested on a universal testing machine and the results were as follows:

The average of values	Applied load	Extend value
(Kenaf: wheat straw)	1665 N	1.53mm

**3. Results and Discussions:**

**3.1 Standard Particle Board:**

Table 3.1: Tensile strength, stress, strain, MOR, MOE, density, IB and young's modulus of the particle board (specimen S)

S	Tensile Strength (MPa)	Stress (MP)	Strain (%)	MOR (MPa)	MOE (GPa)	Density (g/cm <sup>3</sup> )	IB (MPa)	Young's Modulus (MPa)
1	23.7	22.4	1.1	18	2.4	0.7	0.8	2500
2	23.3	22.1	1.0	18	2.7	0.7	0.9	2540
3	23.5	22.0	1.3	19	2.7	0.6	0.9	2520
4	23.4	22.5	1.5	25	2.7	0.6	1.0	2470
5	23.1	22.5	1.1	25	2.5	0.4	0.9	2470
<b>X̄</b>	<b>23.4</b>	<b>22.3</b>	<b>1.2</b>	<b>21</b>	<b>2.6</b>	<b>0.6</b>	<b>0.9</b>	<b>2500</b>
<b>σ</b>	<b>0.62</b>	<b>1.12</b>	<b>0.22</b>	<b>24</b>	<b>0.27</b>	<b>0.01</b>	<b>0.12</b>	<b>33.82</b>

(Hussein , 2018), (IJETT,2021).

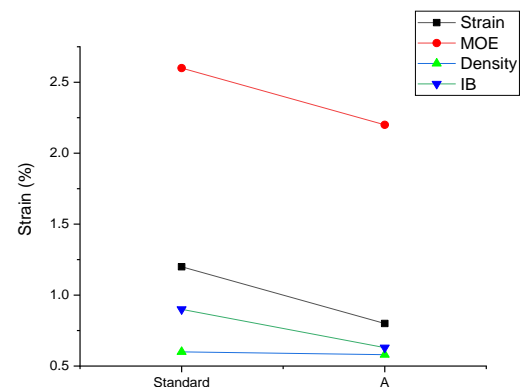
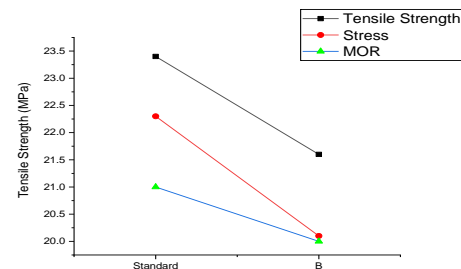
**3.2 Kenaf fibers: wheat straw (50:50)**

Table 3.2: Tensile strength, stress, strain, MOR, MOE, density, IB and Young's modulus of kenaf fiber : wheat straw (50:50)

S	Tensile Strength (MPa)	Stress (MPa)	Strain (%)	MOR (MPa)	MOE (GPa)	Density (g/cm <sup>3</sup> )	IB (MPa)	Young's Modulus (MPa)
1	21.8	20.1	0.6	20.5	2.2	0.59	0.68	2080
2	22.7	20.8	0.8	20.4	2.2	0.59	0.61	2570
3	21.8	20.0	0.8	20.8	2.1	0.56	0.61	2530
4	21.9	20.7	0.8	20.8	2.3	0.58	0.62	2540
5	22.8	20.4	1.0	20.5	2.2	0.58	0.63	2560
<b>X̄</b>	<b>22.2</b>	<b>20.4</b>	<b>0.8</b>	<b>20.6</b>	<b>2.2</b>	<b>0.58</b>	<b>0.63</b>	<b>2550</b>
<b>σ</b>	<b>0.85</b>	<b>1.34</b>	<b>0.28</b>	<b>0.28</b>	<b>0.28</b>	<b>0.014</b>	<b>0.19</b>	<b>35.36</b>

Table (3.3): Comparing the average values of tensile strength, stress, strain, MOR, MOE, density, IB and young's modulus of specimens: standard and kenaf fiber: wheat wtraw (50:50) 1

SPEC	Tensile strength (MPa)	Stress (MP)	Strain (%)	MOR (MPa)	MOE (GPa)	Density (g/cm <sup>3</sup> )	IB (MPa)	Young's modulus (MPa)
STAND	23.4	22.3	1.2	21	2.6	0.6	0.9	2500
K & W	22.2	20.4	0.8	20.6	2.2	0.58	0.63	2550
%	94.87	91.47	66.66	98.09	84.61	96.66	70	102



As shown in Table 3.3 specimen (A) exhibited the value of 22.2(MPa) of the **tensile strength**, this value was close to the **tensile strength** of standard specimen (S), which had the value of 23.4 MPa. This result seemed to be excellent. Specimen (A) showed the value of 20.4 (MPa) for the **stress**, this value was close to the **stress** of specimen (S), which showed the value of 22.3 (MPa). This result could be considered very good. Moreover, specimen (A) exhibited the value of 0.8% of **strain** compared to the value of specimen

(S), which had the value of 1.2 %. Although this value was lower than the **strain** of specimen (S), this result could be considered excellent. It was also observed that specimen (A) exhibited the value of 0.58 (g/cm<sup>3</sup>) of the **density**; this value was close to the **density** of specimen (S), which showed the value of 0.6 (g/cm<sup>3</sup>). This result seemed excellent. As shown in table 3.3, specimen (A) exhibited the value of 20.6(MPA) of the **MOR**; this value indicated a close relationship to the value of **MOR** of specimen (S), having the value of 21 (MPA). This result seemed excellent. In addition, specimen (A) exhibited the value of 2.2(GPA) for the **MOE**; this value matched to some extent the **MOE** of specimen (S), which had the value of 2.6 (GPA). This result could be claimed to be excellent. From table 3.3, it is clear that specimen (A) exhibited the **IB** value of 0.63 (MPA). This value was lower than the **IB** of specimen (S), which showed the value of 0.9 (MPA), because of the reduction in density, which reduced the interfacial bonding between fibers, and led to the formation of voids, thereby decreasing IB. This result was considered good. It is also clear from table 3.3, that specimen (A) exhibited the **Young's Modulus** value of 2550 (MPA). This value was higher than the **Young's modulus** of specimen (S), which had the value of 2500 (MPA). This result seemed to be excellent. A comparison of specimens (A) with the standard specimen (S) across **all eight mechanical properties** tests indicated that specimen (A) exhibited the best performance, receiving **an excellent** rating,

#### 4. Conclusion and Recommendations:

##### 4.1 Conclusion:

Specimen (A) showed mechanical properties which were very close to standard specimen (S). The tensile strength, stress, MOR, MOE, young's modulus and strain obtained were excellent, and the stiffness and IB were very good. But they showed lower flexibility and slight decrease in density. **It can be concluded**, according to the findings of this research, that **kenaf fibers & wheat straw** composites, specimen (A), can be used for interior panels and furniture in green buildings.

##### 4.2. Recommendations for further work:

The following recommendations are proposed by the researcher for future work:

1. Using additional proportions of kenaf fibers.
2. Improving the mechanical properties of specimens by increasing the fiber proportions, increasing the resin content, and applying higher mold pressure.
3. Increasing density enhances the MOR, MOE and IB values and makes specimens more suitable for industrial applications and green building construction.
4. Addition of flame retardant agent or other agent to improve water proof and thickness swelling test or other properties.

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