Tensile Performance of Half-Lap Timber Nailed Joint Strengthened Using CFRP Sheet

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ABSTRACT

The strength of timber structure will slightly reduce due to long service life or constantly sustained under excessive load. Some of the structural member may need to be replaced or rectified. This paper presents findings on the half-lap timber joint strengthened using carbon fibre reinforced polymer (CFRP). The selected timber species are from Malaysian tropical timber, namely Kelampayan (SG7) and Kempas (SG2). The size of each specimen was 41x100x600mm. Six (6) specimens were tested without and with CFRP sheet. Epoxy glue was used as the bonding agent. The behaviour of the specimen was studied through their load-deformation characteristic upon loading and compared to European Yield Model (EYM). Results show that the strengthened specimens performed better than without CFRP. For Kelampayan, the maximum loads for without and with CFRP were 6.33kN and 14.0 kN respectively. The tensile strength of the nailed connection with CFRP for Kelampayan has been increased by 121% compared to without CFRP. As for Kempas, the maximum loads for without and with CFRP are 15.8 kN and 25.0 kN respectively and the connection strength with CFRP has been increased by 58% compared to without CFRP. Both Kelampayan and Kempas failure mode have found failed in mode b for the with CFRP sheet while failure in mode c for the without CFRP sheet. Therefore, it is proven that the use of CFRP sheet has significantly increased the tensile strength of half-lap timber nailed joint for the two-selected species.

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Introduction

The use of timber as structural member have come under serious review and studied recently as good quality logs are alarmingly becoming scarce besides the chronic problems of traditional sawn timber. Many researches regarding the use of timber are needed in strengthen or repair old timber structures as well as to improve the mechanical properties of new timber structures design. Connection is one of the important parts in wood-based products. It can help to increase the strength performance of the structures [1]. Recent studies were found reporting on the successful use of fibre reinforced polymer (FRP) as a strengthening material for timber connection [2-11]. FRP materials classified in many ranges such as glass, aramid or carbon which provide designers with an adaptable and better cost effective construction material due to its large modulus and strength characteristics. Comparing with the traditional rehabilitation techniques, FRP composites have high specific strength, stiffness, flexibility in design and replacement as well as robustness in unfriendly environments. With FRP composites, it is possible and also necessary to achieve the best strengthening result by optimising the constitute materials.

It is commonly stated that a structure is a constructed assembly of joints separated by members and in timber engineering the joint will generally be the critical factor in the design of the structure. The strength of structure is greatly influence by the displacement behaviour. The most common form of connector used in timber connections is the mechanical types which is metal dowel type fasteners such as nail, screw, dowel and bolts. Nailing is the most commonly used method for attaching members in timber construction especially for trusses. With the development of FRP which has many advantages, its application becomes more popular as a strengthening material. In Switzerland, a historic wooden bridge was strengthened using carbon fiber reinforced polymer (CFRP) sheets. In Greece history, mansory and wood structure were upgraded while strong activities on wood strengthening using FRP are going on in Italy [12].

Although research has been done to strengthen timber using FRP, but the comprehensive analysis and design were not clear and established in detail. This is one of the reasons why the application of FRP in timber is very limited [13]. Therefore this research focuses on the application of carbon fiber reinforced polymer (CFRP) sheet to strengthened timber connection. The strength of timber structure will slightly reduce due to long service life or constantly sustained under excessive load. Some of the structure may need to be replaced or rectified. However, as a rule, the rehabilitation of timber structure is more effective than to replace it with new structure due to cost, time and workability. With the advance of technology, many researchers are trying to explore new and efficient alternative to strengthen timber in construction industry. Researches on strengthening timber structure have been carried out in order to maximize the use of timber. FRP is the most potential and suitable material to be use in strengthening timber structure either in construction or for rehabilitation purposes.

This study used the concept of factor of safety in relations to the allowable design strength to 5% offset load and the maximum load as a comparison to prove the reliability of the EYM in predicting the joint for Kelampayan. The similar method was also determined the joint for Kempas for comparison purposes [14]. Harding and Fawkes [15] stated that the 5% offset yield was introduced and became the basis for the description of lateral strength in a single fastener connection. Based on the result present, the curve was linear elastic up to certain value, known as the yield point. After the yield point, or achieving the ultimate load, the line of the graph will become nonlinear which is in plastic range. It is proved that CFRP shall increased about 50% of the load carrying capacity. As reported by Premrov and Dobrila [16], the use of fiber may increased the strength up to 50% and it also reduced the number of crack since FRP is a good material for timber connection.

Therefore, the objective of this study is to develop a technique of strengthening using CFRP pertaining to timber connection in half-lap timber nailed joint. The fundamental properties of CFRP are to increase the strength of timber connection. Previous researches have contributed significantly in encouraging the use of FRP to strengthen the timber structures and also serve as reference for future researchers. However, the number of research in this area for hardwood using tropical timber is very few. Furthermore, the research on half-lap nailed connection in timber strengthened using CFRP sheet is still limited. Therefore, this research will be carried out to identify the tensile performance of CFRP sheet strengthen the half-lap nailed joint for two selected tropical timber species.

European Yield Model (EYM)

The design method for dowel-type fasteners timber connections proposed by Eurocode 5 (EC5) is based on Johansen's yield theory, also known as the European yield model (EYM). The equations based on this theory predict the load-carrying capacity of a single fastener per shear plane loaded perpendicular to its axis, depending on the material properties of the timber, fasteners and the geometry of the connection. For the timber and the connector, a rigid-plastic behaviour is assumed. While this assumption considerably simplifies the analysis, it has a small impact on the final results. Figure 1(a-b) illustrates the failure modes assumed by EYM for single shear dowel type timber-to-timber connections. Figure 1(c) correspond to failure modes where there is only bearing failure in the timber members by embedment and fasteners behave as rigid elements. Figure 1(d-f) represents the failure modes associated with embedding of the timber members combined with plastic hinge, as a consequence of the lower fastener stiffness. In the same way, Figure 1 also shows the failure assumed by EYM for double shear dowel-type timber-to-timber connections. Figure 1(g-h) correspond to failure modes where there is only bearing failure of the timber member by embedment and fasteners behave as a rigid element and Figure 1(j-k) show failure modes where the embedment of the timber members is combined with plastic hinges associated with slender fasteners. Based on the stress distribution shown in those figures and imposing equilibrium, it is possible to quantify the load-carrying capacity associated to each failure mode. The characteristic value of the load-carrying capacity of the joints, per shear plane and per fastener (Fv,Rk), will correspond to the minimum value given by the stress equilibrium and the corresponding failure mode will be the one associated with lower resistance [17].

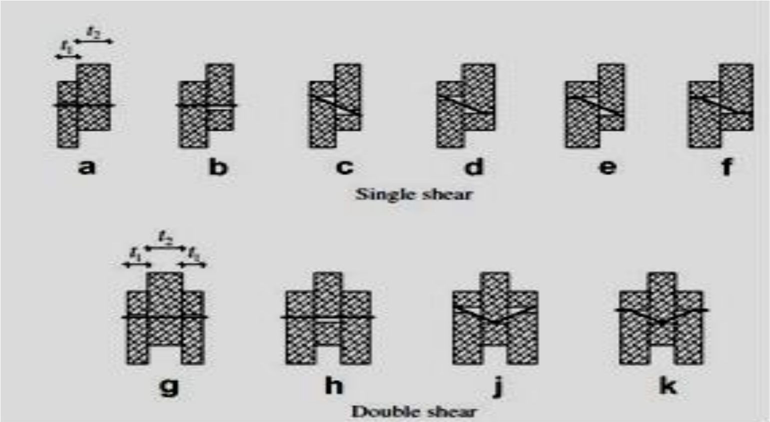

Figure 1: Failure modes assumed by EYM in Eurocode 5, for single and double shear dowel type timber-to-timber connections [17]

Research Methodology

Material Preparation

Figure 2 shows the Kelampayan and Kempas specimens collected from local source. The timbers come from the same batch in order to minimize the influence of the variability in timber properties. Figure 3 shows the timbers being cut into the requested size of the beam which was 41 x 100 x 600 mm.

Figure 2: Kelampayan and Kempas Specimens

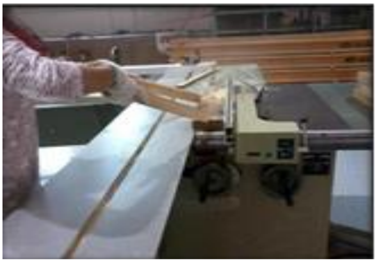

Figure 3: Cutting of specimens

Figure 4 shows the specimens in half-lap joint and Figure 5 shows the specimens were being nailed at the half-lap joint in order to tighten the joint.

Figure 4: Half-lap Joint

Figure 5: Nailed joint

Figure 6 shows the process of gluing the specimens followed by wrapping the specimens with CFRP until it was closely bonded. Figure 7 shows all the specimens were completely wrapped by CFRP, and then they were glued again to ensure that the CFRP was bound closely together with the timber.

Two timber specimens from different species which is Kelampayan and Kempas were used in this research and the tensile test was performed according to the tensile performance or mode of failure. Figure 8 shows the tensile test set up in laboratory. The specimens without CFRP for two types of species were tested to determine the load capacity and the result were used as control. Then, a specimen with CFRP was tested. The Universal Tensile Machine (UTM) was used for tensile test. The specimen was clamped at the extremities of its length and subjected to a tensile load so that in sections between clamps, the tensile force shall be axial. For each test, 1.0mm/min loading rate was applied to each specimen until failure as shown in Figure 9.

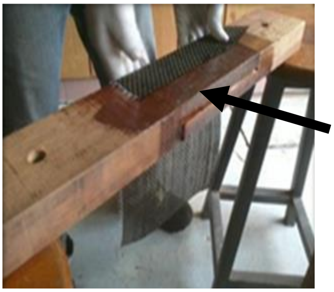

Figure 6: Wrapping of specimens

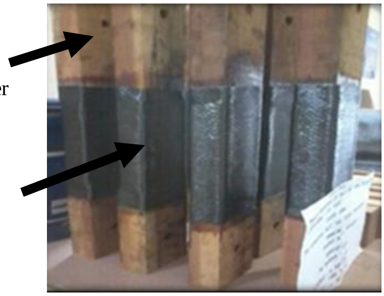

Figure 7: Glued and Wrapped Specimens Completed

Data were recorded in every minute by data recording system. The data recorded are deformation in certain load. The maximum load that the beam sustains before failure occurs as the ultimate tensile load. The data for all the tests were obtained and graph load versus deformation along the specimen were plotted. The result was interpreted and analysed.

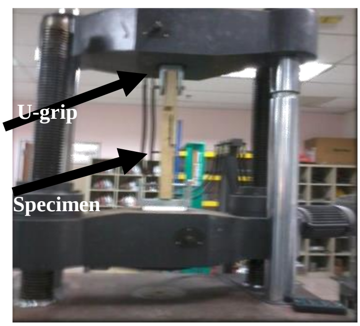

Figure 8: Tensile Test Set up

Figure 9: Specimen After Failure

Result and Discussion

5% Offset Load and Maximum Load With and Without CFRP for Both Species

From the experiment, the results consist of the determination of 5% offset load and maximum load for both with and without CFRP. The results are tabulated in Table 1 and Table 2.

Table 1: 5% Offset Load and Maximum Load For Kelampayan

	5% offset Load, kN		**Maximum Load, kN**	
	Without CFRP	**With CFRP**	**Without CFRP**	**With CFRP**
Specimen (Kelampayan)	6.65	9.98	7.00	10.5
	6.01	13.3	6.33	14.0
	5.70	9.98	6.00	10.5
	4.75	13.9	5.00	13.78
	5.23	11.78	5.50	12.4
	5.13	7.84	5.86	10.68
Average	5.58	11.13	6.33	14

Table 2: 5% Offset Load and Maximum Load For Kempas

	5% offset Load, kN		**Maximum Load, kN**	
	Without CFRP	**With CFRP**	**Without CFRP**	**With CFRP**
Specimen (Kempas)	15.01	23.94	15.8	25.2
	12.7	18.55	13.37	19
	19.19	20.88	20.20	21.98
	18.81	20.9	19.80	22
	11.78	19	12.40	20
	8.55	17.1	9.70	22.45
Average	14.34	20.06	15.80	25

From the tables, for the maximum load for Kelampayan and Kempas without CFRP, the average maximum loads were 6.33 kN and 15.8 kN respectively. Both species had approached the increasing of strength. Comparison between two species shows that Kempas species exhibit higher ultimate load carrying capacity than Kelampayan species. The strength reflected the different strength group of the two species.

As for the maximum load for Kelampayan and Kempas with CFRP, the average maximum loads were 14kN and 25kN respectively. Both species had significantly shown an increment of strength. In comparison between the species, it is shows that Kempas exhibit higher ultimate load carrying capacity than Kelampayan species.

Above all, the average result reported for 5% offset load for both species were lower than the maximum loads as for with and without CFRP. Figure 10 below presented the different pattern of the average maximum load between Kelampayan and Kempas.

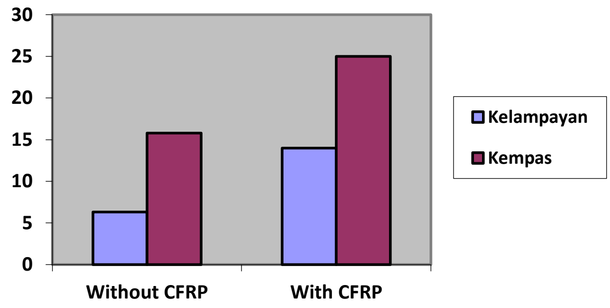

Figure 10: Maximum load without and with CFRP for both species

Based on the analysis, it was found that the utilization of CFRP as strengthened material in timber beam gave the effect to the engineering properties for timber as the maximum load for the specimens strengthened with CFRP increased approximately double compared to the specimens without CFRP strengthening. The result showed that incorporate of CFRP increased the load carrying capacity of the specimens as compared to the specimens without CFRP. On the other hand, Kempas performed better performance in term of strength compared to Kelampayan.

Ultimate Strength Analysis for Kelampayan with and without CFRP

Ultimate tensile strength test for species Kelampayan were analyzed based on Figure 11.

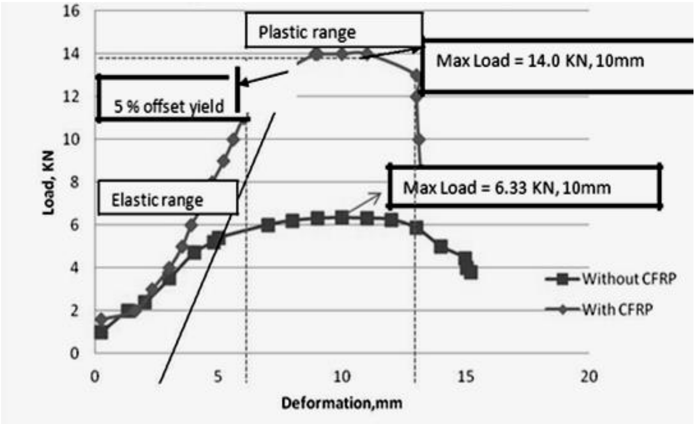

Figure 11. Load-Deformation Curve with and without CFRP

Figure 11 shows the typical load-deformation curve (specimen with and without CFRP) responses for Kelampayan. This figure presented that the maximum load carrying capacities of Kelampayan for with and without CFRP were 14.0 kN and 6.33 kN respectively. From this curve, it was found that both specimens (with and without CFRP) keep increasing or linearly elastic until it reached the ultimate load.

After reaching the ultimate load, the line of the load drops gradually which means that the failures were starting to occur. The specimen with CFRP achieved 14.0 kN compared to the specimen without CFRP which was 6.33 kN only before it starts to fail. Therefore, CFRP was significantly enhanced the strength of the specimens by elevating the ultimate load carrying capacity compared to the specimens without CFRP.

The 5% offset yield was determined where the load-deformation curved is intersected with the line parallel to the linear region with 5% offset diameter of the fastener. The result presented the yield strength of nail timber joints loaded parallel to grain. However, the onset point of yielding in timber is not illustrated in the load-deflection curve. On the other hand, Figure 12 and Figure 13 showed the mode of failure based on EYM for Kelampayan species that was being tested without and with CFRP.

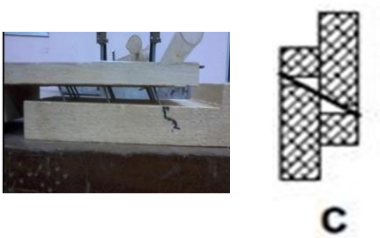

Figure 12: Mode of failure without CFRP

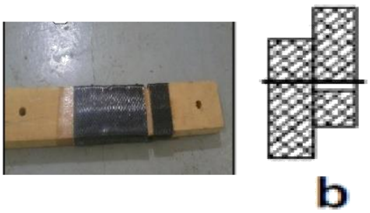

Figure 13: Mode of failure with CFRP

Tensile Test Analysis for Kempas with and without CFRP

Tensile test or ultimate strength test for species Kempas were analyzed based on Figure 14.

Figure 14 exemplified the typical load-deformation curve for Kempas species. This graph illustrated the maximum load carrying capacity for specimen with and without CFRP were 25.0 kN and 15.8 kN respectively. The load carrying capacity incorporate with CFRP has highest value compared to the specimen without CFRP. It is clearly shows that the lines were uniformly increased until it achieved the maximum load and started to fail after the peak loads. The graph started with the linear elastic then after yield point and achieved ultimate load, the lines were drop gradually due to brittle behaviour. When timber is loaded in direct tension, the strain is proportional to stress until it reach the ultimate load. Furthermore, in timber, it only exhibited a small amount of yield before it reaches ultimate load in direct tensile.

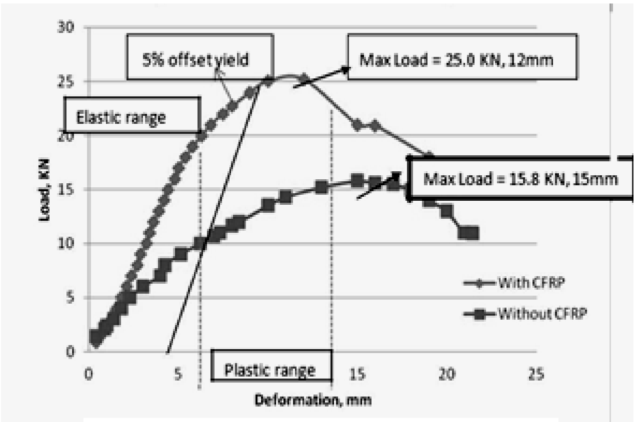

Figure 14: Load- Deformation curve

From the analysis, it was significantly proven that the load carrying capacities were increased once strengthened by the CFRP sheet. It helps to enhance the strength of the connection. Therefore, the use of high fiber and carbon fiber reinforced polymer for timber connection is significant in improving the timber connection. Figure 15 and Figure16 showed the mode of failure based on EYM for Kelampayan species that was being tested without and with CFRP.

Figure 15: Mode of failure without CFRP

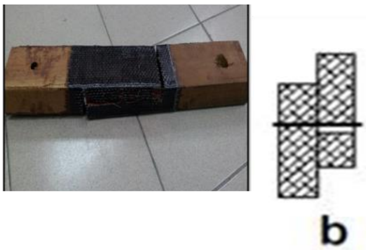

Figure 16: Mode of failure with CFRP

As for the conclusion, the maximum load carrying capacity for without and with CFRP for Kelampayan were 6.33 kN and 14.0 kN and 5% offset load were 5.58 kN and 11.13 kN respectively. Overall, the 5% offset load strength was increased by 121%. The maximum load carrying capacity for without and with CFRP for Kempas were 15.8 kN and 25.0 kN and 5% offset load were 14.34 kN and 20.06 kN respectively. The strength of maximum capacity was increased by 58.2%. The performance of failure behaviour based on EYM for both species was increased. Both Kelampayan and Kempas specimens without CFRP failed in mode c whereas for specimens with CFRP, failed in mode b.

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