Shear Strengthening of Solid Timber Beams Using High Strength Fibre Reinforced Epoxy System

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Abstract. Recently studies of structural members rehabilitation in enhancing structural performance such as for flexural and shear capacity are increasing. Fibre reinforced polymer (FRP) is the current preferred material to strengthen timber structures either in construction or for rehabilitation purposes due to its high potential to improve mechanical performances. Shear failure always occur without any hesitation or warning and this research is conducted since there are least numbers of researches done on the behavior of the timber beam towards the shear resistance. This paper presents the results of experimental works for shear strengthening of solid Yellow Meranti timber beams by externally bonded Carbon Fibre Reinforced Epoxy (CFRE) and Glass Fibre Reinforced Epoxy (GFRE). All beams were designed deficient in shear but satisfactory in bending. A total of nine beams 100 mm × 200 mm × 1475 mm were tested in this programme including control beam. The beams were divided into three groups, namely: Group 1, Group 2 and Group 3 with three beams for every group except the third group that test only two beams. Unidirectional fabric laminate by wet lay-up technique of GFRE and CFRE and pultruded plate of CFRE in the form of plates were used to strengthen three the respective beams for each group of sample in order to compare their horizontal shear stress. Control beam was failed in shear at the neutral axis followed by brittle tensile failure at the bottom middle span. The rest of the strengthened beams failed in tensile at the middle bottom of the beams. From the test, it was observed that all three types externally bonded fibre reinforced epoxy system to the shear zone surface of the beams are effective in shear reinforcing of the timber beams by showing an increase in shear stress at failure of beam reinforced compared to control beam. Among various schemes studied, the beam strengthened with CFRE fabrics from third group provide the most effective strengthening for timber beams with increases of 94% in shear stress at failure. Meanwhile, the rest of the strengthened timber beam give range from 37 to 72% increases in shear stress at failure.

Introduction

Recently studies of strengthening structural members in enhancing structural performance such as for flexural and shear capacity are increasing. Buell and Saadatmanesh (2005), Gentry (2011), Gómez and Svecova (2008) and Hay et. al. (2006) had proved that Fibre Reinforced Polymer (FRP) assist in increasing shear performance of timber beams due to its high potential in increasing the flexure and shear strength. This paper presents the results of experimental works for shear strengthening of solid timber beams by externally bonded CFRE and GFRE.

Materials

The timber species used was Yellow Meranti or also known as Shorea spp. (Dipterocarpaceae) that was characterized as light hardwood having density ranging from 575-735 kg/m^3 air dry (MTC, 1992). All the timber beams were taken from the same batch to avoid any circumstances regarding the variability of timber properties. The beams were than dried in a big oven until the moisture content of the timber were confirm below 19% and then, all beams were taken out from the oven and stacked on shelf and were exposed to room temperature and humidity for six month to allow stabilization of its moisture content so that the effect of moisture content can be eliminated since it can influence the strength properties of the timber. The size of the timber beams used in this study was 100 mm × 200 mm × 1475 mm.

The strengthening material used in this study was carbon type named Sika CarboDur S512 plates obtained from Sika Kimia Sdn. Bhd. which is very high strength, durable, lightweight, non-corrosive and required simple installation. This type of FRP is readily available in market having 50 mm width and 1.2 mm thickness with cross-sectional area 60 mm^2 supplied in rolls. The selection was made because of the availability in market, the specialty to strengthen timber structures and the mechanical properties itself. For the purpose of this testing, Sika CarboDur S512 was cut through the width to obtain 25 mm of width. Carbon and glass unidirectional fabric types namely SikaWrap-300 C and SikaWrap-430 G respectively were also used as strengthening material to compare the performance with timber beams strengthened using plates.

Sikadur-30 is a two part epoxy system consist of epoxy and a hardener and Sikadur-330 330 is a epoxy matrix for laminating which is design in a system with Sika CarboDur and both SikaWrap-300 C and SikaWrap-430 G respectively for bonding reinforcement. Sikadur-30 is a thixotropic combination of epoxy resin and special filler which is designed particularly in structural reinforcing works. This adhesives is easy to mixing and need no primer make it is very good adhesion to timber and Sika CarboDur plates.

Beams Preparations

All beams were designed deficient in shear but satisfactory in bending. A total of nine beams 100 mm × 200 mm × 1475 mm were tested in this programme including control beam. The beams were divided into three groups; three beams for every group except the third group that test only two beams. First group is for preliminary studies and to provide guide lines for improvement to the second and third group in terms of preparation of beam and during testing to get good consequences. High strength class of Glass fibre reinforced epoxy (GFRE) and carbon fibre reinforced epoxy (CFRE) in the form of unidirectional fabric and CFRE in the form of plates were used to strengthen three the respective beams for every group in order to compare their shear performances. Configuration of the testing was shown in the Figure 1. The shear zone was 280 mm in length which was determined by conducting preliminary study and based on standard ASTM D198 (2014)

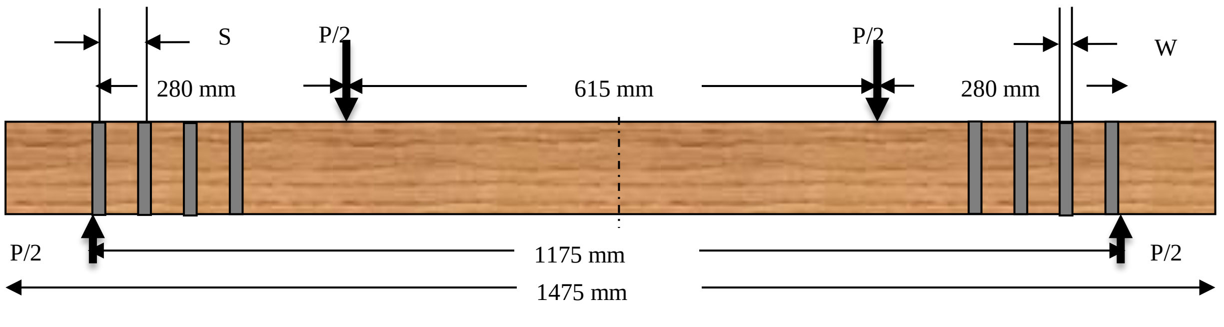
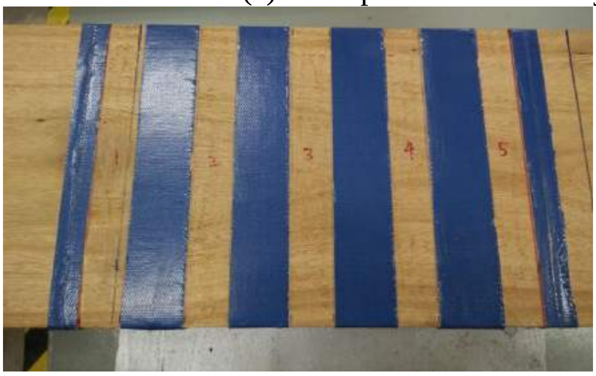


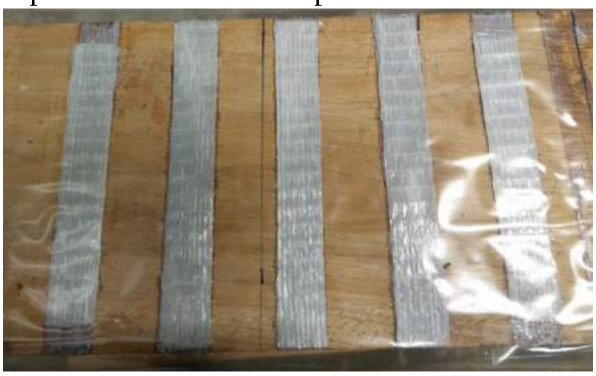
Figure 1: Strengthened beams configuration

All the beams were dried and the surface of timber in contact with FRE was roughened and cleaned using air compressor to get rid of dust. This process is aim to increase bonding capacity between epoxy and timber as had been done by Spadea et al. (1998). For beam strengthened with carbon plate, sikadur-30 was used as adhesive. Sikadur-30 was first mixed with ratio 1:3 and applied at a thickness approximately 1 mm on one side of carbon plate, and thickness of approximately 2 mm on the timber. Carbon plate was then placed properly on the timber and special care was applied. Whilst, sikadur-330 was used as adhesive for beams strengthened with carbon fabrics and glass fabrics. First layer of well-mixed sikadur-330 with ratio of 1:4 were applied on the timber followed a sheet of FRP fabric and the sheet was embedded on the timber surface and then, by using putty knife, air bubbles were forced out. The process was repeated up to three layers which is approximately have uniform thickness throughout the FRE plates. Then, all prepared beams were clamped at the prepared FRE and left for curing for seven days prior to testing. Figure 2 showed the hand lay-up of FRP fabrics improvement from Group 1 (preliminary test) to Group 2 and Group 3. The purpose is to have clean surface of timber beams to facilitate the observation of cracks during the testing.

(a) After process of hand lay-up FRE fabric for Group 1



(b) Preparation before hand lay-up FRE fabric

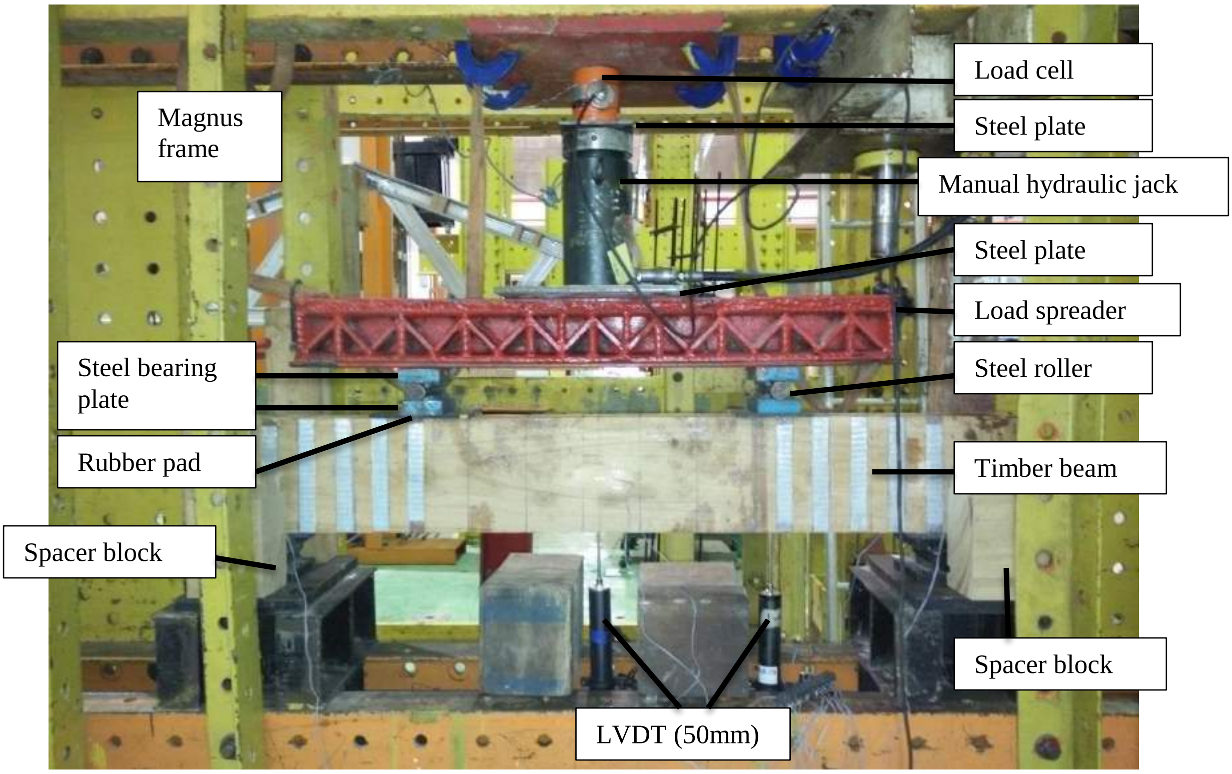


(c) After process of hand lay-up FRE fabric for Group 2 with cleaner finishing

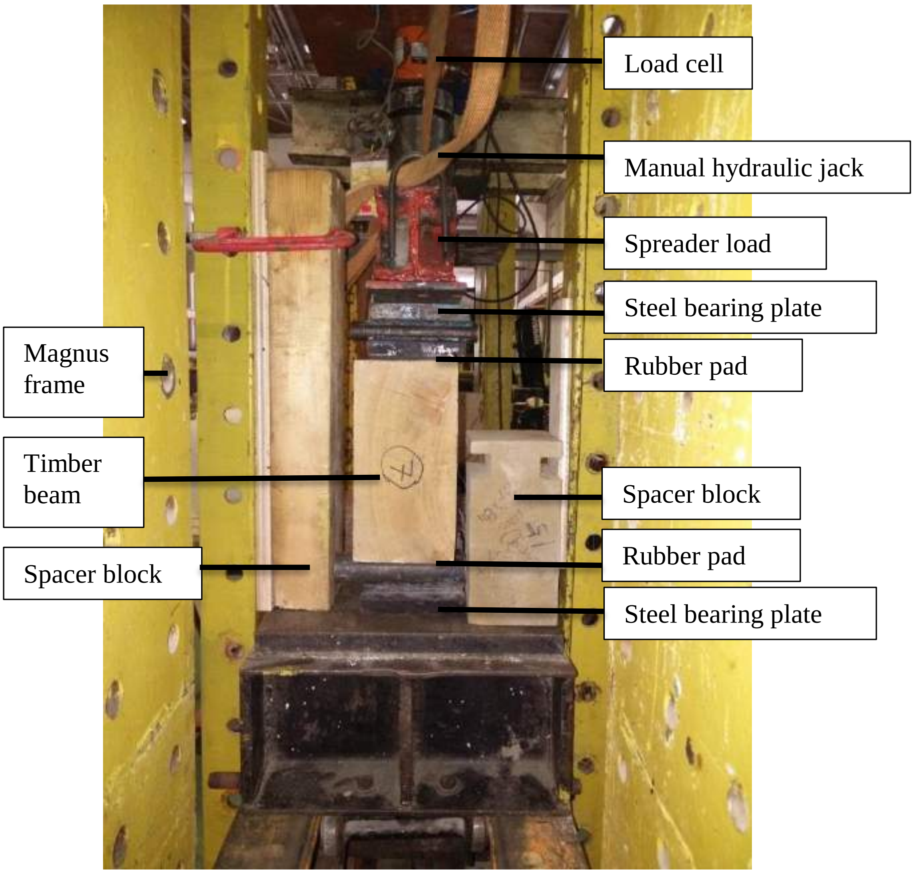
Figure 2: Hand lay-up of FRP fabrics improvement from Group 1 to Group 2 and 3

Test Setup

All beams were tested under four point bending with the length of test span was 1175 mm and shear span of 280 mm. A loading rate of 2 kN/min was applied to each of timber beam from zero to approximately 170 kN and reduced to 1 kN/min when the beams were near to total failure. Electro-Hydraulic Jack was used with load cell of 3 tonnes. Two linear displacement transmission transducers (LVDT) and two strain gauge type BFLA-5-3L for FRP and three strain gauge type LFLA-10-11-3L for timber were used to measure the displacement and strain in the direction of fibres respectively. Figure 3 showed a typical beam being tested under bending.



(a) Front view

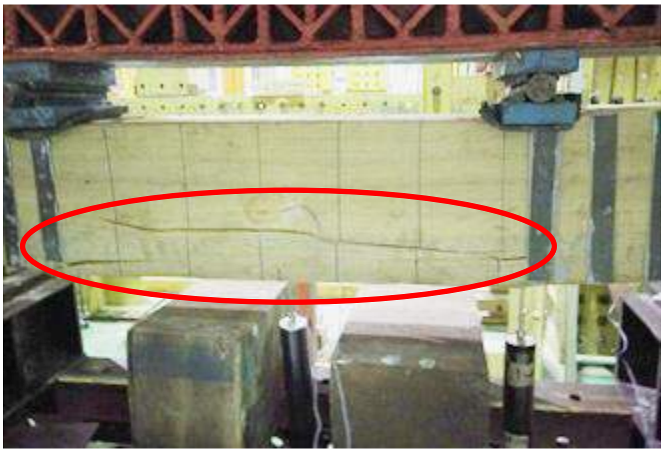


(b) Side view

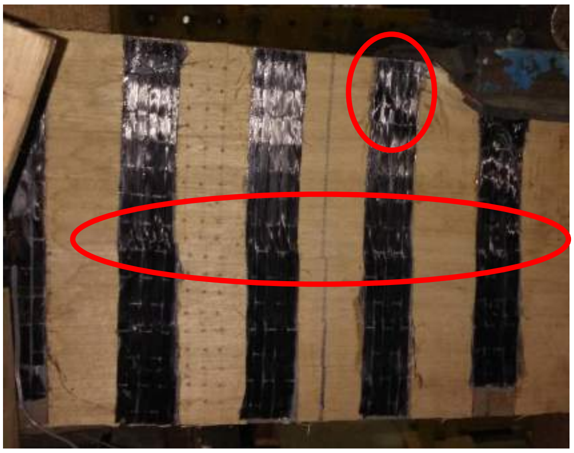
Figure 3: Four point bending testing configuration on beam GF-2 from Group 2

Data Analysis

Control beam without external reinforcement were first tested to total failure as a guideline for the analysis of the strengthened beams. Control beam (CB) was failed in shear at the neutral axis followed by brittle tensile failure at the bottom middle span. The rest of strengthened beams failed in tensile at the middle bottom of the beams with no debonding recorded but FRE rupture indicates that perfect bonding is assured and application of FRE was fully optimized. The load-deflection behaviour of all tested beams were compared. Figure 4 showed the typical mode of failure during the beam test.



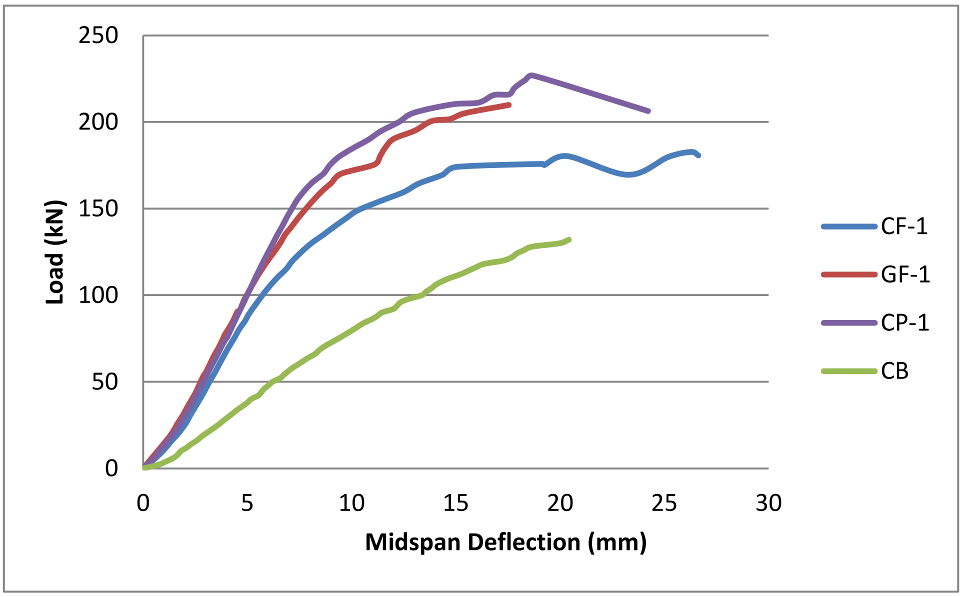
(a) Shear failure at mid span of beam CP-2



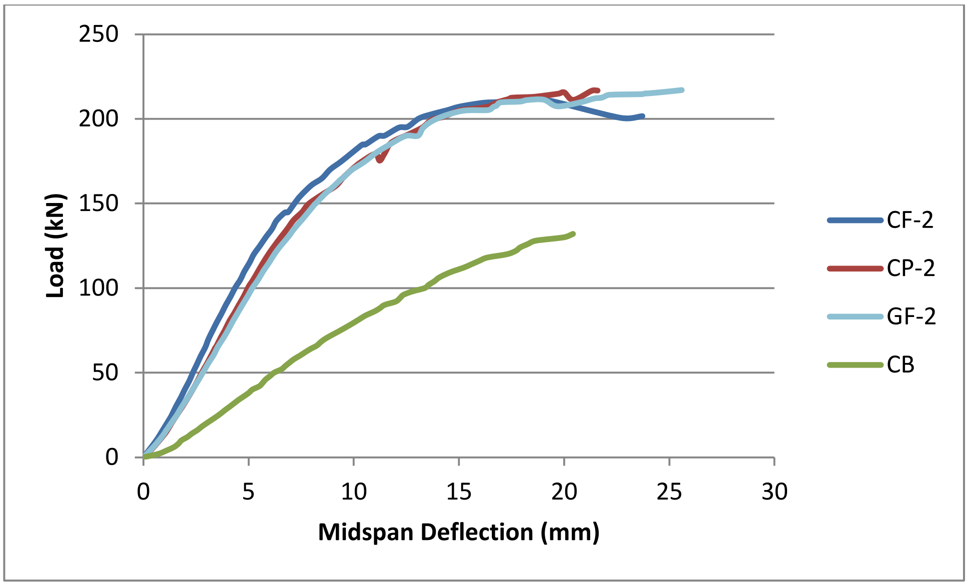
(b) little FRE rupture

(c) Shear and brittle tensile failure at midspan

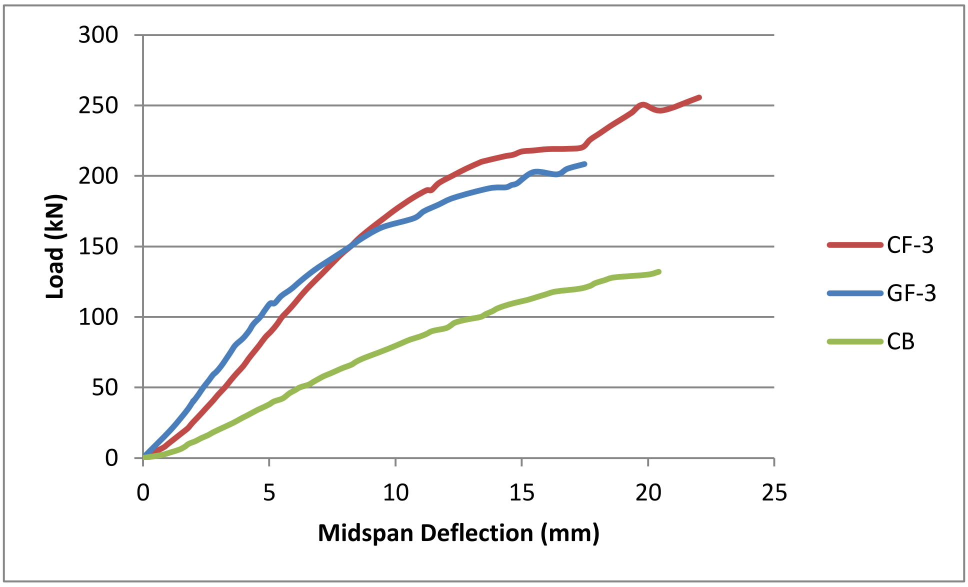
Figure 4: Typical failure of tested almost all strengthened beams



(a) Group 1 versus CB



(b) Group 2 versus CB



(c) Group 3 versus CB

Figure 5: Load-deflection curves for strengthened beam in Group 1, Group 2 and Group 3 versus CB

As can be observed from Figure 5 that showed the relationship between load and deflection for strengthened beams, CFRE fabrics (CF-3) beam from Group 3 led to maximum failure loads of 255.6 kN with 22.02 mm of deflection at the middle span indicating of 94% increment in maximum load compared to Control Beam (CB) which reach a maximum load of 132 kN with 20.42 mm maximum deflection at midspan. From Group 1, CFRE plates (CP-1) beam achieved maximum failure loads of 226.8 kN with 18.70 mm maximum deflection at midspan while for second group, GFRE fabrics (GF-2) beam and CFRE plates (CP-2) beam give maximum load of 216.7 kN and 217 kN with maximum deflection at midspan 21.59 mm and 25.59 mm respectively which show 64% increase of shear stress at failure over control beam (CB). Second group of testing showed the best results because all beams gives intangible different in maximum load and proved that type of FRP is not a crucial factor in strengthening timber beams. CFRE plates were produced in highly control of fibre to epoxy ratio through pultrusion process that answered why it has among the highest difference with maximum load of control beam. In second group, GFRE fabrics supported higher load due to CFRE much stiffer than GFRE. The maximum horizontal shear stress in a beam at failure was as follows, where V is maximum horizontal shear load and A is cross-sectional area of beam:

$$\tau_{max} = \frac{3V}{2A}$$

Generally, from the graph of load-deflection curves, all beams behaved linearly elastic initially up to 160 kN and as the lode increased, the beams tend to behave non-linear plastic until failure. Table 1 showed the results of the testing that showed all strengthened beam proven contribution to the increment of the maximum load over the control beam that lead to increase of shear strength of the beams, however, different type of FRP does not give significant effect to the strengthened beam. The main reason is that each beam differs in the amount of strength reducing defects such as bow, splits, checks, knots and internal crack that is not visible through observation with naked eyes. Gentile et al. (2002) also experienced some deviation of results due to this main reason and this is always applied to timber.

Table 1: Result from timber beam testing

Beam	**Maximum load, P_{max} (kN)**	**Maximum deflection at midspan, (mm)**	**Shear strength at failure (MPa)**	**Percentage increment of τ_{max} over CB (%)**	**Mode of failure**
CB	132.0	20.42	9.90	-	Shear at midspan
GF-3	208.4	17.48	15.63	58	Shear at midspan followed by brittle tensile crack
CF-3	255.6	22.02	19.17	94	Shear at midspan followed by brittle tensile crack
CP-2	216.7	21.59	16.25	64	Shear at midspan followed by brittle tensile crack
GF-2	217.0	25.59	16.28	64	Shear at midspan followed by brittle tensile crack
CF-2	212.1	18.79	15.91	61	Shear at midspan followed by brittle tensile crack
CP-1	226.8	18.70	17.01	72	Shear at midspan followed by brittle tensile crack
GF-1	209.8	17.54	15.74	59	Shear at midspan followed by brittle tensile crack
CF-1	180.7	26.63	13.55	37	Shear at midspan followed by brittle tensile crack

Conclusion

From the test, it was observed that externally bonded fibre reinforced epoxy system to the shear zone surface of the beams was effective technique for shear strengthening of the timber beams. Among various schemes studied, CFRE fabrics beam from Group 3 provide the most effective strengthening for timber beams with increases of 94% in maximum load. Meanwhile, the rest of the strengthened timber beam give range of 37 to 72% increases in maximum load. Ideal timber is almost impossible to obtain as timber is non-homogenous material that act as anisotropic behaviour. Result of the testing can be improved by using free defect timber with the same strength, but it does not represent the actual nature of timber that can be used in construction industry. It is recommended to continue this research using one type of FRE and increase layer of hand lay-up fabrics or shorten the length between the FRE stripes or both techniques.

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