Jurnal
Teknologi

Full Paper

TENSILE BEHAVIOR OF BOLTED TIMBER COMPOSITE HALF-LAP CONNECTION FOR KERUING AND SESENDOK

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Article history
Received
22 June 2015
Received in revised form
23 September 2015
Accepted
24 December 2015

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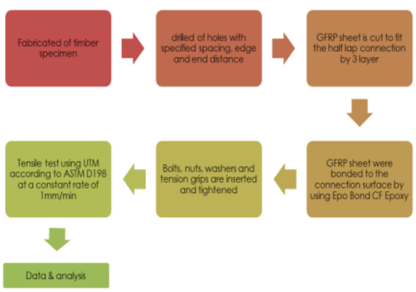
Graphical abstract



Abstract

Over recent years, half-lap connection is widely used all over the world to provide longer structural member due to limited size of sawn timber in construction industries. Timber connected in joints may reduce overall mechanical properties of the structure. This paper present finding on a series of connection of half lap bolted joint member from Keruing (SG5) and Sesendok (SG7) timber species. The half-lap connection were subjected to tensile test and reinforced with GFRP sheet that were conducted until failure to determine their tensile behavior. The results showed that the GFRP help to increase the load carrying capacity of all the timber specimens especially timber species that lies in a weak strength group for almost 30 % by strength.

Keywords: Half-lap joint, GFRP, tensile strength, EYM

1.0 INTRODUCTION

Traditionally, timber has been used as structural members in building construction and it continuously being used up till today even though the use of steel and concrete are quite popular these days. The wide use of timber in structural applications continues today due to the benefits it presents in terms of cost, availability and strength ratio. Malaysian timber species have been categorized into seven (7) strength group (SG) that is SG1 to SG7. Based on MS 544: Part 2: 2001, the load carrying capacity of each timber species represented by their strength group. Timber species in SG5 has higher strength as compared to timber species in SG7.

However, supplying for quality structural timber has been declining. As a result, solid timber beams with bigger size are hard to obtain and limited size of sawn timber can be used in construction industries. Therefore, need of efficiently use the resource and lots of opportunities exists for strengthening of timber members. Connection system in timber is important in order to combine or connect several numbers of timber members, commonly due to the limitation for timber sizes which requires connection. Strengthening of the timber is crucial particularly in connection systems as failure arises normally at connection region. Therefore, it is utmost important to have understanding of characteristics and behavior of timber connection. Thus, this study reported on the tensile behavior of half-lap connection unreinforced and reinforced with GFRP sheet.

In Malaysia, there were few research published in timber engineering especially timber strengthening [1-2]. Timber strengthening using FRP is rarely used because of lack of technical knowledge in the material. In addition, the cost of FRP is considered as high because there are very few companies producing and supplying FPR locally. However, increasing cost of steel makes the use of FRP as construction material more widening. Fiorelli [3] had done a research to evaluate the structural behavior of timber beams strengthened with FRP. The research was focused on the experimental and theoretical analysis of timber beams of the species PinusCaribeaHondurensis which were reinforced with GFRP and CFRP fabrics. The results showed that the flexural stiffness (EI) determined experimentally was greater than the theoretical values. These values are in favor of structural safety. It shows that the increase of stiffness varied from 15% to 29% for beams strengthened with glass and carbon fabric. Dagher [4] had studied on the use of GFRP tendons for timber bridge decks made by treated Eastern Hemlock lamination. After 4.25 years of monitoring, the GFRP tendons have maintained an adequate pre-stress level without having to be re-stressed. Generally, based on all previous research, it shows that FRP was a good material to be used. Thus, this study had been conducted in order to investigate and analyze the performance of selected timber species that reinforced with GFRP sheet for bolted connection.

In the issue of ability, European Yield Model (EYM) is an effective method to identify and categorized the several possible modes of failure for timber connections through double shear strength test [1]. Johansen [5] developed EYM and it has been used universally as the engineering approach in connection design and Larsen [6] had discovered more on the robustness of EYM in evaluating the load-carrying capacity of timber connections. Later, EYM has been used to identify the behavior of nailed joints but with some modifications [7] and bolted timber joints [8-10] or both [11-12]. Some researchers also explored and evaluated more on the timber connections which has been strengthened using wood dowels [13-14]. Since this study is using bolt, thus this EYM model is based on an equilibrium equation for the plastic straining resulting from the free body diagram of bolt in timber connection. All the theories are based on the ductile behavior of timber and bolt in the connection. The timber was predicted to be failed by full bearing and overwhelming in tensile when resisting the load applied by the bolt. In addition, the bolt is assumed to be bending and probably yield, while creating a number of plastic hinges depend on the number shear planes or the number of connection. The strength for various connection geometries and material combinations for two and three-member connections can be predicted or accessed by using EYM (BS EN 1995-1-1: 2004 + Al: 2008). In EYM's approach, the highest capacity of timber joints are taken to be the loads at which either the embedment strength or bearing failure or both occurred for the first time. The several possible modes of failure for timber connections were shown in Figure 1.

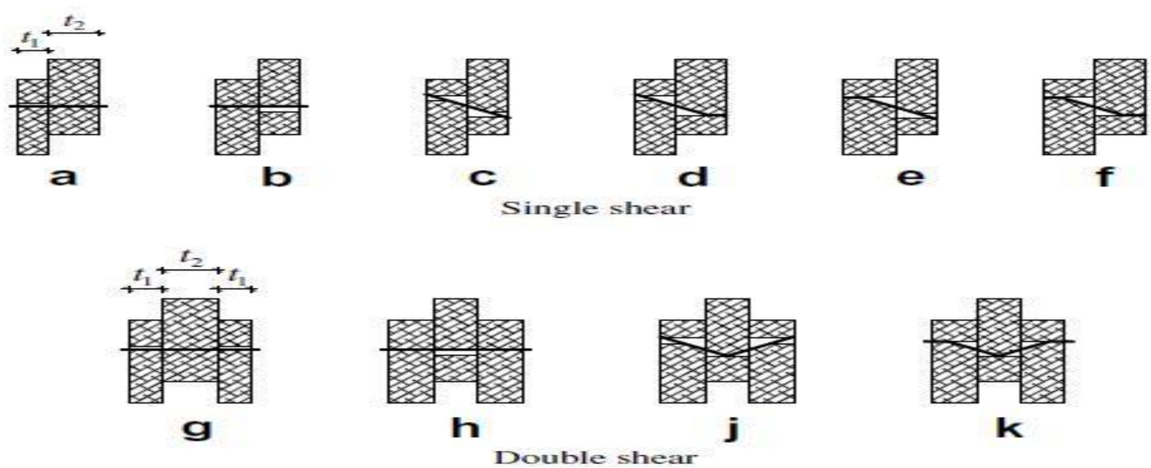


Figure 1 Failure modes assumed by EYM for single and double shear dowel type timber-to-timber connections (BS EN 1995)

2.0 EXPERIMENTAL

2.1 Tensile Test Setup

This study is conducted by experimental test on the composite connection where the composite materials were reinforced with GFRP sheet and solid timber as the main member and fastened by steel bolt. Both timber size and bolt arrangement were designed based on Malaysian Standard (MS544: Part 5: 2001). The samples consist of Keruing (SG5) and Sesendok (SG7) timber species. In order to determine the effect of GFRP sheet on the timber connection, the specimens were fabricated in the form of half-lap joint as shown in Figure 2.

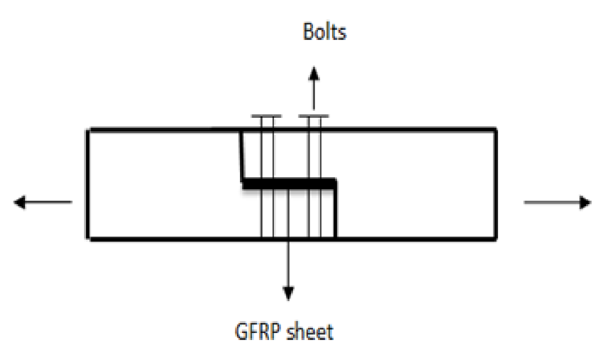


Figure 2 Half-lap connections

Twenty (20) specimens were being fabricated with dimension of 100 x 41 x 392 mm each. Then, forty (40) bolts with 10 mm diameter and convenient length were prepared as fastener. Five (5) specimens were bolted and glued with 3 layer of GFRP sheet and the other five (5) specimens were bolted and glued without GFRP sheet for each timber species. Tensile test was conducted using Universal Testing Machine (UTM) UTS-348 as shown in Figure 3. The applied load was at a constant rate (1.0mm/min) using 1000 kN capacity. The physical properties tests were conducted for each sample. The test was followed by the determination of specific gravity, moisture contents and density of the timber sample.

Figure 3 Tensile test set up by using UTM

3.0 RESULTS AND DISCUSSIONS

From the experimental work, all the connection specimens were found failed at the grip. The results obtained were not fully represents the strength of the connection since it failed at the grip. This finding is considered as preliminary work on the connection unreinforced and reinforced with GFRP sheet.

3.1 Load Carrying Capacity of Tensile Analysis

The results obtained consist of Keruing (SG5) and Sesendok (SG7) timber bolted connection unreinforced and reinforced with GFRP sheet. The summary of the tabulated data for specimens of connection unreinforced and reinforced with GFRP sheet is shown in Table 1 and 2 respectively.

Table 1 Ultimate load and displacement of Keruing and Sesendok connection unreinforced without GFRP sheet

Species	Keruing		Sesendok	
	Ultimate load (kN)	Displacement (mm)	Ultimate load (kN)	Displacement (mm)
1	22.24	22.50	10.65	12.30
2	21.73	8.30	10.13	22.10
3	24.61	15.50	10.40	17.80
4	23.80	13.10	11.23	19.80
5	27.76	15.50	13.82	27.80
Average	24.03	14.98	11.25	19.86
Standard Deviation	2.14	4.59	1.24	5.09
Coefficient of Variance (%)	9	31	11	26

Table 2 Ultimate load and displacement of Keruing and Sesendok connection reinforced with GFRP sheet

Species	Keruing		Sesendok	
	Ultimate load (kN)	**Displacement (mm)**	**Ultimate load (kN)**	**Displacement (mm)**
1	39.86	14.4	13.87	18.1
2	28.95	13.7	18.98	8.2
3	27.22	19.8	11.39	4.1
4	25.07	8.8	18.49	10.0
5	34.88	15.9	17.49	9.0
Average	31.20	14.52	16.04	7.83
Standard Deviation	5.42	3.55	2.94	5.01
Coefficient of Variance	17	24	18	64

Table 1 summarized the results of ultimate load and maximum displacement for Keruing and Sesendok for unreinforced connection. Whereas, Table 2 showed the results of ultimate load and maximum displacement for Keruing and Sesendok reinforced with GFRP sheet. From the tables, for the average ultimate load for Keruing and Sesendok unreinforced with GFRP, the average ultimate loads were 24.03 kN and 11.25 kN respectively. The average ultimate load for Keruing and Sesendok reinforced with GFRP were 31.20 kN and 16.04kN respectively. Comparison between two species showed that Keruing species exhibited higher load carrying capacity compared to Sesendok species. It does show that the finding was inclined to the strength group of the species accordingly. Figure 4 presented the average ultimate load for Keruing and Sesendok for unreinforced and reinforced with GFRP.

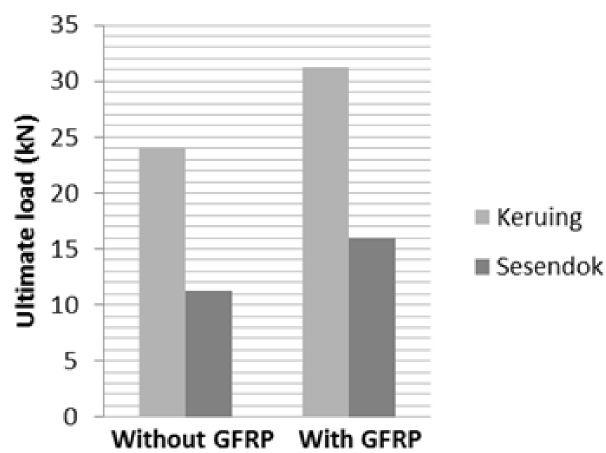


Figure 4 Ultimate loads for unreinforced and reinforced with GFRP for each species

Based on the analysis, it was found that the utilization of GFRP as strengthened material in timber specimens gave beneficial contribution towards engineering properties. The ultimate loads for the specimens reinforced with GFRP sheet slightly higher compared to the specimens unreinforced with GFRP sheet. The result showed that the incorporate of GFRP increased the load carrying capacity of the specimens compared to the specimens unreinforced with GFRP. Overall, Keruing performed better in term of strength compared to Sesendok.

3.2 Behavior analysis

Tensile test were analyzed and the pattern behavior of the results for species Keruing and Sesendok are presented in Figure 5 and 6 respectively.

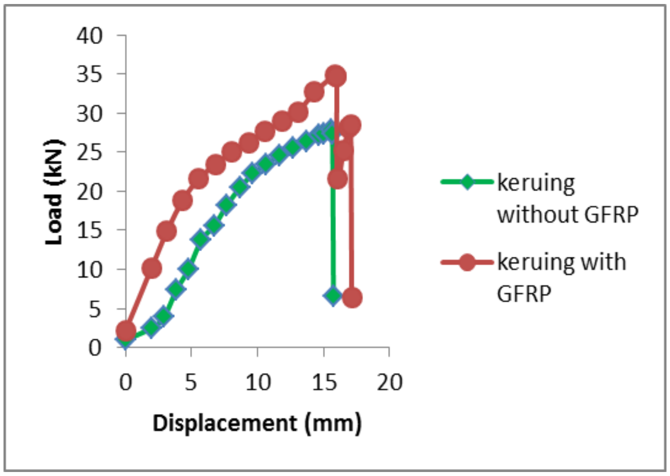


Figure 5 Load-Displacement curve for Keruing connection unreinforced and reinforced with GFRP

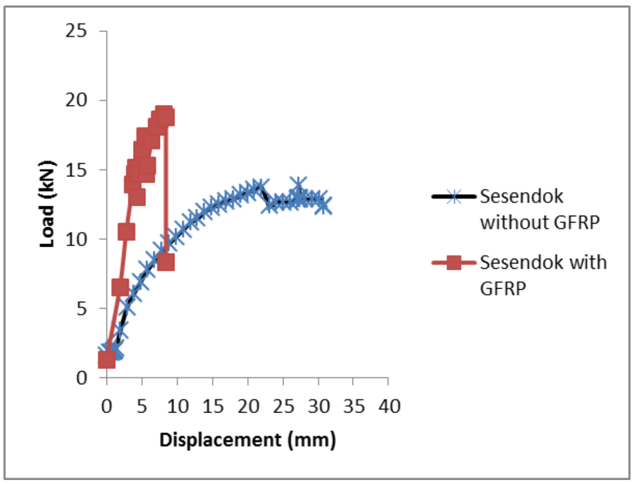


Figure 6 Load-Displacement curve for Sesendok connection unreinforced without GFRP and reinforced with GFRP

Figure 5 shows the load versus displacement pattern for Keruing connection unreinforced and reinforced with GFRP sheet whereas Figure 6 shows the load versus displacement pattern for Sesendok connection unreinforced and reinforced with GFRP sheet. From both (Keruing and Sesendok) graphs, it clearly shows that the specimens of connection reinforced with GFRP sheet exhibited higher loads and small displacement compared to the specimens of connection unreinforced with GFRP sheet. For both species, the load for specimens of connection unreinforced and reinforced with GFRP sheet are keep increasing until it reach their maximum load at specific displacement. After reaching the maximum load, the line of the load drops gradually which means that the failures were started to occur. GFRP is helping the specimens to increase their strength by increasing the load and reducing the values of the displacement.

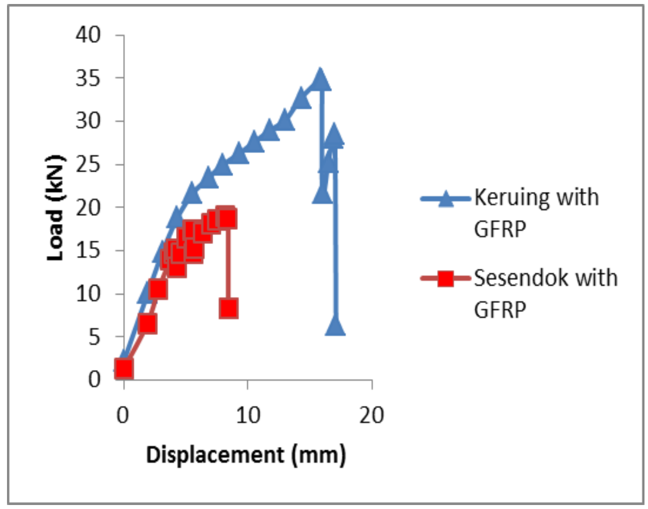


Figure 7 Load-Displacement curves for Keruing and Sesendok connection reinforced with GFRP

Figure 7 illustrates the load versus displacement relationship between Keruing species and Sesendok species connection reinforced with GFRP sheet. Keruing exhibits higher load as compared to Sesendok. This can be explained by the different strength group of each species. Keruing lies in strength group 5 whereas Sesendok lies in strength group 7 which means that Keruing is stronger and more ductile in term of strength compared to Sesendok which is weak and more brittle. However, Sesendok also shows increment in term of strength when being reinforced with GFRP. Thus, GFRP also helps to improve the strength of timber species that lies in weak strength group.

3.3 Yield Mode on Half-Lap Connection Unreinforced and Reinforced eith GFRP Sheet

There were several possible failure modes that can be experienced by the specimens. The summary of the yield modes for the specimens were tabulated in the Table 3 and 4.

Table 3 Yield mode of Keruing connection unreinforced and reinforced with GFRP

Species	Specimen	Yield mode
Keruing	SG5 1	C
	SG5 2	C
	SG5 3	C
	SG5 4	C
	SG5 5	C
Keruing + GFRP	SG5 + GFRP 1	None
	SG5 + GFRP 2	None (Splitting of member)
	SG5 + GFRP 3	None (Splitting of tension grip)
	SG5 + GFRP 4	None (Tearing of member)
	SG5 + GFRP 5	None (Splitting of member)

Table 4 Yield mode of Sesendok connection unreinforced and reinforced with GFRP

Species	Specimen	Yield mode
Sesendok	SG7 1	C
	SG7 2	C
	SG7 3	C
	SG7 4	C
	SG7 5	C
Sesendok + GFRP	SG7 + GFRP 1	None (Shearing of tension grip)
	SG7 + GFRP 2	None (Shearing of tension grip)
	SG7 + GFRP 3	None (Shearing of tension grip)
	SG7 + GFRP 4	None (Shearing of tension grip)
	SG7 + GFRP 5	None (Shearing of tension grip)

Table 3 and 4 showed that the connection of Keruing and Sesendok unreinforced without GFRP had experienced yield mode of type C as shown in Figure 8. The fasteners experienced rigid rotation in shear plane where it increased the tendency of bolt to bend permanently.

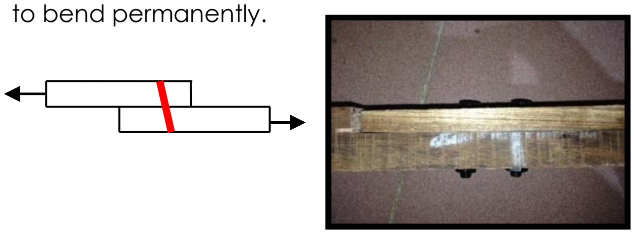


Figure 8 Yield mode C

The specimens of Keruing and Sesendok reinforced with GFRP had experienced yield mode of type B where the fasteners did not bent. However, each specimen had different description based on the physical observation of the specimen after testing such as splitting and tearing of members as well as splitting at the tension grip. Figure 9 showed the illustration of yield mode B. Whereas, Figure 10 showed the image of the physical observation after testing like shearing, tearing and splitting.

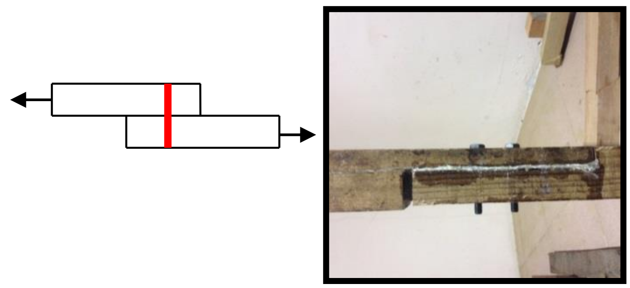


Figure 9 Yield mode B

(a) (b) (c)

Figure 10 (a) Splitting (b) Shearing (c) Tearing

From the test, the average moisture content (BS EN 322:1993) lies in the range of suitable moisture content for five (5) samples of Keruing was 13.03 % and for Sesendok was 13.15 %. While, the average density of Keruing (SG5) was 874.8 kg/m3 and for Sesendok (SG7) was 413.52 kg/m3.

4.0 CONCLUSION

As a conclusion, the GFRP sheet added as reinforcement at the half-lap connection help to increase the load-carrying capacity of the specimens. Sesendok seems to perform better as the strength increased by approximately 30 % compared to Keruing which was increased 23 %. Therefore, GFRP sheet is recommended to use as additional reinforcement especially for low strength group species.

Acknowledgement

Authors express utmost gratitude to RAGS grant: 600-RMI/RAGS 5/3 (61/2013), Research Management Centre (RMC), Universiti Teknologi MARA Selangor for financial support.

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