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Behavior of Timber Beams Strengthened by Jute Fibers

A B S T R A C T

The study involves strengthening timber beams by known jute fibers with various forms of strengthening and comparison the bending test results with the control beams and beams strengthened by steel plates.

Twenty-two timber specimens with dimensions (70×100×1000) mm are divided into eight groups and loaded under a one-point load. The work is carried out to study the flexural and shear strengthening effects on behavior of the tested beams. Four specimens wrapped in U technique in single and double layers, along the whole length of the beam in full and strips wrapping technique, seven beams bonded in full and spiral configuration, seven timber specimens wrapped in flexural strengthening technique with single and multiple layers, and two samples strengthened by steel plates.

The results show that jute fibers strengthening are improved the ultimate loads of timber beams by between (30%-101%) compared with the control beams for different types of strengthening and by about (80%, 85%) using steel plates strengthening. On the other hand, the mid-span deflection are decreased by between (28%-45%) at the same load. Furthermore, it is found that the highest ultimate load deflection is when the beam wrapped in full strengthening technique.

The ductility, stiffness, toughness at yield load and toughness at ultimate load are increased by between (21%-51%), (10%-73%), (45%-373%), and (57%-401%), respectively. The jute fibers strengthening have high elasticity performance and prove that the jute fibers materials have a large potential to act as a structural strengthening material.

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Introduction

Timber is a natural organic material; it had been used since early times in the construction of houses, bridges, other structures, and remains an important construction material to these days [1]. Timber is one of the new building materials recently used in the construction process in Iraq [2]. Recently, the strengthening of various types of timber beams with various materials and configurations to improve its mechanical properties and increasing the resistance to bending and shear loads and increase its stiffness and durability compared to those that are not strengthened by this type of modern strengthening systems [3]. These days the traditional fibers such as glass fibers, carbon fibers, and steel plates were supplanted with the natural fibers, for example, sisal, coir, cotton, linen, and jute fibers attributable to their simple accessibility and its low cost. Many kinds of researches occur on this path [4, 5, and 6].

Ahmad, Javaid, and Dr. Javed Ahmad Bhat [7], studied the ductility of the timber beams strengthened with the carbon fiber reinforced-polymer (CFRP) composites plates. Ten timber beams of Deodar and Kail wood with dimensions of 70×120×2000 mm tested under a four-point bending test till the failure. The experimental work consisted of ten beams that were prepared; eight of these beams strengthened by using CFRP Plates of different widths applied on the tension zone of the timber beams using an adhesive, and the other two beams tested as a control timber beam. The results showed that the strength values of strengthened beams were increased with the increasing percentage of (CFRP) sheets by about 140% for Kail wood beams and 114.28% for Deodar wood beams. Also, the ductility values were increased with the increasing percentage of (CFRP) sheets, where the highest value of ductility index was 4.33 for Kail wood beams and 6.81% for Deodar wood beams.

Ahmed Yusof [8], studied ductility behavior of timber beams reinforced with carbon fiber-reinforced polymer (CFRP) strips. The surface to be strengthened was punched by small holes of 2 mm diameter by 10 mm spacing and the cross-section of the beams strengthened by (CFRP) strips with different areas. The aim was to increase the bonding capacity by making small holes. Five timber beams with dimensions of 100×200×3000 mm were tested and one of these beams was tested as an un-strengthened beam (control beam). The results presented that the ductility values were increased with the increasing percentage of (CFRP) strips.

Jasieńko, J., and Nowak, T. P [9] presented a study on timber beams reinforced with steel sheets and the epoxy adhesive with different types of configurations. Forty-six samples were tested with dimensions 100×200×4000 mm of pinewood consisted of twenty-three samples of new timber beams (NT) and twenty-three samples of old timber beams (OT), which tested under a four-point load bending test till the failure. The study concluded that the load-bearing capacity of timber beams that strengthened with steel sheets that bonded into a cross-section of the timber was increased by 69% compared with (NT) beams and by 100% compared with (OT) beams. Also, the load-bearing capacity of strengthened timber beams with steel sheets glued to the upper and lower surfaces of the beams was increased by 58% with (OT) beams in the case of thickness 4 mm compared with the un-strengthened beam.

Yang, Huifeng, et al. [10], presented an experimental program of testing glued laminated timber beams (glulam) strengthened by using steel materials and fiber-reinforced polymer (FRP) using flexural strengthening method. Forty-six samples with dimensions 75×300×6000 mm of Douglas Fir glulam were tested under a four-point load bending test till

the failure. The test results presented that stiffness, tensile strain, and flexural capacity of the strengthened timber beams were greatly improved compared with the un-strengthened beams by, which the improvement reached 27.5%, 49.4%, and 56.3% respectively.

Karzan, S. Habeeb [11], investigated the post-cracking behavior and controlling the toughness behavior of the jute-fiber reinforced cementitious composites. The experimental work consisted of six groups of samples with dimensions 25×150×600 mm were cast and reinforced with the jute-fiber ropes for each group and tested under a four-point load bending test till the failure. The testing results showed that the increment ratio of the ultimate failure load and the first crack load ranged about (6%-24%) and (10%-46%) respectively due to the increment of the jute-fiber volume fraction. Also, the results showed that the toughness indices were increased with the increment of the jute-fiber volume fraction.

Sen, T., & Reddy, H. J. [12], discussed the behavior of jute textile reinforced-polymer composite (JFRP) system and studied the results of tensile, flexural tests and compared with that of carbon fiber (CFRP) and glass fiber (GFRP) reinforced-polymer composite systems for flexural strengthening of the reinforced concrete beams (RC) by proceeding bending test on this concrete beams using three groups consisted of fourteen beams. The results showed that JFRP, GFRP and CFRP, strengthening systems increased the ultimate strength of the reinforced concrete beams (RC) by 62.5% for JFRP system, 150% for CFRP system and 125% for GFRP system, with the full wrapping technique and by 25% for JFRP system, 50% for CFRP system and 37.5% for GFRP system, with the strips wrapping technique.

Alam, M. A. et al. [13], explained an experimental program of strengthening reinforced concrete beams (RC) by using jute ropes composite plates as an alternative material

of carbon fiber reinforced-polymer (CFRP) for the flexural strengthening of the concrete beams. The experimental program consisted of jute ropes composite plates, with dimensions 80×100×2000 mm were fabricated including fiber content of 25%. The results showed that the failure load of the reinforced beam with jute ropes composite plates was 131 kN, which was 58% higher when compared with the un-strengthened beam. The jute ropes composite plates of the strengthened beam had reduced the deflection in the first stage and increased the ductility at the same time of failure when compared with the un-strengthened beams.

Yaseen A. Salih, et al., [14] investigated the effect of thickness and width of jute fibers strips on all mechanical properties of the reinforced concrete beams (RC). The experimental work consisted of twenty-four samples of RC beams distributed into four groups and tested under a one-point load bending test until the failure. The results showed that ultimate flexural strength, load-carrying capacity, and toughness of the reinforced concrete beams (RC) strengthened with (JFRP) system were increased with the increment of the thickness and width of the strips, while stiffness and ductility were decreased with the increment of strips thickness and width.

The aim of this study is to investigate the behavior of timber beams strengthened by jute fibers and compared with that of control timber beams and beams strengthened by steel plates.

2. EXPERIMENTAL WORK

2.1 Materials

- Timber

White timber (Russian type) is used in this study. The commercial name of this type of timber is (Spruce wood, brought from Russia). The mechanical properties of white timber specimens are evaluated according to the standard specification ASTM D 143-94 [15], as

shown in Table 1. Fig. 1 shows the experimental tests procedures of timber specimens.

Table 1

Mechanical properties of timber specimens

Material property	Sizes (mm)			Tests results(N/mm ²)	Moisture content (%)
	B ^a	H ^b	L ^c		
fc ^d	50	50	200	30	14.18
fc ^e ⊥	50	50	150	6	14
fb ^f	50	50	750	7.8	13.35
MOR ^g	50	50	750	87.12	-
Ew ^h	50	50	200	13600	-
Ep ^j	50	50	150	10400	-

^aB: Width of specimens; ^bH: Height of specimens; ^cL: Length of specimens;

^dfc: Compressive strength parallel to the grain. ^e⊥fc: Compressive strength perpendicular to the grain.; ^ffb: Flexural strength.; ^gMOR: Modulus of rupture.; ^hEw: Modulus of elasticity parallel to the grain.; ^jEp: Modulus of elasticity perpendicular to the grain.



Fig. 1. Mechanical properties tests of timber specimens

Bonding Materials

Sikadur®-31CF is used in this study to bond jute fibers and steel plates to the wood surfaces. The mixing ratio was two parts of component (A) to one part of component (B) by weight (grey paste). The compressive strength test of epoxy

adhesive cube was applied according to the standard specification ASTM D 3410-87 [16] and it was 70 Mpa. Also, varnish is a transparent adhesive coating is used in this study to bond jute fibers to the wood surfaces.

- Steel Plates

The steel plates used in this study with thickness of 1.6 mm and 1.3 mm, a length of 900mm, a width of 70 mm, and the modulus of elasticity is 210 Mpa.

Jute Fibers

Jute is a soft, strong vegetable fiber that can be interwoven into the coarse, strong fiber. It has

good tensile strength, and the fabric elongation is low when breaking, as shown in Fig. 2. Jute fibers are considered as one of the lowest-cost natural fibers [10]. The mechanical properties of jute fibers are evaluated according to the standard specification ASTM 570-98 [17], as shown in Table 2. Fig. 2 shows the experimental tests procedures of jute specimens.



Fig. 2. Mechanical properties tests of Jute fibers

Table 2

Mechanical properties of jute fibers

Fiber	Modulus of Elasticity (GPa)	Water Absorption % (24hr)	Moisture Content% (24hr)	Tensile Strength (MPa)	Tensile Strength of heat-treated jute (MPa)	Tensile Strength of Jute treated with epoxy (MPa)
Jute	19.8	90	9.3	169	209	283

2.2 Details of Tested Timber Beams

The timber beams are designed according to ASTM D 143-94. For all the timber beams specimens used in this study, the cross-section of these beams is 70 mm wide, 100 mm depth, and a length of 1000 mm, with a clear span of 900 mm. The experimental work divided into eight

groups, and Table 3 shows the entire details of the tested timber beams. Fig. 3 shows the whole details of the beams.

In order to describe the tested beams used in this study easily, the symbols are used in the numerating of them. So the alphabetic letter

“T” will refer to timber, second letter “O, E” will refer to origin

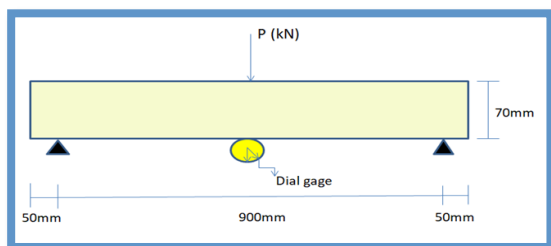
numbers “1 to 22” will refer to the number of the strengthened beams.

and epoxy strengthening, respectively, and, the third letter “B” will refer to the beam. The

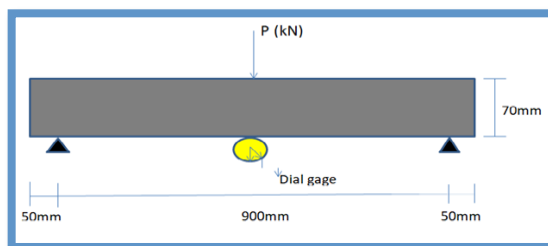
Table 3

The details of the tested timber beams

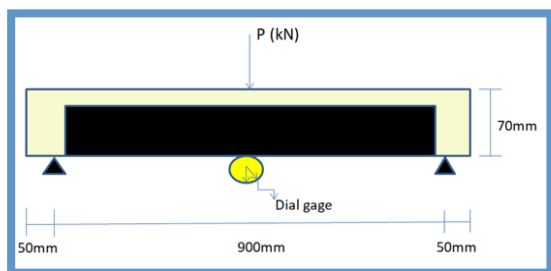
Beam group	Strengthening materials	Beams designation		Type of strengthening	Strengthening scheme	No. of layers
Group A	Nil	Control TOB	beam	No strengthening	Nil	Nil
Group B	Epoxy only	TEB		Flexural+shear	Full cover	One layer
Group C	Jute fibers + epoxy	T1B		Flexural+shear	U-jacket	One layer
		T2B, T3B		Shear strengthening	U-strips of 5cm & 3 cm	One layer
		T9B		Flexural+shear	U-jacket	Two layers
Group D	Jute fibers + epoxy	T4B		Flexural+shear	Full cover,	One layer
		T5B, T6B		Shear	Full strips of 5cm & 3cm	One layer
Group E	Jute+ epoxy	T7-T14B		Flexural	Tension face	One-Six
Group F	Steel+ epoxy	T16B, T22B		Flexural	Tension face	One layer
Group G		T12B		Flexural+shear	Spiral full	One layer
Group H	Jute+ epoxy	T17B, T18B		Shear	Spiral strips of 5cm & 3cm	One layer
	Jute fibers	T15B		Flexural+shear	Full cover	One layer
	+ varnish	T21B		Flexural	Tension face	One layer



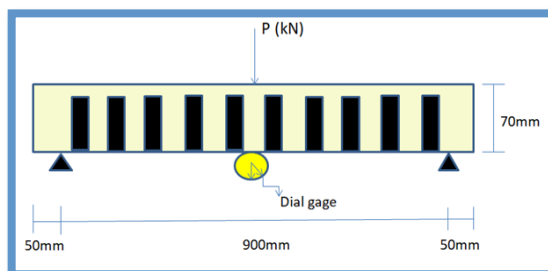
1. Control beam (TOB)



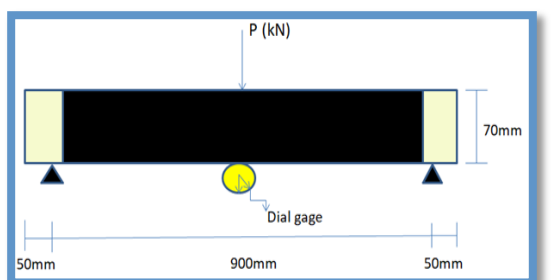
2. Beam strengthened with epoxy only (TEB)



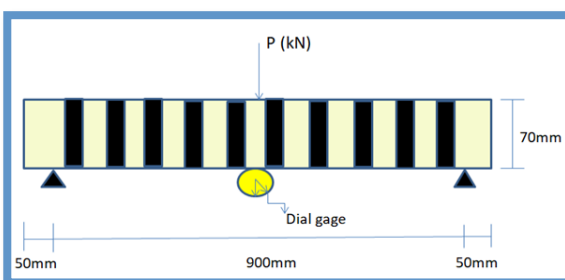
3. Beam strengthened by U-jacket method



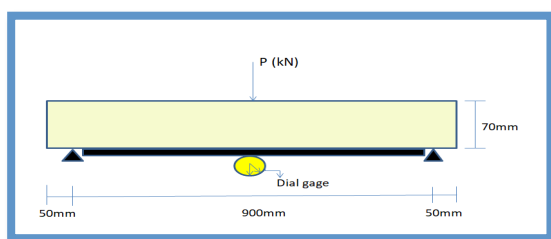
4. Beam strengthened with U-strips method



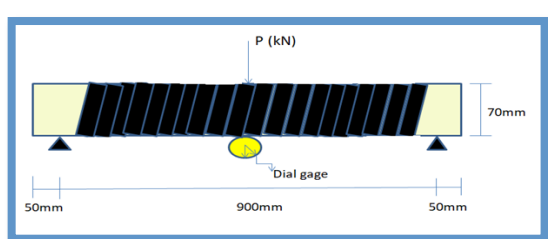
5. Beam strengthened with full method



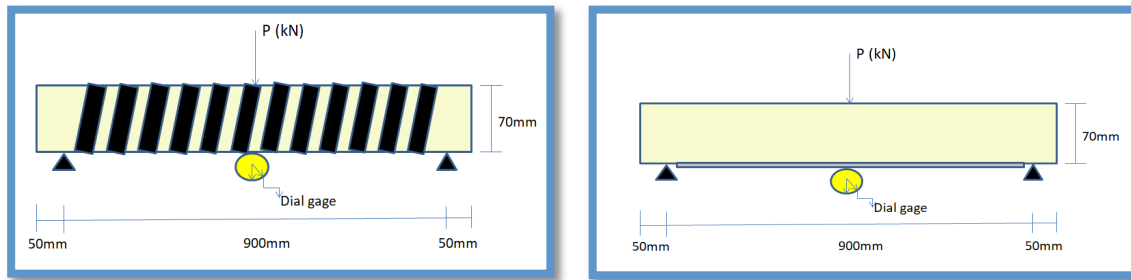
6. Beam strengthened with full strips method



7. Beam strengthened in tension zone



8. Beam strengthened with spiral full method



9. Beam strengthened with spiral strips.

10. Beam strengthened with steel plate.

Fig. 3. Strengthened timber beams with different configurations.

2.3 Test Procedure

The timber beams are prepared, and their surfaces cleaned before adding the adhesives. The jute fibers cut into sections and strips with certain dimensions and according to the data mentioned previously in Fig. 3. The epoxy adhesive applies to the surfaces of beams, and the jute fibers are bonded to them and pressed until jute fibers saturated. Four specimens wrapped in U technique in single and double layers, along the whole length of the beam in full and strips wrapping technique, seven beams bonded in full and spiral configuration, seven timber specimens wrapped in flexural strengthening technique with single and multiple layers, and two samples strengthened by steel plates. After the application of epoxy, the

strengthened beams are left into the laboratory for one week to let the epoxy dry at room temperature and prepared them for testing. On the other hand, two timber beams are strengthened with jute fibers and varnish adhesive also, two beams strengthened with steel plates. All beams are tested under one-point loading as simply supported beams by using the Universal Testing Machine of 2000 kN capacity with a 1.5 kN/sec loading rate. The vertical deflection at mid-span of the beams specimens is measured by using a sensitive dial gauge with an accuracy of 0.01 mm and placed below the bottom face of the beams. Fig. 4 shows the test procedure of strengthened timber beams. Fig. 4 shows the test procedure of strengthened timber beams.



1. Specimens of beams before strengthening.



2. Jute fibers.



3. Application of epoxy on the beam.



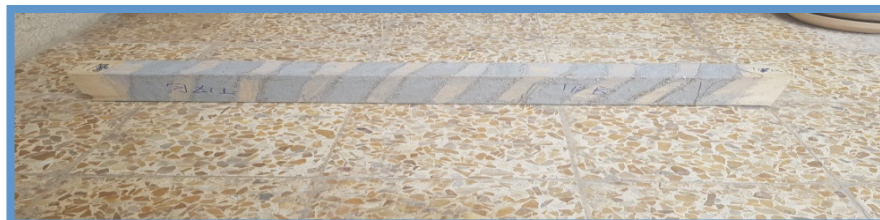
4. Application of jute fibers on the epoxy.



5. U-jacket technique in single layer.



6. Full strips.



7. Spiral strips.



8. Flexural strengthening in three layers.



9. Full cover technique .



10. Beam strengthened by steel plate.



11. Beam under test.

Fig. 4. Test procedure of strengthened beams.

3. RESULTS AND DISCUSSION

3.1 Ultimate Load and Mid-Span Deflection

The ultimate load and mid-span deflection results are listed in Table 4. The results show that the ultimate loads for beams strengthened by jute fibers are increased by between (30%-

101%) for different types of strengthening and by about (80%, 85%) for beams strengthened by steel plates. On the other hand, the strengthening by jute fibers has decreased the mid-span deflection by between (28%-45%) for different configurations compared with the control beams at the same load and by about (44.8%, 44.3%) for the strengthening by steel plates. Furthermore, it is found that the highest ultimate load deflection is when the beam wrapped in full strengthening technique.

Load-Deflection Relationships

The load-deflection curve of timber beams strengthened by epoxy only (TEB), which has 40% higher than the ultimate load of the control timber beam (TOB), as shown in Fig. 5(a). Fig.

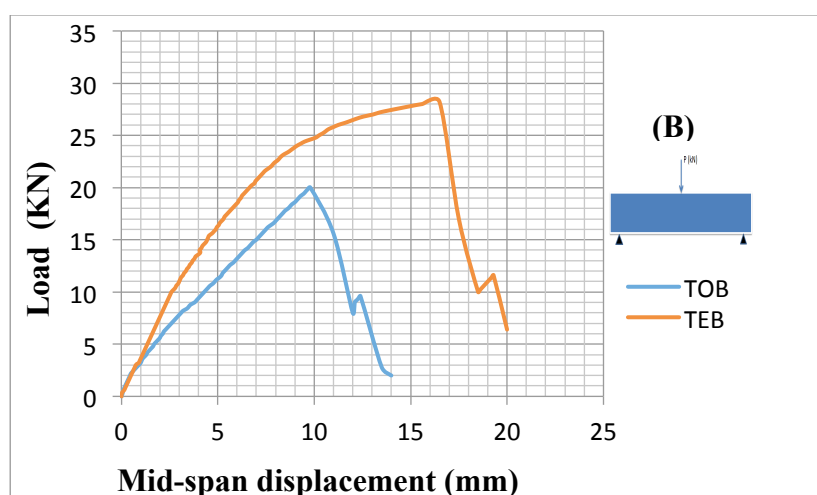
5(b) shows Group (C) that consisted of four beams wrapped in U- jacket, U strips, and double U-jacket method which has 70%, 68%, and 89%, respectively, greater than the ultimate load of the control beam, Fig. 5(c) presents Group (D) of three beams are wrapped in full strengthening and full strips method which have 101% and 79%, respectively, compared with that in the control beam, Fig. 5(d) describes Group (E) of six timber beams for flexural strengthening method by one to six layers of jute fibers which have (30%-71%) compared with the ultimate load of control beam, and finally Group (G) consists of three beams reinforced externally by spiral full cover and spiral strips method which has 89% and 84%, respectively, higher than the ultimate load of control beam, as shown in Fig. 5(e).

Table 4

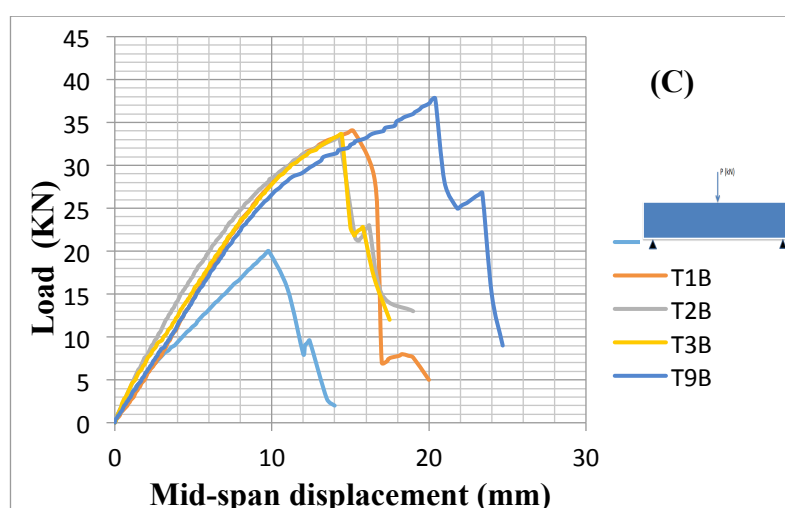
Group designation	Beams designation	Ultimate Load (kN)	Strengthening effect (%)	Mid-Span deflection at same load (mm)	% Decrease In Mid-Span deflection
A	Ave. TOB	20	–	–	–
B	Ave. TEB	28.2	40	6.65	32.1
C	T1B	34	70	6.58	32.8
	T2B	33.2	66	6.63	32.3
	T9B	38.7	89	6	38.7
	T4B	40.2	101	6	38.7
D	T6B	35.8	79	6.45	34.1
	T7B	26	30	7	28.5
	T10B	31	55	6.8	30.6
	T13B	33.5	67	6.78	30.8
E	T14B	34.2	71	6.7	31.6

F	T16B	37	85	5.45	44.3
	T22B	36	80	5.5	43.8
	T12B	37.8	89	5.95	39.2
G	T17B	36.8	84	5.7	41.8
	T15B	24	20	7	28.5
H	T21B	32	60	6	38.7

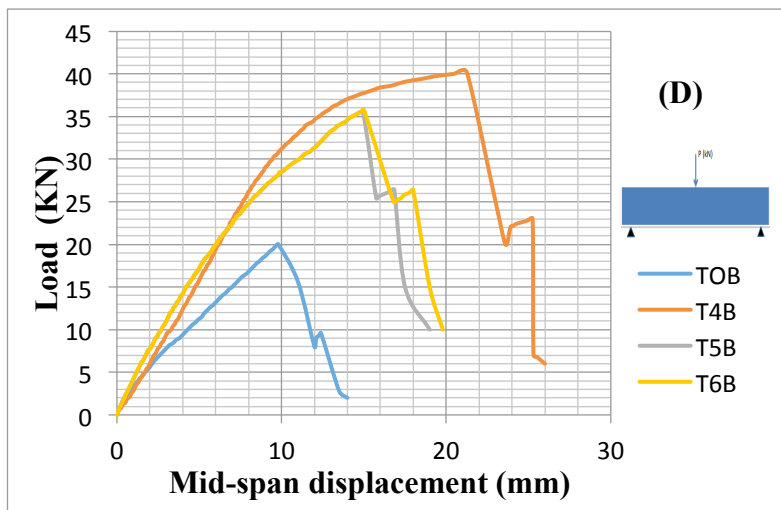
Test results



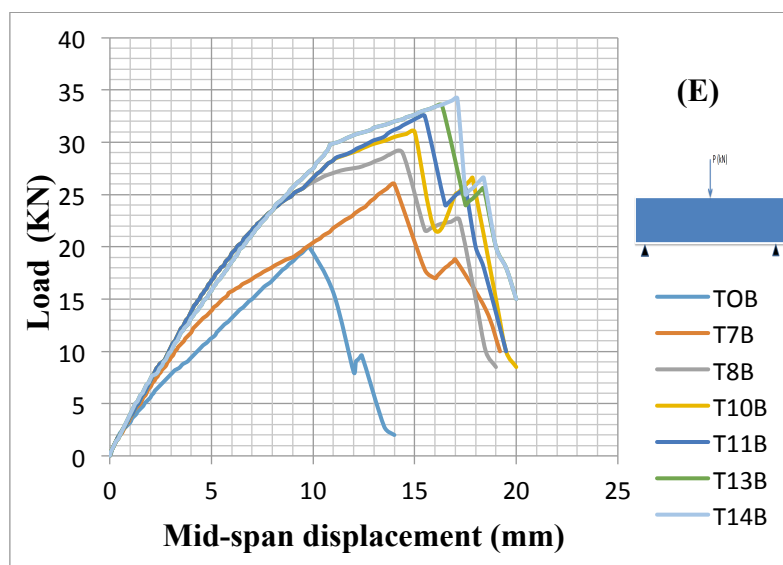
a. Load and Mid-Span Deflection relationship of Group (B)



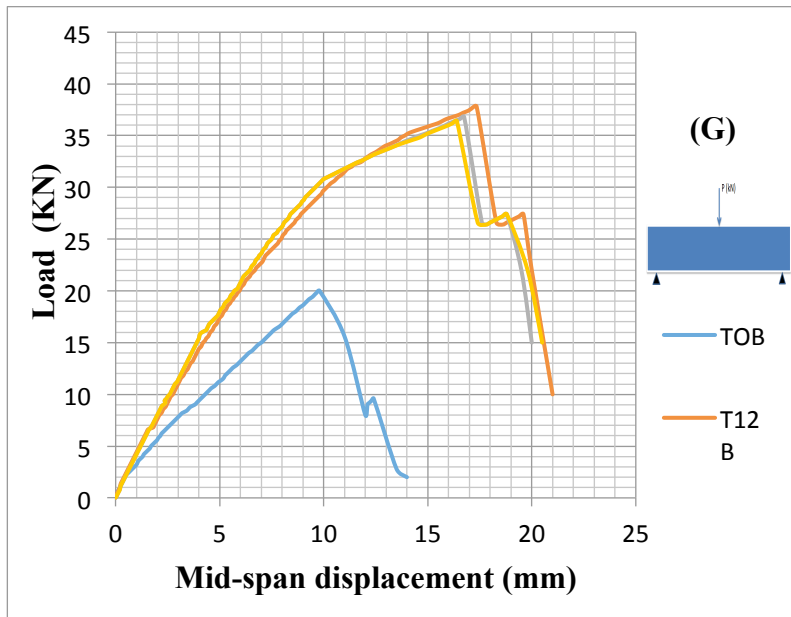
b. Load and Mid-Span Deflection relationship of Group (C)



c. Load and Mid-Span Deflection relationship of Group (D)

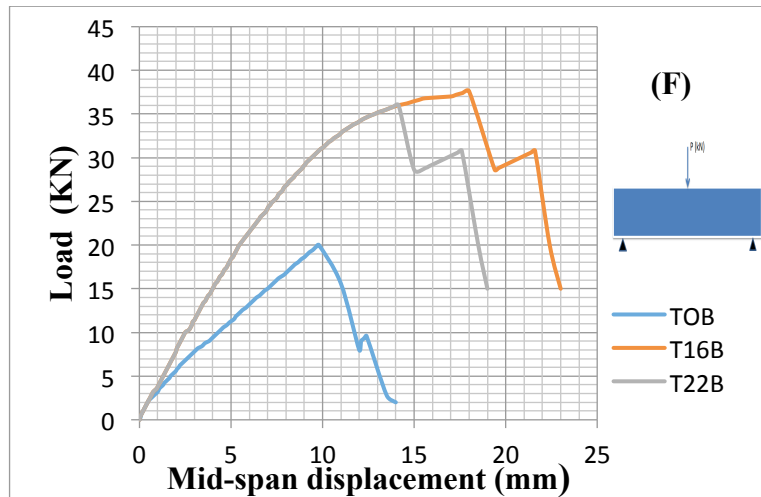


d. Load and Mid-Span Deflection relationship of Group (E)



e. Load and Mid-Span Deflection relationship of Group (G)

Also, Group (F) contains two beams strengthened by using steel plates which has ultimate load of (80%-85%) compared with the control beam, as shown in Fig. 5(f)



f. Load and Mid-Span Deflection relationship of Group (F)

Fig.5. Load-deflection relationships of the tested timber beams.

Ductility

It is noted from the results that the beams strengthened with jute fibers by different configurations have increased the ductility ratios by between (21%-51%) compared with the control timber beam, and the reason is due to the

increment in the mid-span deflection of the strengthened beams at failure and also, the strengthening by steel plates has increased the ductility about 35.7% and 35.6% by using steel, as shown in Fig. 6.

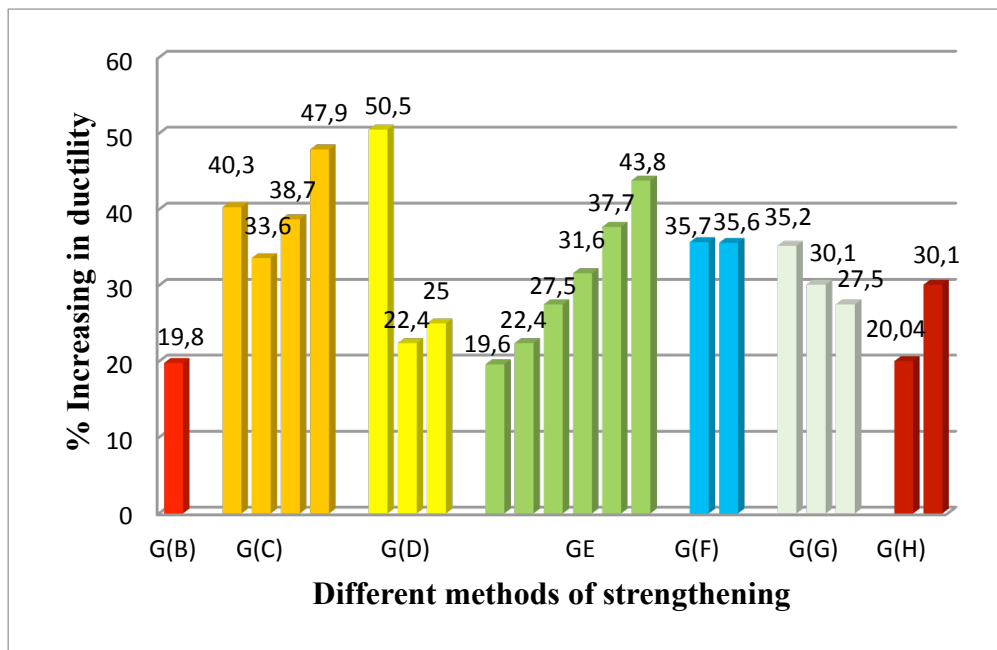


Fig. 6. Increasing ratios in ductility of beams.

3.2 Stiffness

Strengthening by jute fibers has increased the stiffness of timber beams by about (10%-73%) compared with the control beam, and strengthening with steel plates increased the stiffness by 72.7% and 72.5% by using steel plates, as shown in Fig. 7.

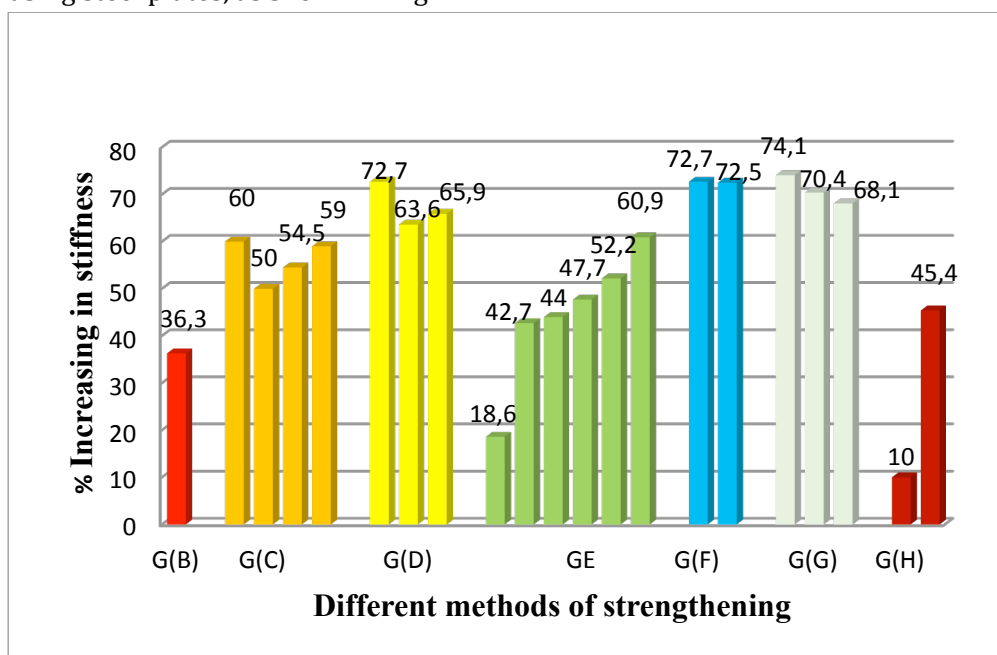


Fig. 7. Increasing ratios in stiffness of beams.

Toughness

Strengthening with jute fibers has increased the toughness and this is due to the decrease of deflection with increasing loading, this increases the area under the curve and increases the

absorption of timber beams for energy. The results show that the toughness of strengthened timber beams is increased by between (45%-373%) and by between (57%-401%) at the yield loads and the ultimate loads, respectively, compared with the control beams. On the other

hand, the strengthening by using steel plates has and by about (2 increased the toughness by about (342%, 391%) 50%, 320%) at the yield loads and the ultimate loads, respectively, as shown in Fig. 8 and Fig. 9.

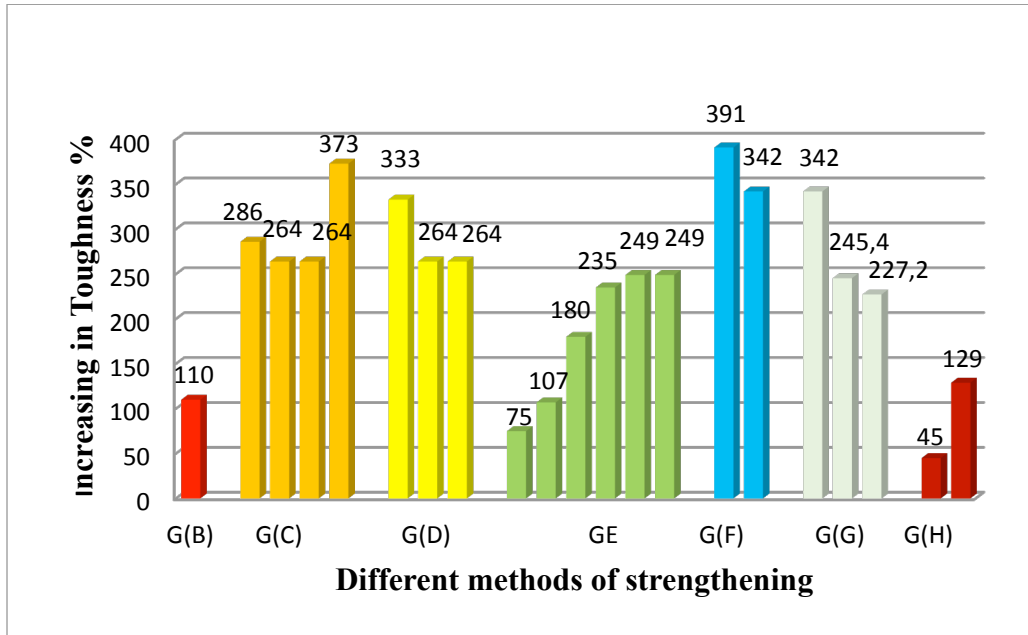


Fig. 8. Increasing ratios in toughness at the yield loads.

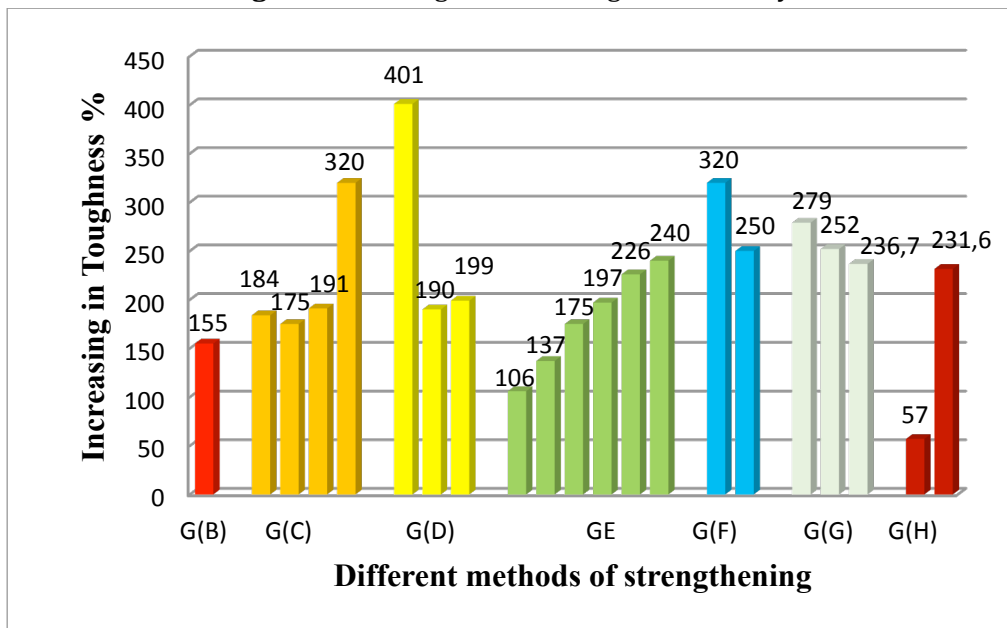
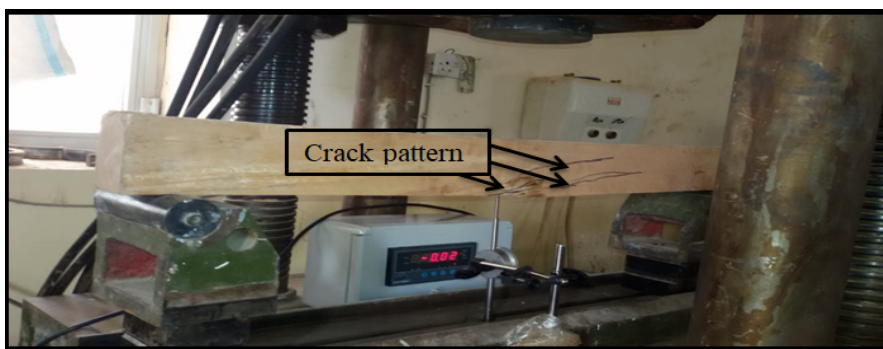


Fig. 9. Increasing ratios in toughness at the ultimate loads.

4. Failure Modes

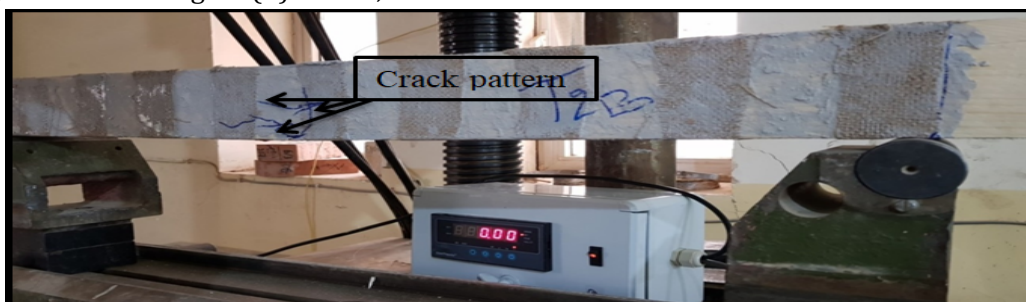
The Failure modes of the control timber beams in bending with span parallel to the grain are both cross-grain tension and splintering tension, as shown in Fig. 10(a).



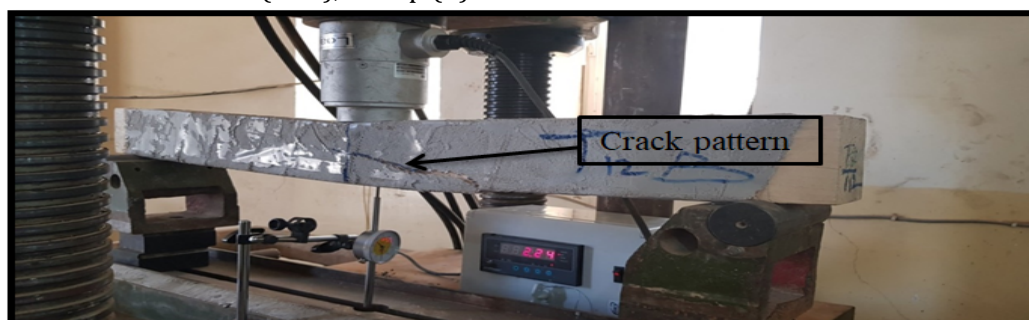
a. Failure mode of control beam (TOB)

The failure mode of strengthened timber beams of Group (C) and (G) is cross-grain tension and the number and distribution of failure cracks in these groups are less than those in control beams and other tested beams, as shown in Fig. 10(b) and (c). Also, the failure pattern of Group (E) is cross-grain tension but the number of cracks is greater than those in beams of groups (C), (D) and (G), as shown in Fig. 10(d). While, the failure

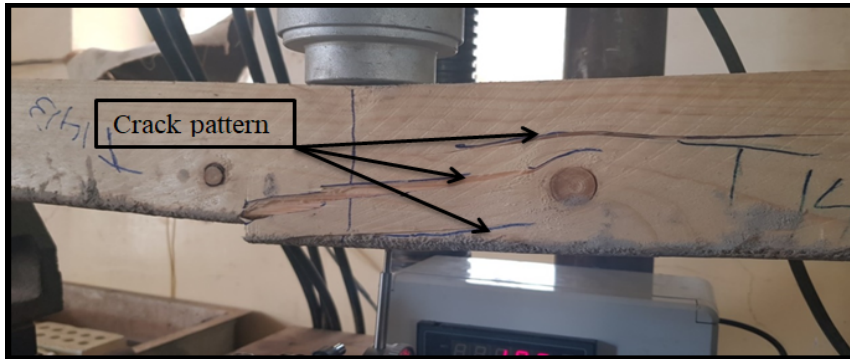
mode of Group (D) is the splintering tension and the distribution of cracks in these beams are less than those in the control beams and the other strengthened beams, as shown in Fig. 10(e). For Group (F), the failure patterns are cross-grain tension and the number of cracks in these beams is less than the cracks in the control beams, as shown in Fig. 10(f).



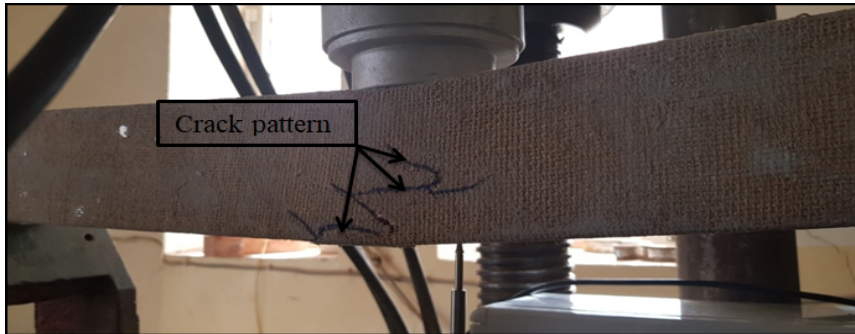
b. (T2B), Group (C)



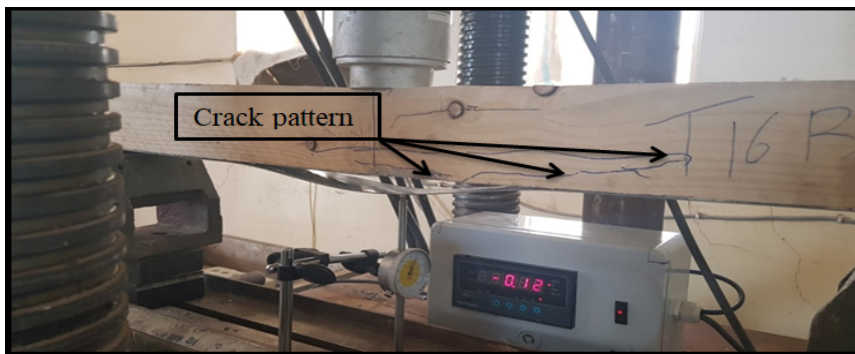
c. (T12B), Group (G)



d. (T14B), Group (E)



e. (T4B), Group (D)



f. (T16B), Group (F)

Fig. 10. The failure mode of

tested beams.

4. CONCLUSIONS

1. Increasing the area of jute fibers led to an increase in the ultimate loads of tested beams by about (30%-101%) compared with the control beam. Furthermore, it is found that the highest ultimate load is when the beam wrapped in full strengthening technique.
2. Strengthening by steel plates improved the ultimate loads of beams (T16B, T22B) by 16% greater than the beams strengthened by

jute fibers (T7B-T14B) but, by 5%, 19%, and 5% smaller than the beams of U technique with double layer, full strengthening technique and spiral full method (T9B, T4B, T12B), respectively.

3. The use of jute fibers and epoxy has increased the ultimate loads of beams (T4B, T7B) by about (50%, 68%) compared with beams strengthened by jute fibers and varnish (T15B, T21B).

4. The jute fibers were increased the durability of timber beams, and this increment

depended on the increasing strengthening ratio of jute fibers.

5. The mid-span deflection values for beams strengthened by jute fibers have decreased by between (28%-45%) compared with the control beam at the same load, and this due to the good bonding between jute fibers and timber beams.

6. The ductility ratios have increased by between (21%-51%) with the increasing area of jute fibers compared with the control beam.

7. The ductility ratio for beams reinforced by steel plates is 35.7% compared with the control timber beam, which is less than the ductility ratios of strengthened timber beams by using five to six layers of jute fibers (T14B, T13B).

8. The stiffness ratios have increased by between (10%-73%). The stiffness ratio of beams reinforced by steel plates is 72.7% compared with the control beam, which is greater than the stiffness ratios for beams wrapped in five to six layers of jute fibers (T14B, T13B).

9. The toughness of beams has increased by about (45%-373%) at yield load values and by about (57%-401%) at the ultimate load values, respectively, and this is due to the decrease of deflection with increasing loading.

10. The toughness ratio of beams strengthened by steel plates is between (250%-391%) compared with the control beam, which approximately the same toughness ratios of beams (T14B, T13B).

11. The numbers and distributions of failure cracks of the beams are decreased during testing due to the high elasticity of jute fibers and the good bonding between wood and jute fibers.

12. The jute fibers have high elasticity performance and proved that the jute fibers materials have a large potential to act as a structural strengthening material, and these

fibers have attributable to their simple accessibility and its low cost.

13. Using the timber strengthened by jute fibers as a new construction material is a successful step in the construction progress with good specifications, suitable prices, and a short time of construction.

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