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Performance of Hybrid kenaf - bagasse particle boards compared with Commercial Board

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ABSTRACT

The pursuit of sustainable construction materials requires exploring bio-composites as alternative for conventional particle board used in green buildings. This study evaluate the mechanical properties of bio-composite panels made from a mixture of (kenaf fibers : bagasse fibers) with urea-formaldehyde (UF) resin as sustainable alternative to conventional particleboard. Two types of panels were analyzed: a standard (Specimen S) and specimen(B) (kenaf fibers: bagasse fibers) (50:50). Key properties assessed included tensile strength, stress, strain, modulus of rupture (MOR), modulus of elasticity (MOE), Density, internal bond (IB) and young's modules. The specimen (B) exhibited **Tensile Strengths** of (21.6) MPA,as compared with the (Specimen S) which has the value of 23.4 MPA. The specimen (B) exhibited **Stress** of (20.1) MPA, as compared with the (Specimen S) which has the value of 22.3 MPA. The specimen (B) exhibited **Strain** of (0.84,) %, as compared with the (Specimen S) which has the value of 1.2%. The specimen (B) exhibited **MOR** of (20) MPA,as compared with the (Specimen S) which has the value of 21 MPA. The specimen (A) exhibited **MOE** of (1.8) GPA, as compared with the (Specimen S) which has the value of 2.6 GPA. The specimen (B) exhibited **Density** of (0.48) **g/cm^3** as compared with the (Specimen S) which has the value of 0.6 **g/cm^3**. The specimen (B) exhibited **IB** of (0.63) MPA, as compared with the (Specimen S) which has the value of 0.9 MPA. The specimen (B) exhibited **young's modules** of (2280) MPA, as compared with the (Specimen S) which has the value of 2500 MPA. **This study concludes** that the Also the specimen B is shown mechanical properties which are **relatively close** to the standard (specimen S). The tensile strength, MOR, MOE, Young′s Modulus and strain were **very good** and the **stiffness** was **good**, but it showed **lower flexibility** and a slight decrease in internal bonding. It can be **concluded** according to the findings of this study that (specimen **B**) can be used for **interior panels (non –load bearing uses) and furniture** in green buildings.The study **recommended** using additional proportions of kenaf fibers, improving the mechanical properties of specimens by increasing the fibers proportions, increasing the resin content and by applying higher mold pressure and increasing density enhances the MOR, MOE and IB values and makes specimens more suitable for industrial applications and green buildings construction.

Key words: composite materials, Sustainable, construction, exploring, fibers, green buildings kenaf fiber, bagasse fibers, Bagasse fibers, urea formaldehyde resin, sustainable, alternative, particleboard

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 biology of both plants and animals, for holding tissues together (Reeves, Tripathi et al. 2022). Human uses for fibers are diverse. They can be spun into filaments, string, or rope, 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 for example plants, animals and synthetic fibers are either made up of chemicals or by processing natural fibers to create new fiber structures or properties (Jagadeesh, Puttegowda et al. 2021).

Natural fibers are environmentally friendly, low production price and easily available and have good definite strength and modulus (Rajeshkumar, Seshadri et al. 2021). Natural fibers are extracted from different parts of the plant for instance stem, leaf, bark and fruits and they are classified accordingly. The most extensively and AS Singha,2008 used plant fibers are sisal kenaf, banana, coir and hemp (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 a 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, for the reason that the problem arises when a high of fibers is to be used as in case of steel fibers. But for use of very high percentage of fibers, there is a need to invent a methodology for casting. Fiber Volume fraction and fiber content are tow terminology used for expressing the quantities of fibers in a given composites 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 not only keeping the strengthening properties of the matrix that was used, however always providing biocompatibility. (Iannace, Bravo-Moncayo, Ciaburro, Puyana-Romero, & Trematerra, 2019) .The interest in biocomposites is speedily growing in terms of industrial applications such as (aerospace, military applications, construction, automobiles, railway coach_ and packaging) and fundamental research, due to its great benefits (renewable, cheap, recyclable, and biodegradable). Biocomposites can be used separately or as a complement to standard materials such as carbon fiber (Balaji, Karthikeyan, Swaminathan, & Raj, 2018).

Growing environmental awareness and increasing interest in sustainability have led to the development of bio-composites for structural applications. The availability of natural issues urged the need to search for new choices which could substitute the regular composites with bring down environmental impact. These made an enthusiasm for common materials which could be utilized as reinforcing materials in composites and are along these lines called as green composites or eco-composites or bio-composites (M. Li et al., 2020).

Green composites are a kind of bio-composites where both the matrix and/or reinforcement are based on cellulose. Furthermore, 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 for synthetic fibers as reinforcements in composites for decades. (Choudhury & Debnath, 2021).

The utilization of natural fiber reinforced green composites in many applications is due to of broad research attempted and excellent properties such as low density, great strength, handling adaptability, high stiffness, and so forth. Reports proved that natural fiber based composites have picked up in significance importance as the reinforcing component in composites. (Mahmud et al., 2021)

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

Historically, kenaf fiber was first used as cordage. Industry is exploring the use of kenaf in paper making and non woven textiles . Like most kenaf composite products exploit the long part ratio of kenaf fibers and fiber bundles. One method to do this to form the kenaf into a non-woven textiles mat that can be used for erosion control ,seedling mulches or oil spill absorbents. After a matrix is added to the kenaf mats , they can be pressed 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. (P. Ramesh, Durga Prasad, & Narayana, 2018)

The interest in natural fiber reinforced biocomposites has been growing speedily during recent years, 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 biocomposites 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 a inexpensive and more quickly renewable source of cellulose-rich fibre, wheat straw has a great potential of being used as reinforcement in biocomposites (Zhang & Xu, 2021).

The objectives of this study (to reduce the agricultural waste by using it to manufacture biocomposites for ecofriendly building panels green buildings, to manufacture panels for buildings such as (partition board, preformed roofing, flooring materials, windows and door) with low cost and high durability, to ensure the buildings availability and the ease of construction and reconstruction of different building parts and to benefit from such buildings houses in disasters such a season flood or earthquakes.

2.Material and methods:

2.1 Material

Kenaf fibers and wheat straw where used as a source of fibers for this research work. Kenaf fibers and Bagas fibers were collected from Blue Nile state.


Fig (2.1): Kenaf fibers **Fig (2.2): Bagas fibers**

Table 1: physical properties of kenaf fibers

No.	Property	Typical value range
1	Density	1.2-1.45 g\cm^3
2	Tensile strength	295-930 mpa
3	Young's modules	14-60 Gpa
4	Elongation at Break	2.7-1.5%
5	Moisture Apsorbation	13-8%
6	Degradation Temperature	200-250 ^{0}c
7	Cellulose Content	45-57%
8	Hemicellulose	25-50%
9	Lignin	15-20%
10	Ash content	8-15%
11	Fiber Length	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 Bagasse fibers

No.	Property	Typical value range
1	Density	1.25-1.45 g\cm3
2	Tensile strength	100-290 MPA
3	Young′s Modulus	5-17 GPA
4	Elongation at Break	3-1.1%
5	Moisture Absorption	15-9%
6	Degradation Temperature	220-280c
7	Cellulose Content	55-40%
8	Hemicellulose	20-15%
9	Lignin	24-18%
10	Ash content	4-1%
11	Fiber Length	1.59-1.15mm
12	Fiber Diameter	1.72-9.8micro

Wang,X,Sun,X,& Wang, W.(2021)

2.1.2 Binding

Commercial urea formaldehyde (UF) Resin was imported from china with concentrated 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 Composites fabrication:

2.2.1.1 Improvement the absorbency of kenaf fibers:

Kenaf fibers and bagasse have been immersed in caustic soda solution concentrically 2% for 45 minutes at 70c. these fibers are washed with hot water for 5minutes and then these fibers are washed with water and soap at 80c for 5minutes.finally the fibers are washed with water and soap at room temperature.

2.2.1.2 Particles preparation

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

Fig (2.4): Kenaf fibers Particles

Fig (2.4): Bagasse fibers Particles

Fig (2.6): Grinding machine

2.2.1.3Manufacturing of panels:

The panels were designed and one specimen was produced using raw materials, the one variables' specimen was as follow; A(Kenaf: Bagas) (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 Bagas and placed on the metallic plate, then mixed carefully after that 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 steering, and finally, 5mm of formic acid was added to the mixture as hardener material and mixed with other components of the mixture, after that the ingredients were poured in the mold. The mold was entered in the oven at 100c° for 1 hour at the pressure of $1.9*10^{-5}$ bar, the mold was removed from the oven and exposed to the cold air of 20c° for 30min 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 Explaination 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 the mechanical load.A strong interfacial bond improve tensile strength, stiffiness, and internal bonding of composite.

Table (2.4): The percentages and weights of panel specimen (Kenaf: Bagas)(50:50)

Specimen	(Kenaf: Bagas) (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 Panels 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 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 to applying force.
- Load cell , measure the applied force (load value).
- Grips / fixtures, hold the specimen.
- Extensometer / displacement.
- Sensor-measures (extension value).
- Control system & software, records load, extension, stress, strain and draws 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 are:

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

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

2. Measure dimensions:

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

3. Edge finishing:

Smooth the edges using fine sand paper. Ensure the specimen is 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. Make gauge length:

The marks were draw to define the gauge section where the strain will 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. 5The grips were tightened carefully to avoid slippage.
3. Make sure to 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 which, width, thickness, gauge length. The cross head speed has been adjusted (commonly 2mm/min for composites), zero the load cell and extensometer.

- **Start the test:**

Once the start was pressed, the cross head was moved up word, the specimen was beginning to stretch. The machine was 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 provided by 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 (ΔL)
- Unit: mm

Use in calculations:

Strain= Extension/ Lo

Extension = (ΔL)

Gauge length **=** Lo

Applied load value:

Applied load value is 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

σ = P/A

σ = Stress (MPA)

P value = Applied load (N) &Taken from Applied load

A (mm^2) = cross sectional area & width x thickness

To convert to mega:

1MPA = 1 N/mm^2

Strain:

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

Formula

£ = ΔL **/** Lo

Where:

£ = strain

ΔL value = Extension taken from Extent value

Lo **=** gauge length

Definition of Ultimate tensile strength:

Tensile strength is maximum stress a material can withstand while being stretched before breaking. It represent 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 (mm^2) = cross sectional area & width x thickness

Definition of Young's modulus:

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

Formula

E= Young's modulus (MPA)

E= Δ σ / Δ**£**

Where

E= Young's modulus (MPA)

Δ σ=change in stress in the liner region

Δ**£**= 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 = ΔP / Δ σ

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):

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} =Peak load at failure

A = bonded area (mm^2)

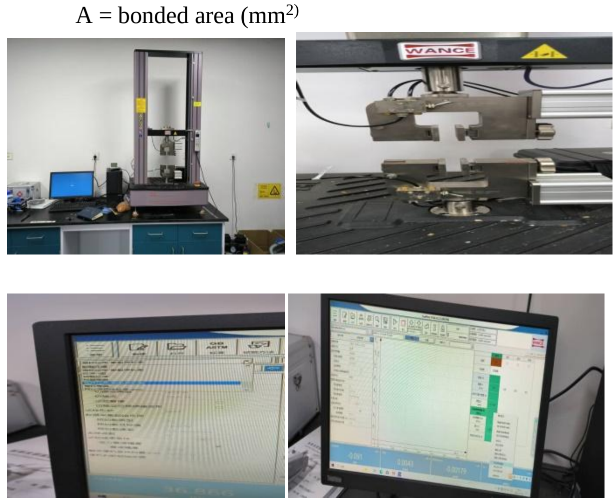


Fig (2.11): Universal testing machine (UTM)

The standard diminutions of A **UTM**:

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

From the A UTM taken the applied and extended values.

Density:

Density is the mass of material per unit volume.

Formula:

Density =mass (g)/ volume (mm^3)

Volume= b x d x L

d= thickness (mm)

b= width (mm)

L= length (mm)

Applied value definition:

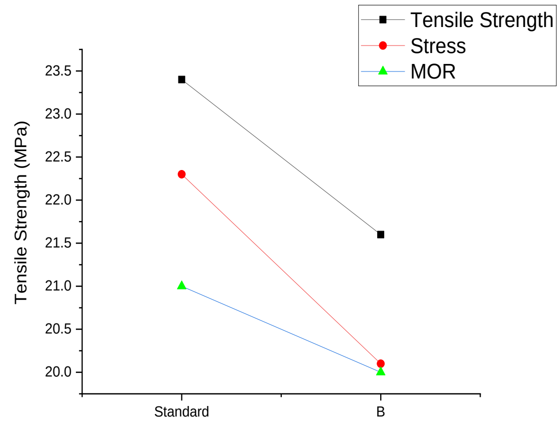
It is practical benefit obtained from using the universal testing machine to measure the actual mechanical performance of materials under real loading conditions.

Extended value definition:

It is 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 is 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: Bagas)	**1665 N**	**1.53mm**



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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 (MPA)	Strain (%)	MOR (MPa)	MOE (GPa)	Density (g/cm^3)	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
X̄	**23.4**	**22.3**	**1.2**	**21**	**2.6**	**0.6**	**0.9**	**2500**
σ	**0.62**	**1.12**	**0.22**	**24**	**0.27**	**0.01**	**0.12**	**33.82**

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

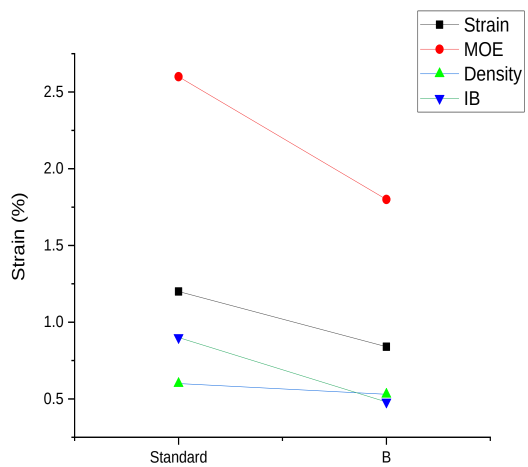
3.2 Kenaf Fibers: Wheat Straw (50:50)

Table 3.2: **Tensile Strength, Stress, Strain, MOR, MOE, Density, IB and Young′s Modulus of Kenaf Fiber : Bagas Fiber (50:50)**

S	Tensile Strength (MPA)	Stress (MPA)	Strain (%)	MOR (MPa)	MOE (GPa)	Density (g/cm^3)	IB (MPa)	Young′s Modulus (MPa)
1	21.7	20.2	0.9	20.0	1.8	0.53	0.48	2280
2	21.4	19.8	0.8	20.0	1.7	0.54	0.48	2270
3	21.2	20.1	0.9	20.4	2.1	0.53	0.49	2290
4	21.9	20.0	0.9	19.8	1.8	0.55	0.48	2880
5	21.8	20.4	0.7	19.8	1.6	0.50	0.47	2280
X̄	**21.6**	**20.1**	**0.84**	**20.0**	**1.8**	**0.53**	**0.48**	**2280**
σ	**0.73**	**1.25**	**0.19**	**0.24**	**0.26**	**0.011**	**0.18**	**32.11**

Table (3.3): comparison the average values of Tensile Strength, Stress, Strain, MOR, MOE, Density, IB and Young′s Modulus of specimens: standard and Kenaf Fiber: Bagas Fiber (50:50)

SPEC	**Tensile Strength (MPa)**	**Stress (MPa)**	**Strain (%)**	**MOR (MPa)**	**MOE (GPa)**	**Density (g/cm^3)**	**IB (MPa)**	**Young′s Modulus (MPa)**
STAND	23.4	22.3	1.2	21	2.6	0.6	0.9	2500
K &B	21.7	20.2	0.9	20.0	1.8	0.53	0.48	2280
%	92.73	90.58	75	95.23	69.23	88.33	53.33	91.2



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As shown in Table 3.3 the (specimen B) exhibited the value of 21.6(MPA) for the **tensile strength**, this value is close to the **tensile strength** of the (Specimen S) which showed the value of 23.4 MPA. This result can be concluded that there is a strong relationship between the standard and B. Also the (specimen B) exhibited the value of 20.1 (MPA) for the **stress,** this value is the close to the **stress** of the (Specimen S) with the value of 22.3 (MPA). This result seems to be very good. From Table 3.3 the (specimen B) exhibited the value of 0.84 % of **strain** as compared with the value of the (Specimen S) with the value of 1.2 %. Although this value is the lower than the **strain** of the standard (Specimen S) but this result showed excellent relationship. It can also be observed that the (specimen B) exhibited the value of the **density** of 0.53 (g/cm^3)**,** this value is relatively close to the **density** of the (Specimen S) which has the value of 0.6 (g/cm^3). This result seems to be very good. It is obvious that the (specimen B) exhibited the value of 20 (MPA) of the **MOR,** this value is relatively close to the **MOR** of the (Specimen S) with the value of 21 (MPA). This result seems to be very good. Also, the (specimen B) exhibited the **MOE** value of 1.8 (GPA)**,** this value is relatively close to the **MOE** of the (Specimen S) which showed the value of 2.6 (GPA). This result seems to be very good. It is also clear that the (specimen B) exhibited the **IB** value of 0.48 (MPA) this value is lower than the **IB** of the (Specimen S) which showed the value of 0.9 (MPA),because a reduction in density, which reduces the interfacial bonding between fibers and leads to the formation of voids, therby decreasing IB. This result seems to be acceptable. Finally, the (specimen B) exhibited the value of 2280 (MPA) for the **Young′s Modulus**, this value is relatively lower than the **Young′s Modulus** of the (Specimen S) which has the value of 2500 (MPA).This result seems to be very good. A comparison of the specimens (**B**) with the Standard (Specimen **S**) across **all** eight **mechanical properties** tests indicate that the specimen **B** exhibited the best performance, receiving **very good** rating,

4. Consolation and Recommendations:

4.1 Consolation:

The specimen **B** showed mechanical properties **relatively close to** the Standard (Specimen **S**). The tensile strength, MOR, MOE, Young′s Modulus and strain were **very good** and the **stiffness** was **good**, but it showed **lower flexibility** and a slight decrease in **internal bonding.** It is suitable for **interior panels** (non –load bearing uses) 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 fibers proportions, increasing the resin content and by applying higher mold pressure.
3. Increasing density enhances the MOR, MOE and IB values and makes specimens more suitable for industrial applications and green buildings 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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