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Strengthening of Timber Beams using Glass Fiber Reinforced Polymers and Wire Mesh.

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Abstract

An experimental study was carried out to investigate the performance of timber beams strengthened using fiber reinforced polymer and wire mesh. A series of ten timber beams with 200 × 125 mm rectangular cross section and 2000 mm long were tested up to failure under one-point load. The current study examined the effect of strengthened materials types, the thickness of the used sheets and strengthening configuration. The results showed that all of strengthening schemes investigated in this study were efficient in augmenting the load carrying capacity of timber beams but didn't enhance their stiffness. Using welded wire mesh significantly enhanced the failure capacity and energy absorption capacity of the strengthened beams as compared to GFRP sheets.

Keywords: *Timber Beams, Welded Wire Mesh, Carbon Fiber Reinforced Polymer, Load Carrying Capacity.*

Introduction

Timber is broadly used as a chief structural material in construction for hundreds of years specially in Europe until concrete and steel became the preferred materials at the beginning of the 20th century, According to Alfred Swenson and Pao-Chi Chang. (1980).. Since the beginning of the 1960's, researches have been conducted in order to reintroduce timber as a competitive material in structural design .A. André, and Robert Kliger,. (2015) stated that timber has many inherent advantages, the most important characteristic of timber its high strength to weight ratio, which means that timber is easy to handle and move because there is no formwork required. Using of timber in construction does not necessitate long time for hardening which will shorten construction time. Moreover, the construction costs will be reduced because no heavy machinery is needed. In spite of these significant advantages, timber structures have a number of problems attributed to design failure (one of the reasons is the different strength of timber), excessive loading and infestation by termites . Ashurst, J. and Ashurst, N. (1988) published that to prevent the effect of these problems the attention tended towards increasing the load capacity of timber structures by developing different method. Although various methods have been adopted to strengthen timber construction, the use of fiber reinforced polymer (FRP) and reinforcing wire mesh techniques have been shown to be very efficient for structural improvement. Compared to traditional strengthening techniques, FRP and reinforcing wire mesh strengthening methods have many advantages that contributed in making it a competitive material. A large body of researches has been concerned with the use of FRP as a strengthening material over the past three decades. However, there is a scarcity of published work concerning the strengthening of timber beams. Talukdar and Banthia (2010) carried out an experimental investigation to study the use of Sprayed Fiber Reinforced Polymer (SFRP) for retrofit of timber beams. A total of 10-full scale specimens were tested. Two different timber preservatives and two different bonding agents were investigated. Strengthening was characterized using load deflection diagrams. Results indicate that it is possible to enhance load-carrying capacity and energy absorption characteristics using the technique of SFRP Of the two types of preservatives investigated, the technique appears to be more effective for the case of creosote-treated specimens, where up to a 51% improvement in load carrying capacity and a 460% increase in the energy absorption capacity were noted.

Yusof, (2010) investigated the ductility behavior of timber beams strengthened with CFRP (carbon fiber reinforced polymer) plates. The surface to be bonded was spiked by punching small holes of 2 mm in diameter with 10 mm spacing. The aim is to increase bonding capacity by having small studs. Five beams with the dimension of 100 mm × 200 mm × 3000 mm were tested where one of the beams was used as control beam.

Ted W. Buell, P.E.; and Hamid Saadatmanesh (2005) investigated whether applying composites in the form of either a fabric wrap or laminate strips to timber beams would increase the load capacity of the beams. Bidirectional carbon fabric was the primary strengthening material used. A total of 10 solid-sawn Douglas Fir timber beams were taken from a timber stringer bridge in Yuma, Ariz. that was replaced in 1999. Seven of the 10 creosote-treated beams were reinforced with carbon fiber and then tested for bending strength, shear strength, and stiffness. Three of the beams were tested as unreinforced control specimens. The results show that applying carbon fabric to the timber beams provides significant increases in the bending and shear capacity, and nominal increases in the stiffness of the beams. Allowable stress modification factors are conceptually discussed that could potentially be used by engineers to determine the safe load-carrying capacity of beams reinforced with carbon fiber. However, a statistically significant number of timber beams strengthened with carbon fiber need to be tested to arrive at definitive stress modification factors.

Borri, A., Corradi, M., and Grazini, A. (2005) bonded CFRP (epoxy) sheets with different density in the tension area of timber beams. Some beams were reinforced with pre-stressed CFRP sheets. It was reported a maximum load increase around 40 and 60% and a stiffness increment by 22.5 and 29.2% for the un-reinforced beams with lower and higher CFRP density respectively (if compared to the control). A total of 20 creosote-treated Douglas FIRbeams with dimensions of 130×330×4,500 mm were tested in three-point bending. This study found that the strengthening with GFRP laminates, on average, increased the strength and the stiffness of the beams, respectively, by 36 and 3% for Group T and by 31 and 3.5% for Group TC. An analysis of a database of fiber-reinforced polymer (FRP)–strengthened timber beams tested by other researchers facilitated further study on the effect of FRP on the behavior of timber. The comprehensive analysis revealed a minimal stiffness increase in timber beams strengthened with FRP. Some evidence exists, however, that the beam span-to-depth ratio is an important factor to consider when strengthening timber beams. Beams with smaller span-to-depth ratios showed some increase in stiffness with increasing the reinforcement ratio; however, beams with larger span-to-depth ratios showed no real enhancement of beam stiffness, unless the reinforcement ratio was around 7 times the minimum code-recommended value. This result supports the current CSA provisions that do not advocate for stiffness increase when this strengthening method is used. The analysis shows that stiffness increase in GFRP-strengthened timber beams, based on results of small- scale samples, is minimal.

It is evident that few studies have tackled the potential of using GFRP and reinforcing welded wire mesh in strengthens of timber beams. Hence, the present study explores the ability of using GFRP and welded wire mesh in strengthening (200 mm x 125 mm x 2000 mm) timber beams. The effectiveness of strengthening materials, the thickness of sheets and strengthening configuration in increasing the strength and stiffness of the timber beams were among the parameters investigated. All beams specimens were tested under monotonic increasing load up to failure.

Methodology

Reinforcing Wire Mesh:

Two different types of Reinforcing Wire Mesh were used for flexural strengthening of the test beams. Reinforcing wire mesh type1 has 4 mm wire mish diameter and 400 N/mm2 yield strength whereas reinforcing mesh type two has 4 mm wire mish diameter and 440 N/mm2. Figure 1 shows reinforcing wire mesh types. Table 1 summarizes the mechanical properties of the steel wires mesh.

(a) reinforcing wire mesh type 1

(b) reinforcing wire mesh type 2

Figure 1 reinforcing wire mesh types.

Table 1 Mechanical properties of steel wires mesh.

NO #	Diameter of wire mish (mm)	Yield strength (N/mm^2)	Ultimate strength (N/mm^2)	Elongation (percent)
1	2.4	400	511	2.5
2	4	440	612	33

GFRP and resin epoxy:

Unidirectional high strength glass sheets (Sika Wrap®-430 G) was used in strengthening the timber beams specimens. The glass fiber reinforced polymer sheets had a 500 mm width and 0.17 mm thickness. Impregnating resin (Nitofix) was used for gluing the sheets to the timber surface. Nitofix is an easily worked multi-medium viscosity adhesive based on solvent-free epoxy resins. It is supplied as a two-pack material which on mixing cures to a high strength, oil, water and chemical resisting film with exceptional adhesive properties. Equal quantities of each component scooped from the tins and mixed together. The technical data of SikaWrap®-430 G and Nitofix are presented in Tables 2 and 3, respectively.

Table 2 Properties of SikaWrap®-430 G

Fiber Type	fabric sheets (SikaWrap®-430 G) High strength E-glass fibers
Fiber orientation	0o (unidirectional)
Construction	Wrap: Glass fibers (99% of total areal weight) Weft: Thermoplastic heat-set fibers (1% of total areal weight)
Areal Weight	455 g/m^2 ± 22 g/m^2
Fabric Thickness	0.17 mm (based on the total carbon content)
Fiber Density	2.56 g/cm^3
Fabric width	500 mm
Tensile strength	2300 N/mm^2 (nominal)
Tensile E-modulus	76000 N/mm^2 (nominal)

Table 3 Properties for impregnation resin (Nitofix)

Properties Pot life:	2 ½ hours at 20^oC 1 – 1 ½ hours at 40^oC
Curing time:	12 hours at a temperature of not less than 20^oC
Full cure:	24 hours as above stronger joints will be achieved if the joints are warmed to a maximum of 100^oC during the curing period. At this temperature the cure will be completed in 20 minutes.
Temperature:	Curing takes place at temperatures above 5^oC. At lower temperatures, curing will be retarded maximum cure temperature 100^oC.
Linear coefficient of expansion:	60 x 10-6 per ^oC
Modulus of elasticity:	2000 N/mm2 (0.3x106 lbs/in^2)
Joint strengths:	33 N/mm2 (4750 lbs/in^2). Aluminium abraded or etched 14 – 20 N/mm2 (2 – 3000 lbs/in^2) steel abraded or etched. Lap joint shear tests for brass, lead, tin, polythene, PVC with aluminium show join strength in excess of 7 N/mm^2 (1000 lbs/in^2)
Shelf life:	12 months minimum if stored below 20^oC

Layout and detailing of test specimens

Ten timber beams with 125 mm x 200 mm rectangular cross section and 2000 mm length were tested groups as follows:

1. Two were used as control unstrengthen specimens (control beams).
2. Specimen was strengthened using single layer of the reinforcing wire mesh type1.
3. Specimen was strengthened using double layer of the reinforcing wire mesh type1.
4. Specimen was strengthened using single layer of the reinforcing wire mesh type2.
5. Specimen was strengthened using double layer of the reinforcing wire mesh type2.
6. Specimen was strengthened using double layer of GFRP.
7. Specimen was strengthened using four layer of GFRP.
8. Specimen was strengthened using double layer of GFRP and one layer of the reinforcing wire mesh type1.
9. Specimen was strengthened using double layer of GFRP and one layer of the reinforcing wire meshtype2.

Details of the test specimens are summarized in Table 4. All column specimens were subjected to monotonic increasing load up to failure using displacement control to assess their strength, stiffness and ductility.

Table 4 Summary of test specimens and parameters

Specimen Designation	***Strengthen Scheme***	
	Strengthened material	***No. of Layers***
Control TB1	None	
Control TB2		
TB-WM1-1L	Wire mesh type 1	Single layer
TB-WM1-2L	Wire mesh type 1	Double layer
TB-WM2-1L	Wire mesh type 2	Single layer
TB-WM2-2L	Wire mesh type 2	Double layer
TB-G-2L	GFRP	Double layer
TB-G-4L	GFRP	Four layer
TB-WM1/1L + G/2L	Wire mesh type 1 + GFRP	Single layer
		Double layer
TB-WM2/1L + G/2L	Wire mesh type 2 + GFRP	Single layer
		Double layer

TB: timber beam, WM1: wire mesh type 1, WM2: wire mesh type 2, C: glass FRP L:layer

Flexural testing

The simply supported timber beams were tested under one points-bending test to determine the load–deflection curves using 4000 kN capacity compression testing machine (4000 kN Universal Testing Machine). The compressive load was increased gradually using displacement control at a constant rate of 0.5 mm/ min. Test data was recorded with an automatic data acquisition system at a rate of five readings per second. An LVDT, placed at the middle point of the bottom of the beam, was connected to a data acquisition system to measure mid-span deflection (Fig. 2). All beams were tested under monotonic increasing load up to failure.

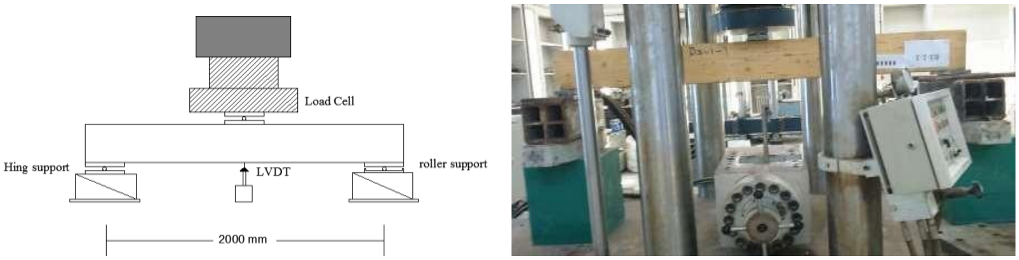

Figure 2 Instrumentation of the test specimens

Results and Discussion

The flexural behavior of the specimens was evaluated through the load–displacement curves in terms of maximum axial load resistance, corresponding deflection, stiffness and toughness. The tabulated Δmax value defines the axial displacement value corresponding to a point located on the post-yield part of the actual curve wherein the axial load drops by 20%, indicating a state of strength failure. The initial axial stiffness represents the slope of a straight line that starts from the origin and intersects the load-displacement curve at an axial load corresponding to 60 % of the ultimate axial load. Toughness is computed as the area underneath the load-deflection. Figures 3-12 present the load-deflection curves and for the different test specimens. Table 2 summarizes the characteristics of the experimental load-displacement curves for the different test specimen.

[a] Numbers between brackets in this row represent a percentage of control specimens test specimen

Table 2 Characteristics of the experimental load-deflection

Specimen Designation	***Failure Load*** F_u ***(kN)***	***Δmax)mm)***	***Secant Stiffness (kN/mm)***	***Toughness (kN. mm)***
Control TB1	71.5	31.1	6.3	1110.9
Control TB2				
TB-WM1-1L	81.1 (113.4)[a]	28.1 (90.3)	5.3 (84.1)	1139.9 (102.6)
TB-WM1-2L	79.1 (110.6)	25.8 (83.0)	5.4 (85.7)	1120.4 (91.9)
TB-WM2-1L	82.3 (115.1)	40.0 (128.6)	3.8 (60.3)	949.6 (85.4)
TB-WM2-2L	79.1 (110.6)	41.7 (134.1)	4.1 (65.1)	1649 (148.4)
TB-G-2L	73.9 (103.4)	25.7 (82.6)	3.4 (53.9)	923.7 (83.1)
TB-G-4L	77.9 (109.0)	23.1 (74.3)	4.1 (65.1)	887.8 (79.9)
TB-WM1/1L +G/2L	77.2 (108.0)	40.0 (128.6)	5.5 (87.3)	1544 (139.0)
TB-WM2/1L +G/2L	77.6 (108.5)	44.1 (141.8)	6.2 (98.4)	1711.1 (154.0)

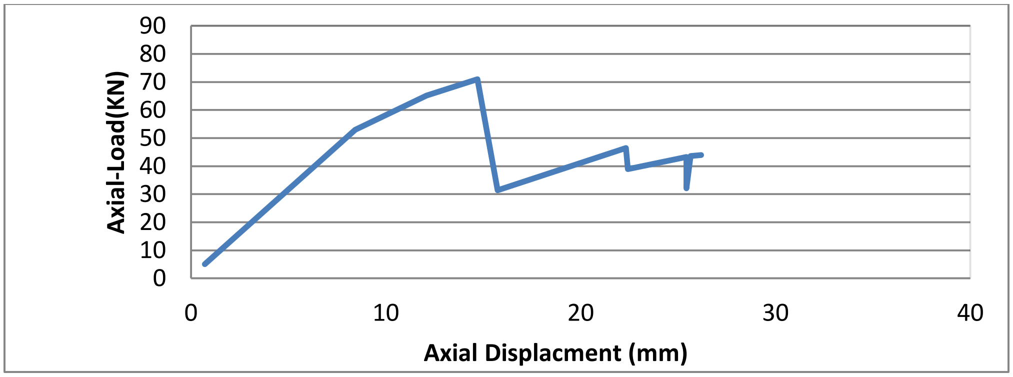

Figure 3 Axial load-displacement curve for Control TB1 specimen

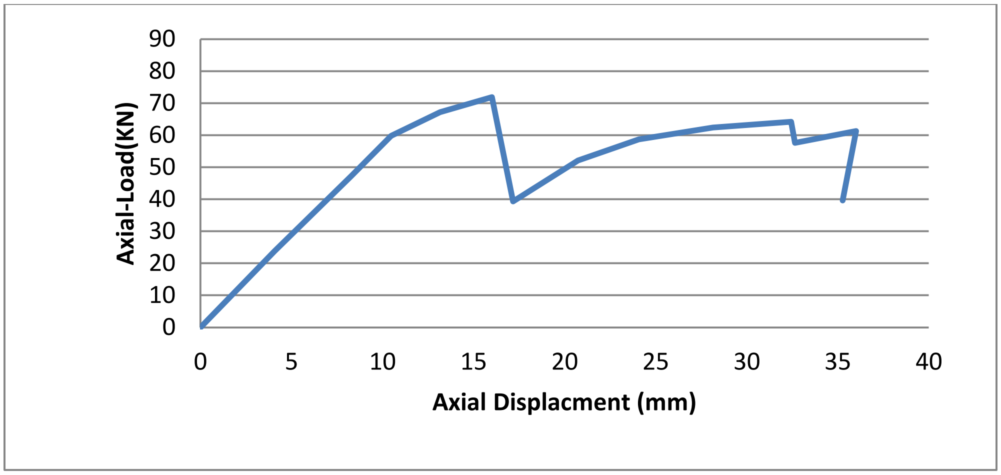

Figure 4 Axial load-displacement curve for Control TB2 specimen

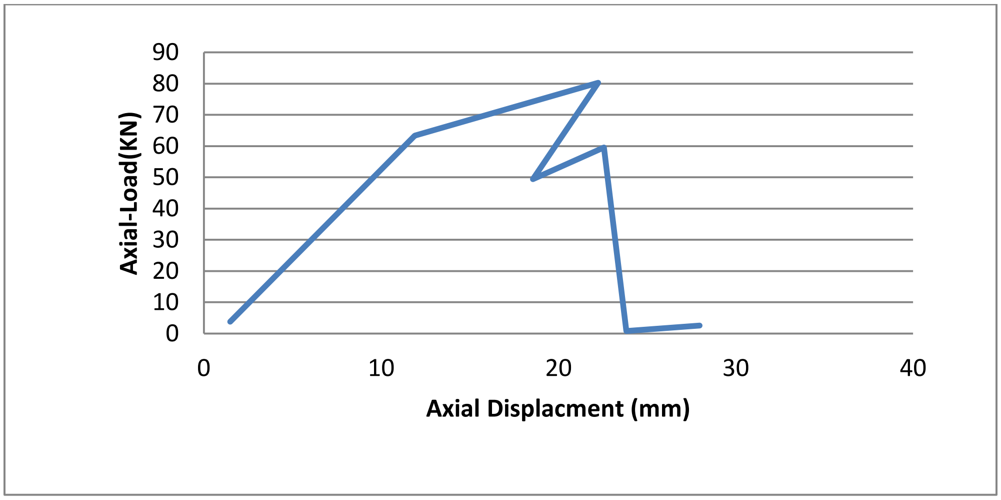

Figure 5 Axial load-displacement curve for TB-WM1-1L specimen

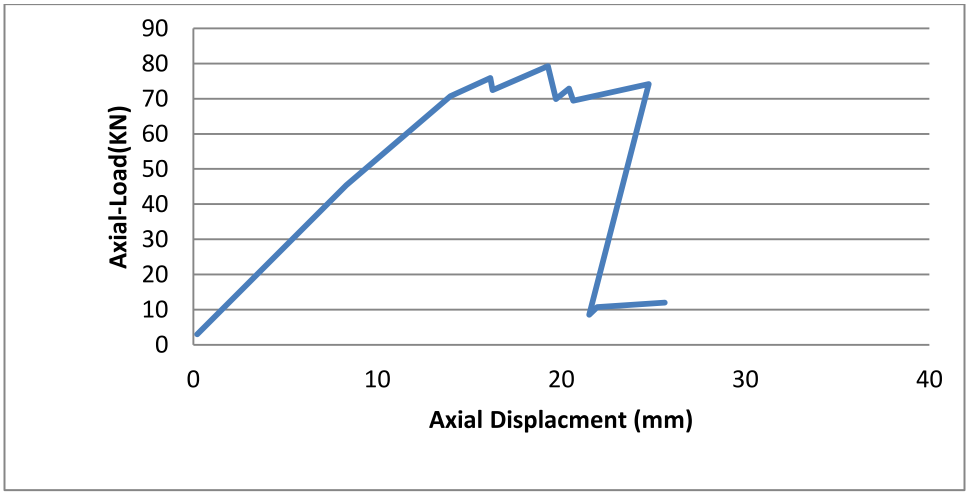

Figure 6 Axial load-displacement curve for TB-WM1-2L specimen.

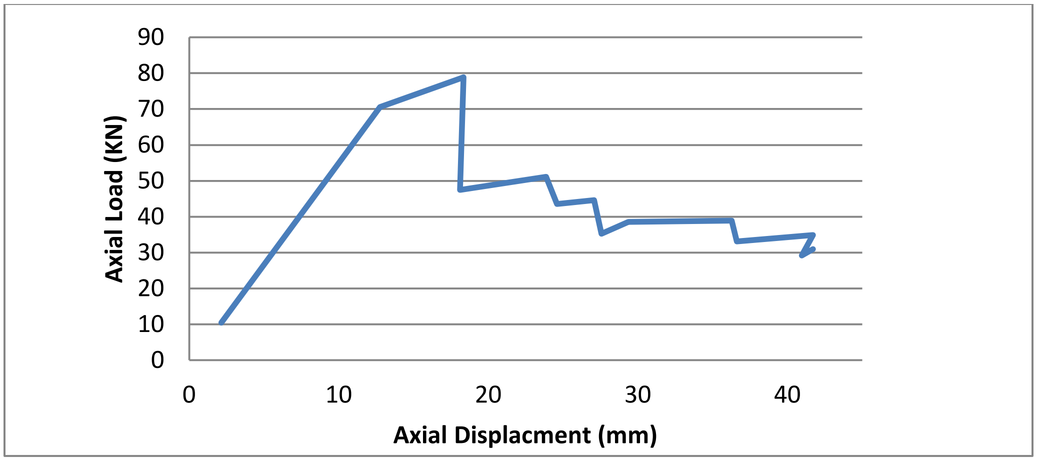

Figure 7 Axial load-displacement curve for TB-WM2-1L specimen.

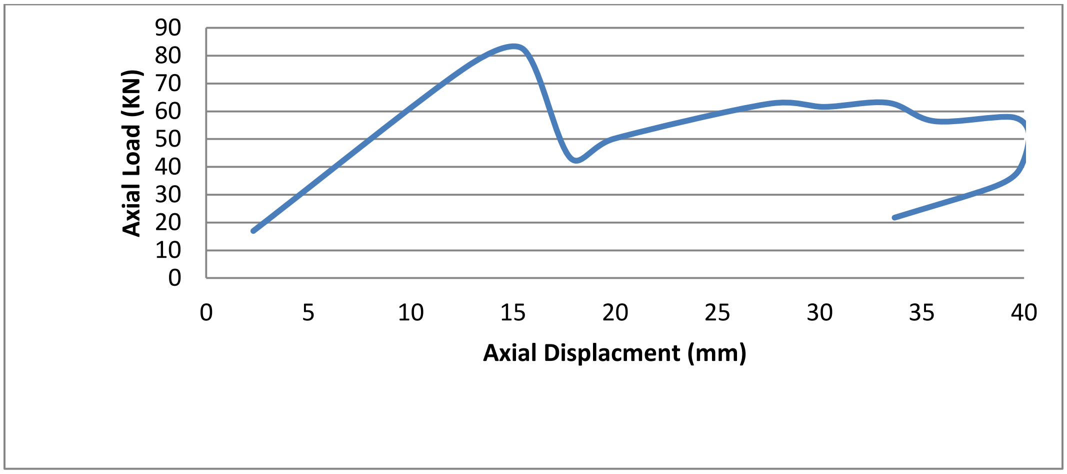

Figure 8 Axial load-displacement curve for TB-WM2-2L specimen.

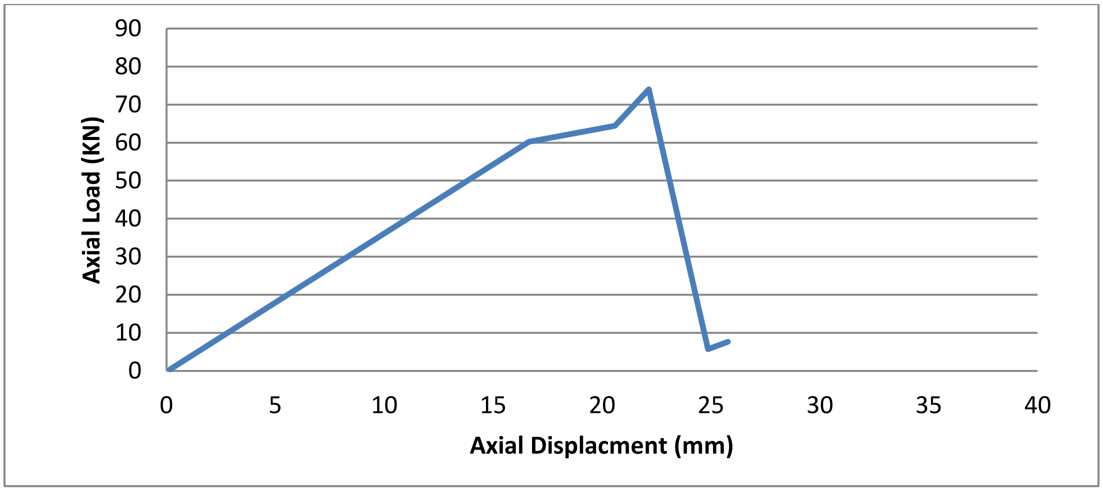

Figure 9 Axial load-displacement curve for TB-G-2L specimen.

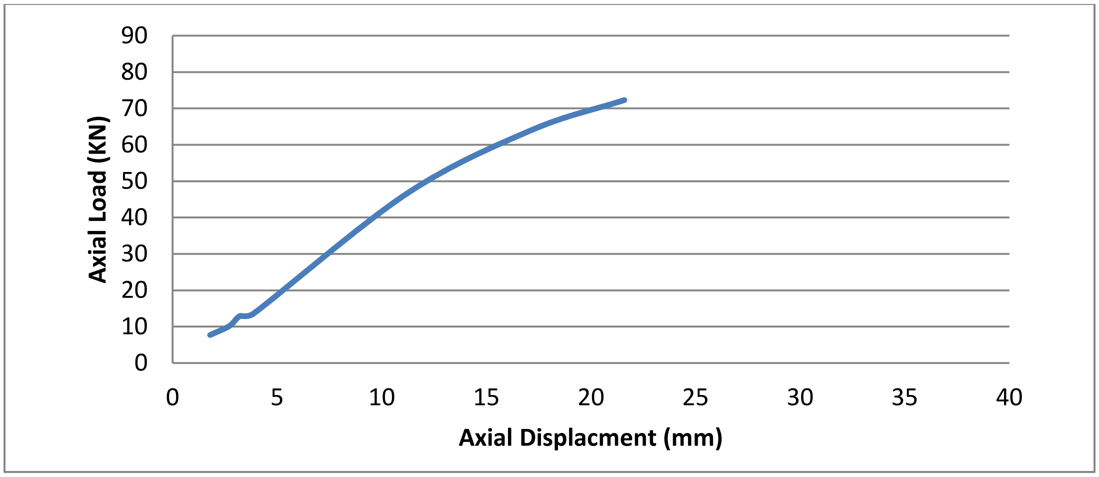

Figure 10 Axial load-displacement curve for TB-G-4L specimen.

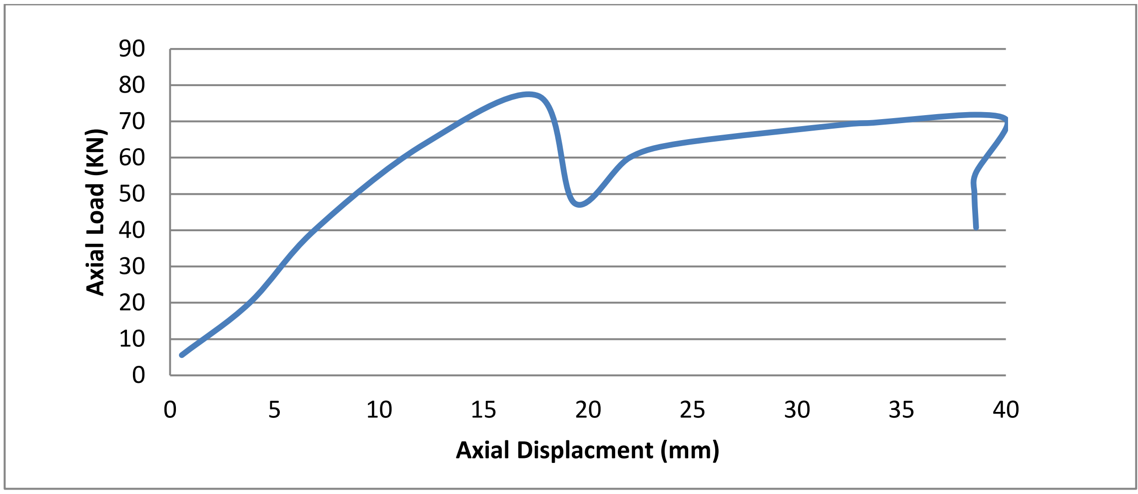

Figure 11 Axial load-displacement curve for TB-WM1/L+G/4L specimen.

Reinforcing wire mesh type 1

The results presented in Table 4 show that the maximum axial load for beams strengthened with one and two layers of reinforcing wire mesh type 1 exceeded that of the control specimens by 13.4% and 10.6% with a corresponding decrease in maximum displacement by 10% and 17%, respectively. The toughness showed significant improvements where it reached 2.6 times (for one layer of WM1) and 8.5 times (for two layers of WM1) that of the control specimens whereas the axial stiffness was reduced by about 15.9% and 14.2%, respectively.

Reinforcing wire mesh type 2

Inspection of Table 4 shows that strengthened with one and two layers of WM2 have increased their axial compressive strength by 15.1% and 10.6%, respectively with a corresponding increase in maximum axial displacement by 28.6% and 34.0%, respectively. The initial secant stiffness of specimens TB-WM2-1L and TB-WM2-2L have decreased by 39.7% and 34.9%, respectively. A significant decrease in toughness of specimens TB-WM2-1L was observed: toughness of specimens TB-WM2-1L was found to be 14.5% lower than that of the control timber beams specimens. Whereas a significant increase in toughness of specimens

TB-WM2-2L was observed: toughness of specimens TB-WM2-2L was found to be 32.6% higher than that of the control timber beams specimens

Glass fiber reinforced polymers

It can be noticed from Table 4 that the maximum axial stress (failure stress) of the strengthen beam using 2 layers and 4 layers of GFRP was reduced significantly by 3.4% and 9.0%, respectively. The initial secant stiffness of specimens TB-G-2L and TB-G- 4L have decreased by 46.0% and 34.9%, respectively. A significant decrease in toughness was observed: toughness of specimens TB-G-2L and TB-G-4L was found to be 16.8% and 20.0%, respectively lower than that of the control timber beams specimens.

Glass fiber reinforced polymers and Reinforcing wire mesh

Examination of Table 4 reveal that using type one and two of wire mesh with two layers of GFRP wraps have increased the axial compressive strength of the strengthen timber beams by 8.0% and 8.5%, respectively with a corresponding increase in maximum axial displacement by 28.6% and 41.8%, respectively. On the other hand, secant stiffness decreased by 12.6% in specimen TB-WM1/1L +G/2L and 1.6% in specimen TB- WM2/1L +G/2L. Toughness was found to be higher than in the control unstrengthen specimens.

Failure modes

Figure 12 shows a typical beam at failure. All of the 10 beam specimens tested in this part of the program failed in flexure, only compression failure modes were observed.

(a) Control TB1 specimen

(b) TB-G-2L specimen

(c) TB-WM1-1L specimen

(d) TB-WM1-1L specimen

(f) TB-WM1/1L +G/2L specimen

Figure 12 Beam Failure Modes

Conclusion

The following points highlights the main outcomes and conclusions derived from the test results:

1- All of the investigated strengthening schemes managed to increase the original axial resistance of the unstrengthen beams. However, none of these schemes succeeded in increasing the axial stiffness of the beams.
2- Strengthening timber beams with wire mesh type 1 exhibited superior performance in terms of ultimate load capacity.
3- Using a single-layered of wire mesh type one to strengthen timber beams was more efficient as compared to use a double layer the axial strength of timber beams.
4- Strengthen the timber beams using a single or double-layer resulted in significant increase in their axial capacity, maximum axial displacement but adversely affected their stiffness.
5- The use of four layers of GFRP sheets rather than a double layer resulted in a substantial increase in the axial load resistance, stiffness, and toughness of the jacketed beams but adversely affected their toughness and maximum axial displacement.
6- Using a wire mesh type two with a double layer of GFRP external warps significantly enhanced the axial load resistance, maximum axial displacement, stiffness and toughness of the timber beams as compared to a wire mesh type one with a double layer of GFRP external warps.

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