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Toughness of Timber Beams Strengthened with Jute Fibers

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ABSTRACT

This research involves investigating the toughness behavior of timber beams strengthened by jute fibers with various forms of strengthening. Ten timber specimens with dimensions (70×100×1000) mm are divided into four groups and loaded under a third point loading. The experimental program was carried out to investigate shear and flexural strengthening effects on toughness, toughness indices, ultimate loads, and the mid-span deflection of the tested beams. One beam as a control beam (un-strengthened beam), four specimens are wrapped in U technique in single and double layers along the whole length of the beam in full and strips wrapping technique, three specimens are wrapped in full technique along the whole length of the beam in full and strips wrapping technique, three timber specimens wrapped in flexural strengthening technique with two, four, and six layers of jute fibers. The results show that jute fibers strengthening increases the toughness ratios of timber beams by about (175%-320%), (190%-401%), and (106%-240%) for U, full, and flexural strengthening techniques, respectively, at the ultimate loads compared with the control beam. Furthermore, it is found that the highest toughness ratio is when the beam is wrapped in full strengthening technique.

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متانة الاعتاب الخشبية المقواة بألياف الجوت

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الخلاصه

يتضمن مشروع الدراسة تقوية العتبات الخشبية بألياف الجوت المعروفة بتقنيات تقوية مختلفة. في هذه الدراسة ، تم اختبار أحدى عشرة عينة من الأخشاب مقسمة في أربع مجموعات من العينات تحت حمولة من نقطة واحدة بأبعاد (70 × 100 × 1000) مم. تم تنفيذ البرنامج العملي لدراسة تأثير تقوية القص و الانثناء على المتانة ، مؤشرات المتانة ، الاحمال النهائية, و سلوك الحمل - الأود في عوارض الأخشاب المقواة. نموذج خشبي واحد كعتبة مرجعية (غير مقواة), أربعة نماذج من العتبات الخشبية مقواة بتقنية U في طبقات مفردة ومزدوجة لتقوية الانحناء والقص، ثلاث نماذج مقواة بتقنية الالتفاف الكامل، وثلاثة عينات من الأخشاب المقواة باستخدام تقوية الانثناء في مناطق الشد باستخدام طبقتين, أربع, وستة طبقات من ألياف الجوت. أوضحت النتائج النهائية أن تقوية العتبات الخشبية بألياف الجوت قد زادت من نسب المتانة للعتبات الخشبية بنسبة (175%-320%),

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(190%-401%), و بنسبة (106%-240%) باستخدام تقوية U , الالتفاف الكامل, و تقنية تقوية الانثناء في مناطق الشد, على التوالي, عند الاحمال النهائية مقارنة بالعتبة المرجعية. وقد وجد ان اعلى نسبة متانة عندما يتم تقوية العتبات الخشبية بتقنية اللف الكامل.

1. INTRODUCTION

Timber is considered an organic and natural material, it has been used since the early times in the construction of bridges, houses, frames, and remains as a very important construction material till these days [1]. On the other hand, timber material is considered one of the new building materials that have been used in construction process in Iraq, recently [2]. Recently, the strengthening of different types of wood beams with different materials and types to improve the mechanical properties and increase its resistance to shear and bending loads and increase the durability and stiffness compared to the beams that are not reinforced by these types of modern strengthening techniques [3]. Now adays the traditional fibers such as the carbon fibers, steel plates, and glass fibers were supplanted with natural fibers, for example, cotton, sisal, linen, coir, and jute fibers attributable to its simple accessibility and the low cost. Several types of studies were conducted on this path [4, 5] and [6]. Many researchers have studied the behavior of timber beams such as Ahmad and Bhat [7] who studied the ductility of ten timber beams of Deodar and Kail wood beams strengthened with the carbon fiber reinforced-polymer (CFRP) composites plates and tested under a four-point bending test till the failure where the strength values and the ductility values of strengthened beams were increased with the increasing percentage of (CFRP) sheets. Also, Ahmed [8] studied the ductility of beams reinforced with the carbon fiber-reinforced polymer (CFRP) strips increased with the increase of the percentage of (CFRP) strips. On the other hand, Jasieńko, J., and Nowak [9] and Yang, et al., [10] approved that the strengthened timber beams with steel sheets and epoxy have a better results in load-bearing capacity when tested under a four-point load bending test till the failure by (56.3%, 58%). On the other hand, Karzan [11] investigated the toughness behaviour of jute fibers reinforced cementitious composites specimens and these researchers showed an increment toughness and toughness indices with the increment of jute fibers volume fraction. Recently many systems of jute textile reinforced-polymer composite systems were studied by Sen and Reddy [12] and they discussed the flexural behavior of ten reinforced concrete beams, and the results showed that (JFRP) strengthening system had increased the ultimate strength of the tested (RC) beams by 62.5% for JFRP full wrapping technique and by 25% for JFRP system strips wrapping technique.

Yaseen, et al., [13] investigated the effect of thickness and width of jute fiber strips on the mechanical properties of twenty-four reinforced concrete beams (RC). And all the results described that the toughness and load-carrying capacity of the strengthened beams increased with the increment of thickness and width of the strips.

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

The flowchart of the experimental work of this study is shown in Fig. 1

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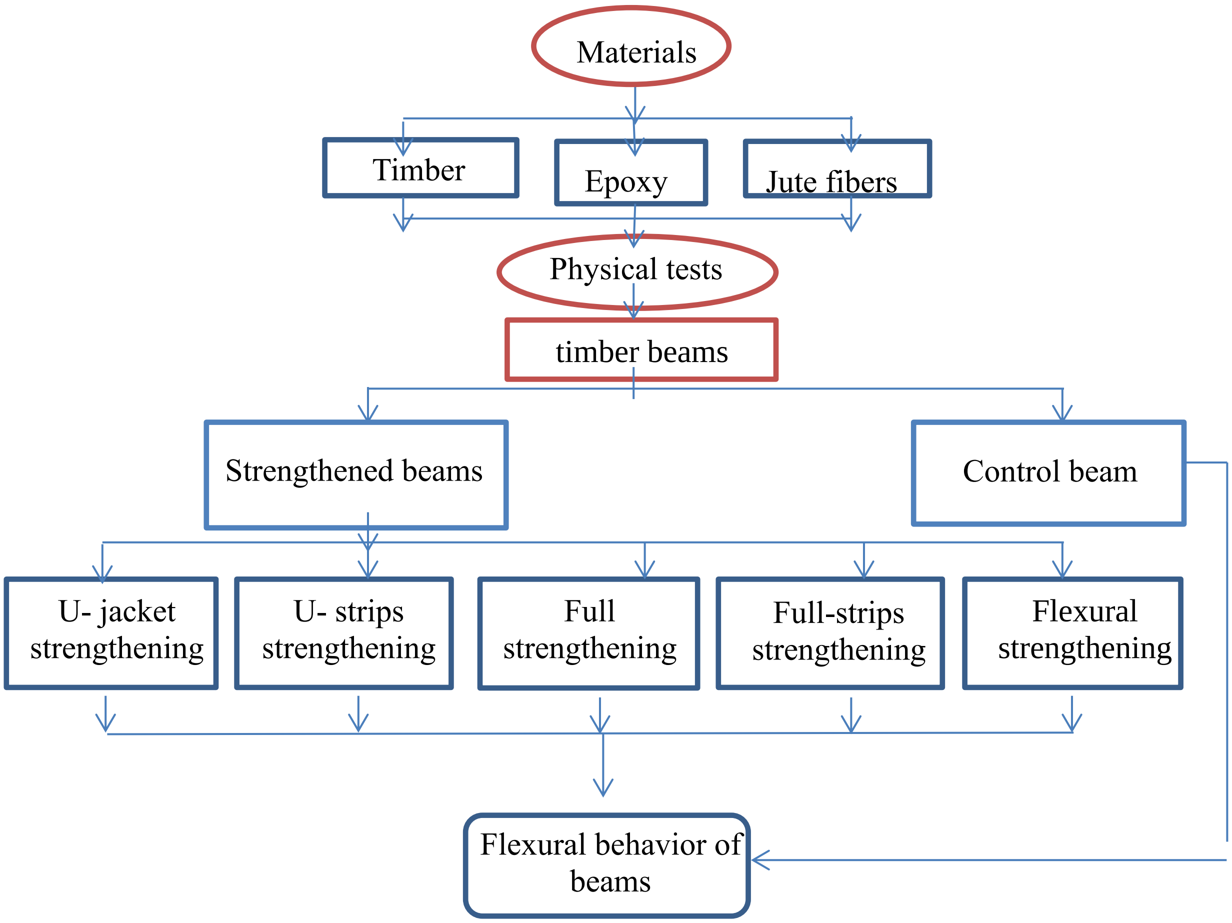


Fig. 1. Flow chart of experimental work (preparing the materials and strengthening of beams)

2.1 Materials

- Timber

White Russian timber, as shown in Fig. 2 is used in this study. The commercial name of this type of timber is (Spruce wood). The mechanical properties of white timber specimens are evaluated according to the standard specification ASTM D 143-94 [14], as shown in Table 1. Fig. 3 shows the experimental tests procedures of timber specimens.

Fig. 2. White Russian timber

Table 1

Mechanical properties of timber specimens.

Material Property	Sizes (mm)			Tests results(N/mm²)	Moisture content (%)
	B[a]	H[b]	L[c]		
fc[d]	50	50	200	30	14.18
⊥fc[e]	50	50	150	6	14
MOR[g]	50	50	750	87.12	-
Ew[h]	50	50	200	13600	-
Ep[j]	50	50	150	10400	-

[a]B: Width of specimens; [b]H: Height of specimens; [c]L: Length of specimens; [d]fc: Compressive strength parallel to the grain. [e] ⊥fc: Compressive strength perpendicular to the grain.; [g]MOR: Modulus of rupture.; [h]Ew: Modulus of elasticity parallel to the grain.; [j]Ep: Modulus of elasticity perpendicular to the grain.

Fig. 3. Mechanical properties tests of timber specimens

- *Epoxy Adhesive*

Sikadur®-31CF is used to bond jute fibers to timber surfaces. The mixing ratios were two parts of the component (A) to one part of the 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 [15] and it was 70 Mpa, as shown in Fig. 4.

a. Epoxy components b. grey paste c. Compressive strength test

Fig. 4. Sikadur®-31CF Epoxy Adhesive

- *Jute Fibers*

Jute is strong vegetable fiber. It has good tensile strength, and the fabric elongation is low when breaking, as shown in Fig. 5. The mechanical properties of jute fibers are evaluated according to the standard specification ASTM 570-98 [16], as shown in Table 2.

Fig. 5. Jute fibers

-Tensile Strength Test

The tensile strength test of jute fibers is included using the jute fibers with 300 mm length and 50 mm diameter. The ends of jute samples are fastened with iron plates of 50×70 mm dimensions to be installed in a tensile machine until its rupture with a loading rate of 0.4 kN/sec, as shown in Fig. 6.

(a) (b)

(c)

Fig. 6. Tensile strength test (a) Jute fibers; (b) jute fibers treated by epoxy; (c) tensile strength test machine

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	60	79.5	122.4

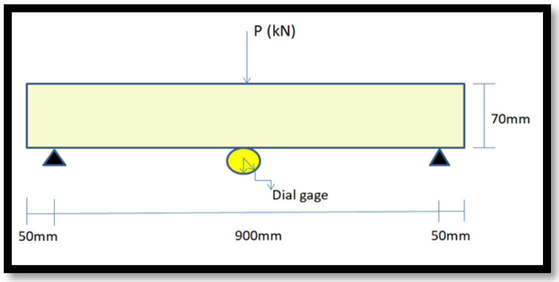
2.2 Details of Tested Timber Beams

All the timber beams specimens used in this study have cross-section of 70 mm wide, 100 mm depth, and a length of 1000 mm, with 900 mm clear span. The experimental work consisted of four groups. Table 3 and Fig. 7 show the details of all tested beams.

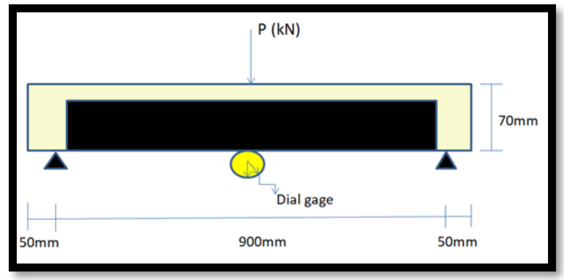
Table 3

The details of the tested timber beams.

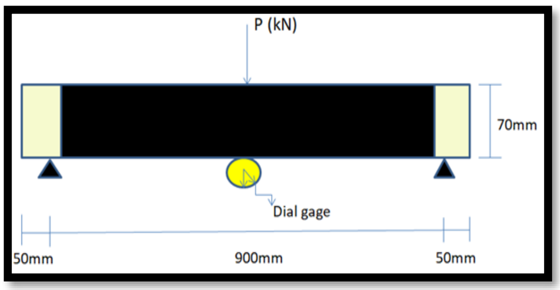
Beam group	Strengthening materials	Beams designation	Type of strengthening	Strengthening scheme	No. of layers
A	Nil	Control beam To	No strengthening	Nil	Nil
B	Jute fibers + epoxy	T1	Flexural+shear	U-jacket	One
		T2	Shear strengthening	U-strips of 5cm	One
		T3	Shear strengthening	U-strips of 3cm	One
		T4	Flexural+shear	U-jacket	Two
C	Jute fibers + epoxy	T5	Flexural+shear	Full cover,	One
		T6	Shear	Full strips of 5cm	One
		T7	Shear	Full strips of 3cm	One
D	Jute+ epoxy	T8	Flexural	Tension face	Two
		T10	Flexural	Tension face	Four
		T11	Flexural	Tension face	Six



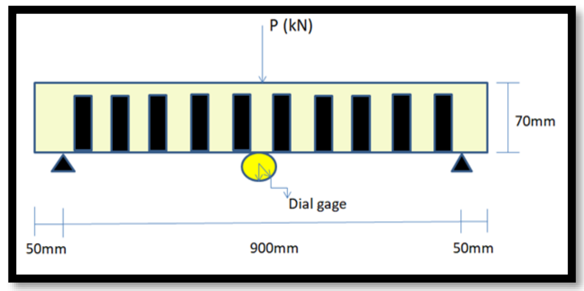
1. Control beam



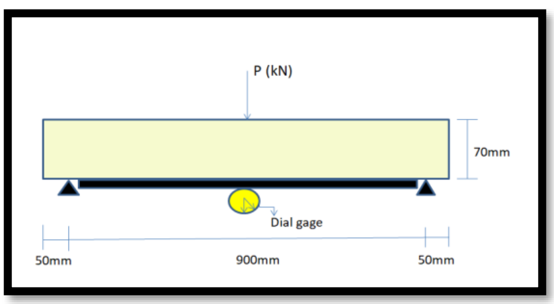
2. U- jacket



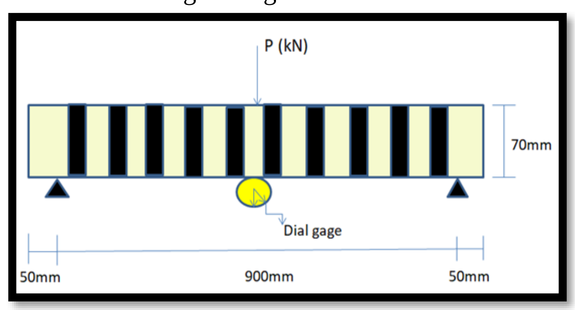
3. U-strips



4. Full strengthening



5. Full strips



6. Flexural strengthening

Fig. 7. Timber beams strengthened by different types of strengthening.

2.3 Test Procedure

All the beams are prepared, and the timber surfaces are cleaned before adding epoxy. Jute fibers are cut into strips of different dimensions and according to the data mentioned previously in Fig.7. The epoxy **(Sikadur®-31CF)** is applied to the wood surfaces of beams, and the jute fibers are bonded and pressed to them until the fibers are saturated. Four specimens are wrapped in U-technique in single and double layers, along the entire length of the beams in strips and full wrapping techniques, three beams are bonded in full configurations, three timber specimens are wrapped in flexural strengthening technique with two, four, and six layers. After the application of adhesive, all the strengthened beams are left into laboratory for 10 days to let the epoxy dry at the room temperature and prepare the samples for the testing. All beams are tested under a third-point load as simply supported beams by using the Universal Testing Machine with a 1.5 kN/sec loading rate and 2000 kN capacity. 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 timber beams. Fig. 8 shows the test procedure of strengthened timber beams.

1. Specimens of beams before strengthening.

2. Application of epoxy and jute fibers on the beam

3. U-jacket strengthening technique in single layer as compared with control beam (T0)

4. U-strips technique before adding epoxy

5. U-strips after adding epoxy

6. Beam wrapped with full technique after adding epoxy

7. Flexural strengthening method in two to six layers

8. Sample T1 under test

Fig. 8. Test procedure of strengthened beams.

3. RESULTS AND DISCUSSION

3.1 Ultimate Load and Mid-Span Deflection

All beams samples have been tested until failure. The ultimate loads and first crack loads of the tested specimens are shown in the following Table 4. The results show that the ultimate loads of the tested timber beams increased by about (66%-89%) for U-strengthening technique, (77%-101%) for full strengthening technique, (30%-71%) for flexural strengthening technique**.** Furthermore, it is found that the highest ultimate load deflection is when the beam is strengthened by jute fibers for full strengthening technique.

Table 4 :

Test results.

Group	Beams designation	First crack Load (kN)	Ultimate Load (kN)	increasing in Pu % due to strengthening (%)	Mid-Span deflection at same load (mm)	% Decrease In Mid-Span deflection
A	Ave. T0	9.8	20	_	_	_
B	T1	24	34	70	6.58	32.8
	T2	25	33.2	66	6.63	32.3
	T3	26	33.6	68	6.65	32.1
	T4	28	38.7	89	6	38.7
C	T5	31	40.2	101	6	38.7
	T6	29	35.4	77	6.5	33.6
	T7	28.5	35.8	79	6.45	34.1
D	T8	24	29	45	6.8	30.6
	T10	25	32.5	62	6.78	30.8
	T11	30	34.2	71	6.7	31.6

3.2 Load-Deflection Relationships

The load-deflection curves of the tested beams have been drawn at all the levels of loading up to the failure, as shown in the following Fig. 9 to 12.

a- Control timber beams (T0): The deflection of the control beam (T0) increased with the increase of the applied loads. Load-deflection curve of the control beam is linear until the first crack accrued in the tension zone which is approximately the same yield load. The ultimate load of the tested beam is 20 kN and the maximum deflection at this load is 9.8 mm, as shown in the following Fig.9.

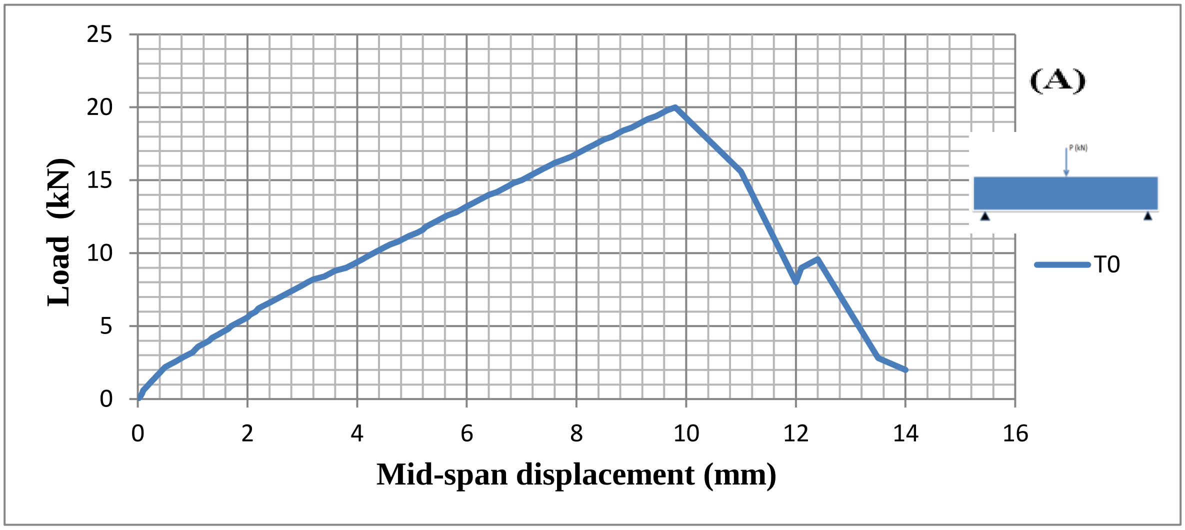


Fig. 9. Load and Mid-Span Deflection relationship of Group (A)

b. Contains four reinforced beams: Beam (T1) has 70% greater than the ultimate load of the control beam, which is higher than the ultimate load of beams (T2 and T3) of 66% and 68%, respectively. Also, beam (T4) has 89% higher than the ultimate load of control beam, as shown in Fig.10 below, and this is due to the fact that increasing the area of jute fibers lead to an increase in the ultimate loads of the tested beams.

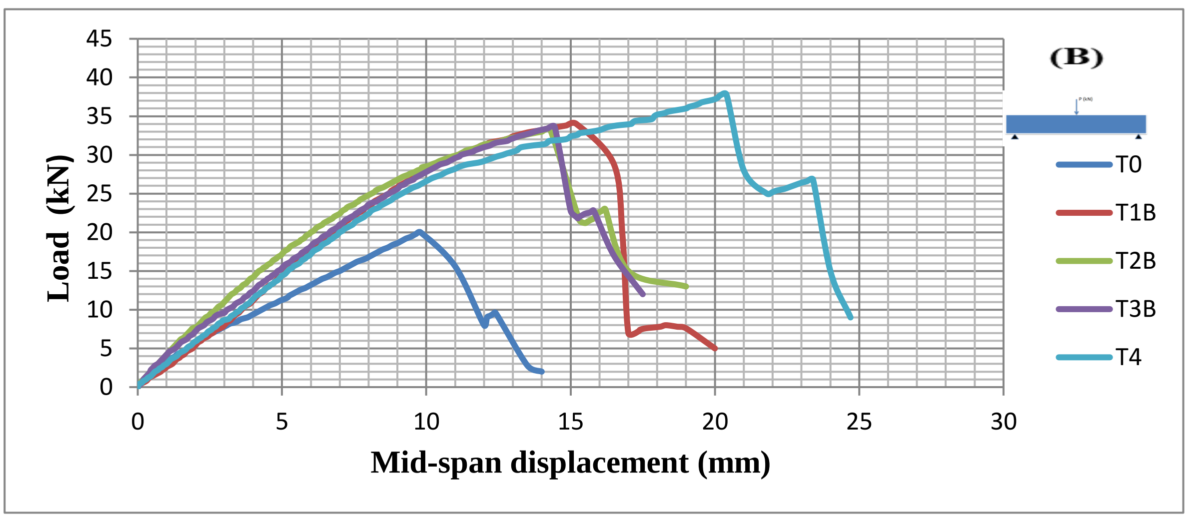


Fig.10. Load and Mid-Span Deflection relationship of Group (B)

c. Comprises of three beams: Sample (T5) has 101% greater than the ultimate load of the control beam, which is greater than the ultimate load of the strengthened beams (T6 and T7) of 77% and 79%, respectively, as shown in Fig.11 below, and this is due to the increasing area of jute fibers lead to an increase in the ultimate loads of the tested timber beams.

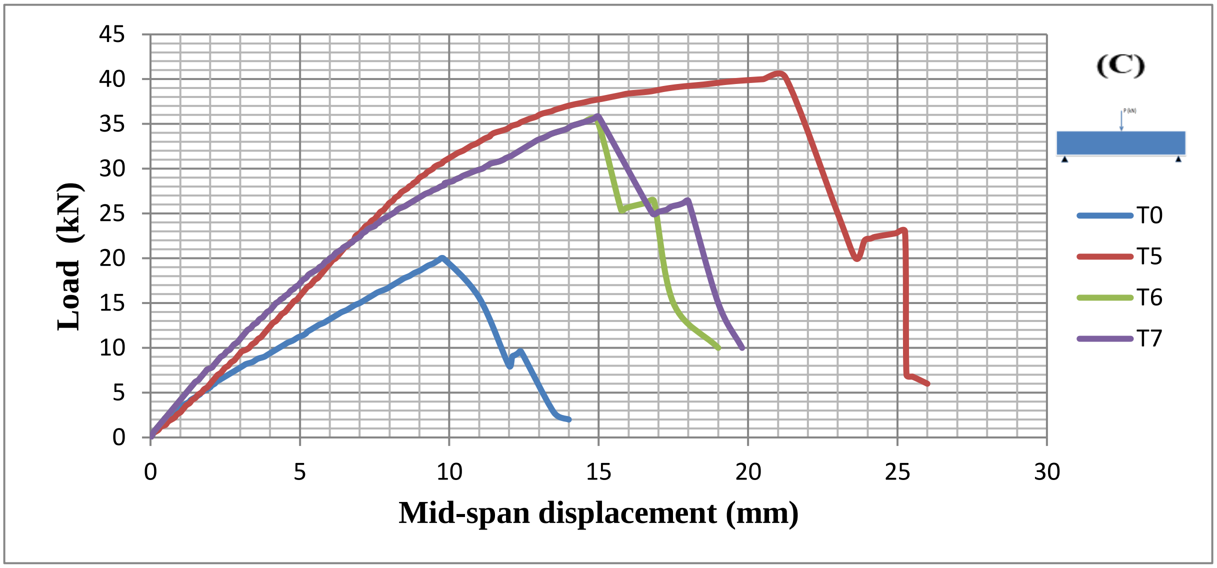


Fig. 11. Load and Mid-Span Deflection relationship of Group (C)

d. Includes three beams (T8, T10, and T11) having un ultimate loads of, 45%, , 62%, and 71%, respectively, and they are greater than the ultimate load of the control beam (To). The increment in layers of jute fibres lead to an increase in the ultimate loads, as shown in the following Fig.12.

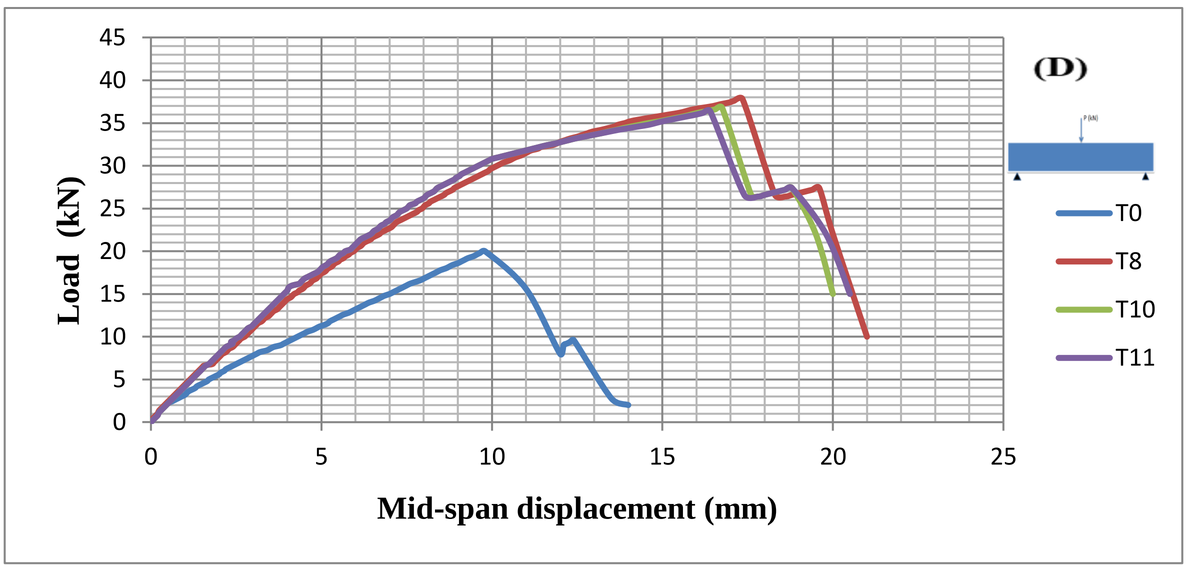


Fig. 12. Load and Mid-Span Deflection relationship of Group (D)

3.3 Toughness

The Strengthening method with jute fibers has increased the toughness ratios and this is due to the decrease of mid-span deflection with increasing loading, this increases the area under the curve of the tested sample and increases the absorption of beams for energy. The results show that the toughness ratios of beams are increased by about (286%-373%) for U-strengthening method, (264%-333%) for full strengthening technique, and (107%-249%) for flexural strengthening technique at the yield loads compared with the control beam. Also the toughness ratios of beams are increased by about (184%-320%) for U-strengthening technique, (199%-401%) for full strengthening method, and (137%-240%) for flexural strengthening method at the ultimate loads compared with the control beam, as shown in the following Fig.13 and 14.

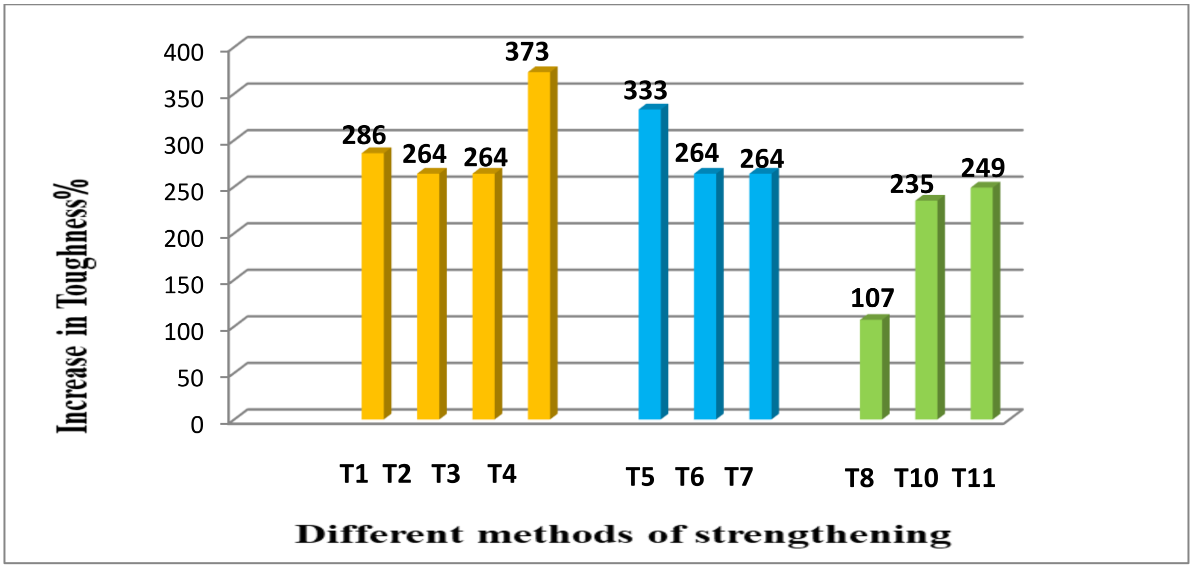


Fig. 13. Increasing ratios in toughness at the yield loads.

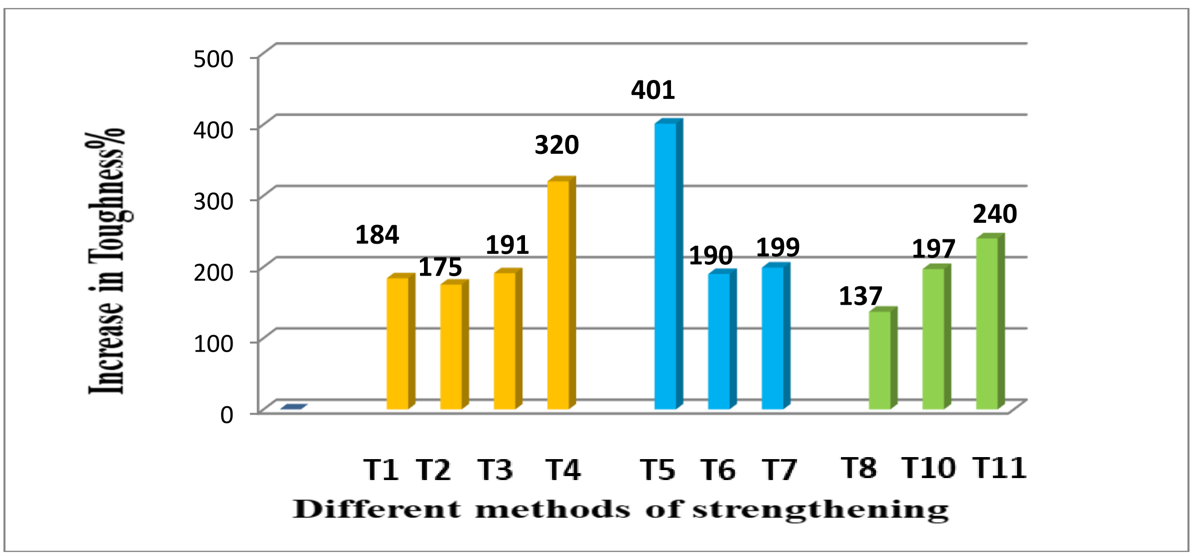


Fig. 14. Increasing ratios in toughness at the ultimate loads.

3.4 Toughness Index

The toughness values are calculated at deflection δ which is means the pre-peak toughness (elastic limit) while there are three other deflections (at 3δ, 5.5δ, and 10.5δ) which mean the post-peak toughness, and that is according to the standard specification ASTM C1018 [17]. In addition, toughness indices values (I_5, I_{10}, and I_{20}) are also calculated which are defined as ratios between the post-peak toughness and the pre-peak toughness values, as shown in Fig.15 below.

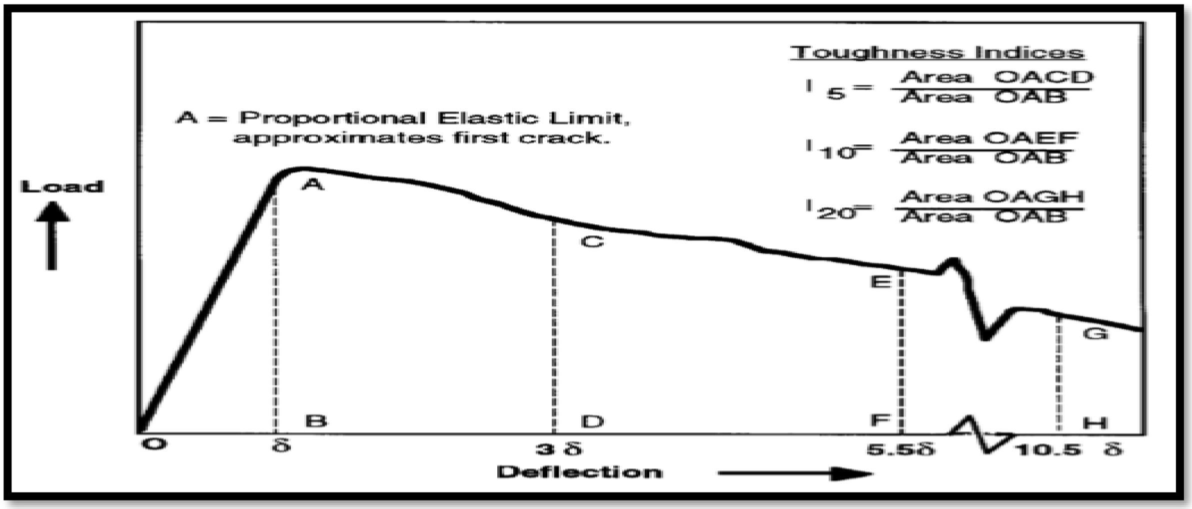


Fig. 15. Toughness index calculation diagram [17]

Where:

The toughness indices are:
I_5: Area OACD/Area OAB.
I_{10}: Area OAEF/ Area OAB.
I_{20}: Area OAGH/ Area OAB.
Area OAB: Toughness corresponding to deflection of δ, (Tδ)
Area OACD: The toughness versus to deflection of 3δ, (T3δ)
Area OAEF: Toughness corresponding to deflection of 5.5δ, (T5.5δ)
Area OAGH: The toughness versus to deflection of 10.5δ, (T10.5δ)

From Fig. 16 note that the toughness index (**I_5**) values are increased by about (28.4%-83.8%) for group (B), (71.5%-88.7%) for group (C), and (20%-29.9%) for group (D). Also, Fig. 17 shows that the toughness index (**I_{10}**) values are increased by about (46.6%-68.5%) for group (B), (46.3%-76.9%) for group (C), and (34.8%-48.8%) for group (D). ON the other hand, Fig. 18 shows that the toughness index (**I_{20}**) values are increased by about (46.6%-68.5%) for group (B), (46.3%-76.9%) for group (C), and (34.8%-48.8%) for group (D). The reason for this increment is due to the good elasticity of jute fibers so that these fibers have distributed the spread of failure cracks in the strengthened timber beams.

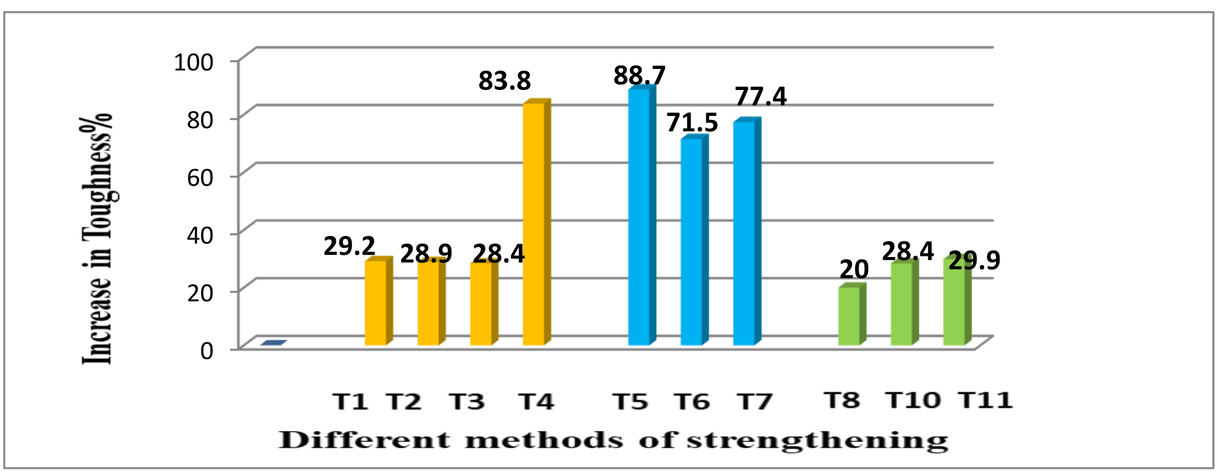


Fig. 16. Increasing ratios in toughness Index (**I_5**) compared with the control beam

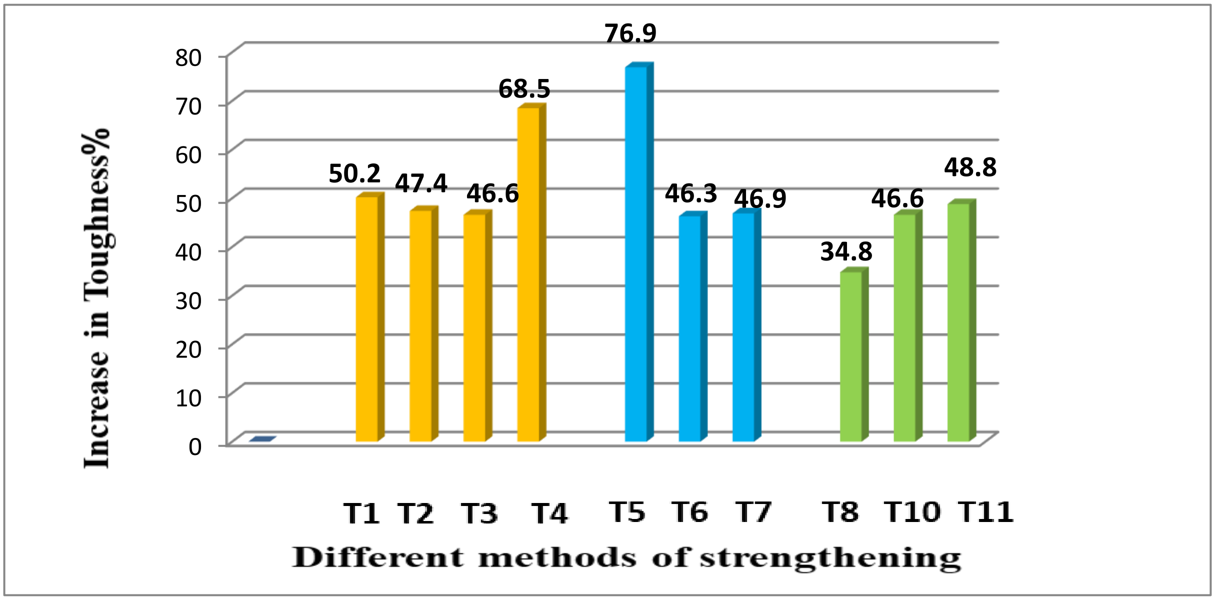


Fig. 17. Increasing ratios in toughness Index (I_{10}) compared with the control beam

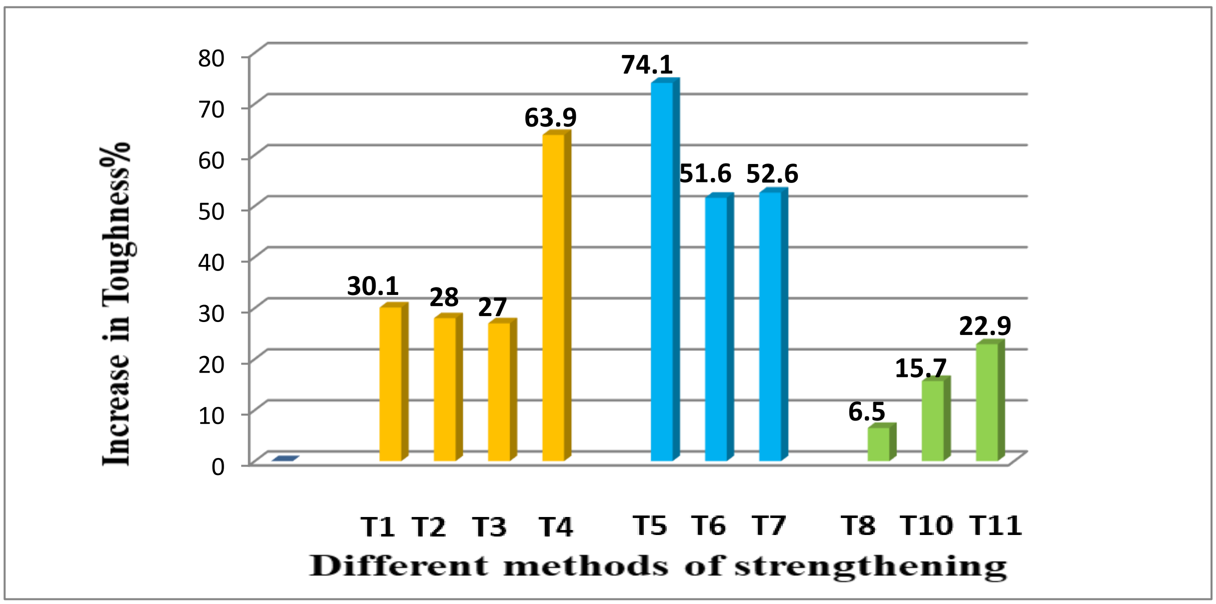


Fig. 18. Increasing ratios in toughness Index (I_{20}) compared with the control beam

3.4 *Failure Mode*

The failure modes of all tested timber beams in bending with span parallel to the grain are different according to the types of strengthening. The failure modes of the control beams are cross-grain tension and splintering tension, as shown in Fig. 19.

Fig. 19. Failure mode of T0

Also, The failure mode of strengthened timber beams of Group (B) is cross-grain tension but, the number and distribution of failure cracks in beams of this group are less than those in control beams, as shown in Fig. 20 and Fig. 21.

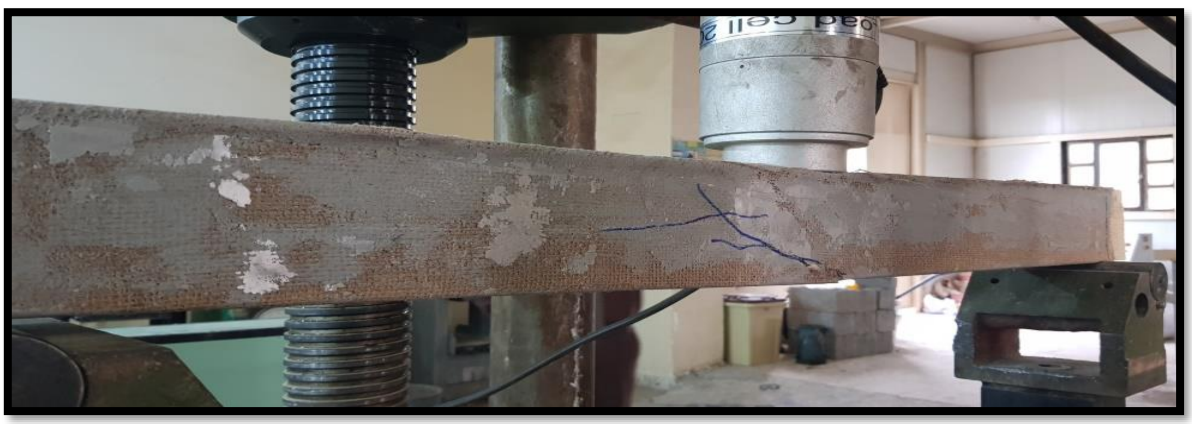


Fig. 20. T1

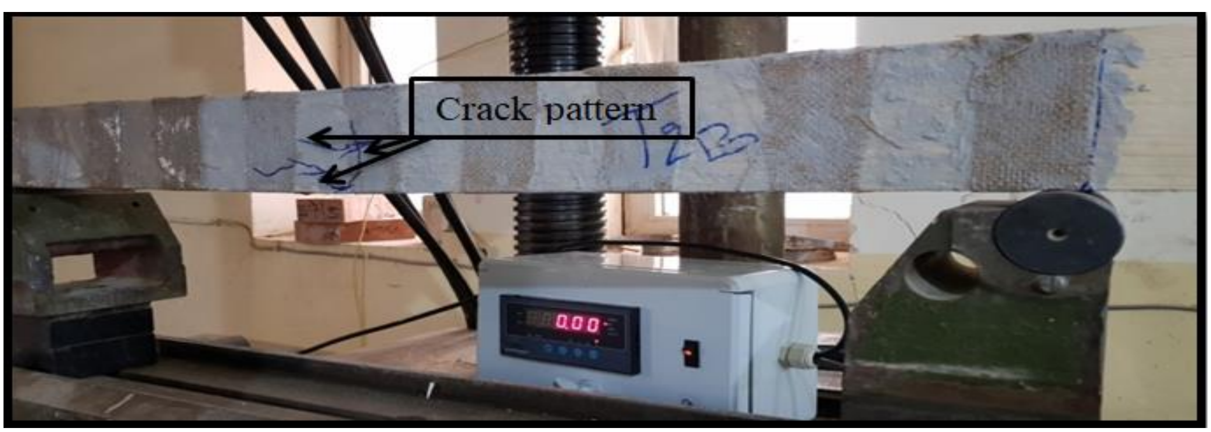


Fig. 21. T2

While, the failure mode of Group (C) is the splintering tension and the distribution of cracks in these beams are less than those in the control beams and the beams of Group (B), as shown in Fig. 22.

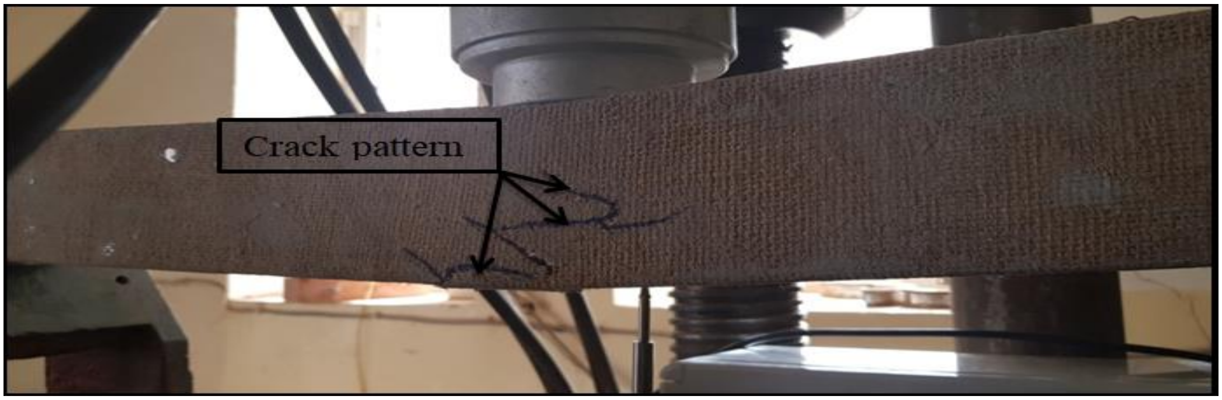


Fig. 22. T5

Finally, the beams of Group (D) have the largest distribution of cracks due to the decreasing in area of jute on tension face of each beam. On the other hand, these cracks decreased with increment in jute area, as shown in Fig. 23 and Fig. 24.

Fig. 23. T7

Fig. 24. T10

4. CONCLUSIONS

1. Increasing the area of the jute fibers has led to an increase in ultimate loads of the tested timber beams by about (66%-89%), (77%-101%), and(30%-71%) for U, Full, and flexural strengthening technique, respectively, when compared with the control beam.

2. The mid-span deflection of the beams strengthened by jute fibers have decreased by about (32.1%-38.7%), (33.6%-38.7%), and (30.6%-31.6%) for U, full, and flexural strengthening methods, respectively, when compared with the control beam at the same load, and this decrease is due to the good bonding between wood beams and jute fibers.

3. The toughness ratios of the tested beams increased by about (184%-320%), (199%-401%), and (137%-240%) for U, full, and flexural strengthening techniques, respectively at the ultimate loads when compared with the control beam. Also, the toughness indices (I_5), (I_{10}), and (I_{20}) values of the strengthened beams highly increased with the increment of jute fibers area.

4. The reason of the increment in toughness ratios and toughness indices values of the tested beams is due to the good elasticity of the used jute fibers so that the fibers have distributed spread of failure cracks in the reinforced timber beams.

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

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