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Research paper

Tensile Resistance of GFRP Wrapped Steel-Dowelled Half-Lap Timber Connection

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Abstract

Generally, the use of timber mainly focuses on simple structures or structures that can take small loads. This paper report on tensile resistance of steel dowelled timber connection wrapped with glass fibre reinforced polymer (GFRP). It involved experimental work in laboratory designed to determine the tensile strength behaviour for half-lap timber connections with steel dowel as the mechanical fasteners. Bintangor species representing strength group 5 and Yellow Meranti species representing strength group 6 were tested in the conditions of with and without the GFRP wrapping. The performances of the connections were observed using the European Yield Model (EYM) as the guideline. The EYM theory is generally used to determine the load carrying capacity of timber-to-timber, panel-to-timber and steel-to-timber connections, reflecting all possible modes of failures. All half-lap connection members were tested at the rate 0.0006 mm/min using the universal testing machine. As a result, it was found that the steel-dowelled half-lap timber connection with GFRP wrapping performed better than the timber connection without the wrapping. The ultimate load of GFRP wrapped connections made of Bintangor and Yellow Meranti species were found increased at 17% and 44% higher compared to the connection without the GFRP wrapping accordingly.

Keywords: *Bintagor; Yellow Meranti; ultimate load; timber connection.*

1. Introduction

Behaviour of tensile resistance especially for composite timber connections constitutes as one of the most important matters in designing timber connections. Timber connections have been widely used in timber structures mostly as wood trusses. As stated by Xu *et al.* [1], tension and compression in timber is dissymmetric strengths, the behaviour in the joints is not only controlled by the load-carrying capacity of the individual fastener but it also depends on the form of the joint itself and the interaction of the fasteners. This relation influences the stress distribution in the joint portion. However, the problems that may occur in composite timber connection are due to termites or any other defects. Not many selections can be made once the timber members lost its strength or function; it is either by replacing the total members or rectifying the defects. Therefore, this study proposed a method of rectification by using GFRP sheet as a wrapping material to steel-dowelled timber connection. This method is efficient in avoiding modification of the whole structures in circumstances of only a particular timber member or connection of the existing building facing any defect or in need of rectification. This study shall also enhance the understanding on the performance and effectiveness of GFRP as a strengthening material. On the other hand provide a new rectification alternative for the timber connection system.

1.1. Timber Connections

Timber is an ideal material and widely used in construction as components consist of strength to weight ratio compared to concrete and steel. In particular, in term of its structural attributes and environmental efficiency include reducing pollution. There are several advantages of timber such as easy to work and fix and very convenient for end users. Connections are often considered as the critical point of timber structures and connection were transfer load from top to the bottom plate which is from member to other member [2]. Timber connection behaviour is very sensitive with variations in moisture conditions. Other factors affecting the timber connection are specific gravity, density and mechanical properties. Mechanical fastener such as steel dowel is one type of the timber connection. Steel dowels connections produced better connections appearances compare to the bolted connections and also even harder in strength [3]. Hassan *et al.* [4] studied on the shear performances of tropical wood species on the mortice and tenon connections. They reported that the shear strength capacity of joint dowelled with steel is higher than wood dowelled. Guan and Masafumi [5] stated that there are several factors will affect the load carrying capacity of a fastener. The factors are such as the end distance, embedding and shear strengths of the timber and the reinforcement and also geometrical dimensions of the timber component, reinforcement and the fastener itself. There are several factors that can affect the strength of timber included its species, defects and growth rate. The valuation of these factors gives a piece of timber a specific

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grade which is related to its ultimate strength, that being a proportion of its yield strength or breaking strength [6]. According to the widely accepted design rules, the calculation of mechanical timber connections is based upon Johansen's theory, which is known as the European Yield Model (EYM). Dorn et al. [7] have studied the research from Johansen [8] mentioned that the EYM only predicts the ultimate loads associated with ductile failure modes and brittle failure modes for which shearing out and splitting perpendicular to grain are not foreseen. This is because the EYM does not allow modelling of brittle failure modes, design codes prescribe empiric minimum dimensions for connections. Gentile et al. [9] have studied the flexural behaviour of timber beams connected with GFRP dowels. They found that the flexural strength increased by 18% to 46% by using the proposed testing technique changed the failure mode from brittle to ductile compression failure. Similar significant finding is also reported by Yusof and Saleh [10]. They stated that timber beam strengthened with GFRP rods had an increase in its ultimate load carrying capacity. The percentage of strength increment is between 20% to 30% in range. The ductility of wood pieces glued using spikes of fiberglass rods will be improved respectively [11].

1.2 European Yield Model (EYM)

The EYM can predict yield strengths for various connection geometries and material combinations for two- and three-member connections. From Figure 1, failure modes from a to c represents the bearing failure in the timber members by embedment and fasteners behave as rigid elements. While, from d to f shows the failure modes associated with embedding of the timber members combined with plastic hinge, as a consequence of the lower fastener stiffness. For double shear, g and h shows the failure modes where there is only bearing failure of the timber member by embedment and fasteners behave as a rigid element while j and k show failure modes where the embedment of the timber members is combined with plastic hinges associated with slender fasteners [12]. The failure mode of the connection is able to forecast with reliability by using the European Yield Model, used in Eurocode 5 [13].

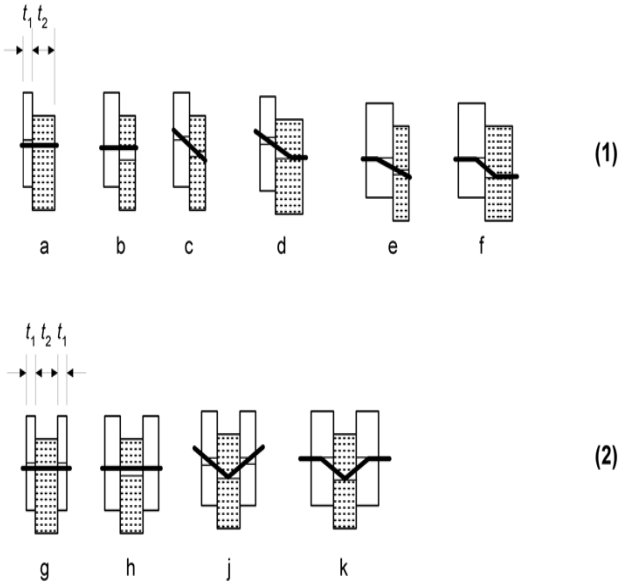


Fig 1: Failure modes for timber and panel connections (1) Single Shear (2) Double Shear [14].

[1] On the other hands, Harding and Fowkes [15] mentioned that the load deformation curve need to be offset a distance 5% of the fasteners diameter from the origin of the load deformation curve which is the intersection of the load deformation curve with a straight line parallel to the initial portion. Recent used of FRP is reported by Nolan and Padilla [16]. The application is for strengthening concrete bridges. They advised that due to its inelastic behavior and the emerging findings from ongoing research, current applicable design codes significantly reduce the allowable stress capacity that can be assumed when designing with FRP. Engineers must take into consideration the more stringent reduction factors in the applicable codes when designing with FRP reinforcing.

2. Methodology

The main aim of this study is to determine the tensile resistance of half-lap timber connections fastened using steel dowel with and without GFRP wrapping. In this experiment, Bintangor and Yellow Meranti timber species were selected. Five (5) numbers of timber connections fastened with three (3) numbers of steel dowels with 12mm in diameter each were prepared. The samples were then tested using universal testing machine as in Figure 2 to determine the tensile results. The tests were done at the rate 0.0006 mm/ min. From this experiment, the physical strength properties such as the moisture content, density and the specific gravity of timber species were also analysed.



Fig 2: Connection under tensile load.

Results of comparison of with and without the GFRP wrapping half-lap timber connections between Bintangor and Yellow Meranti species are reported in the following sections.

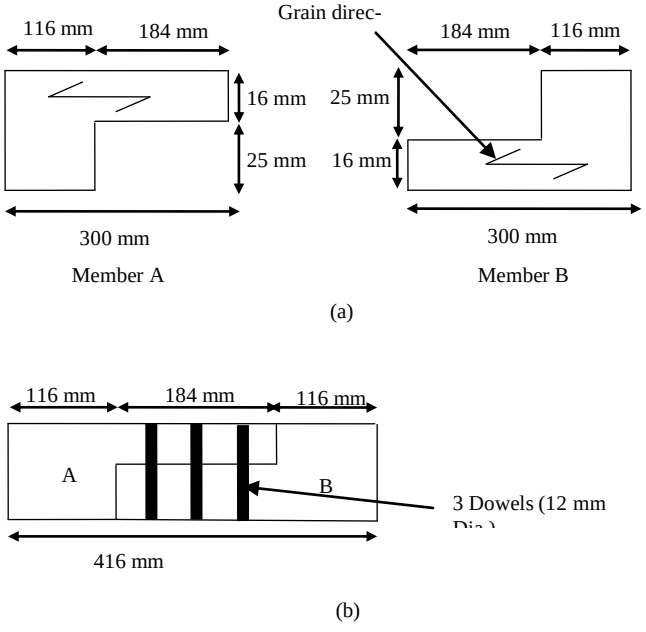


Fig. 3: (a) Details of timber dimensions (b). Configuration of dowels.

3. Results and Discussions

Results of comparison of with and without the GFRP wrapping half-lap timber connections between Bintangor and Yellow Meranti species are reported in the following sections.

3.1. Tensile Test for Half-Lap Steel-Dowelled Timber Connection without GFRP Wrapping

The load carrying capacity of steel-dowelled half-lap timber connections without GFRP wrapping for 5 Bintangor specimens are summarized in Table 1.

Table 1: Average Load carrying capacity for Bintangor and Yellow Meranti without and with GFRP.

Species	Description	$P_{5\%}$ (kN)	Pmax (kN)	Displacement (mm)
		Average		
Bintangor	Without GFRP	13.3	20.9	22.8
	With GFRP	11.3	25.2	28.1
Yellow Meranti	Without GFRP	7.6	12.9	20.8
	With GFRP	10.3	23.0	32.0

From the experiments, for the connection without the GFRP wrapping, it was found that the average value 5% offset of yield and ultimate tensile strength for Bintangor is 13.3kN and 20.9kN respectively. Bintangor timber connections can withstand in average of 22.8mm displacement. While for the Yellow Meranti the average 5% offset of yield and ultimate tensile strength for Yellow Meranti is 7.6kN and 12.9kN respectively. Yellow Meranti timber connections can withstand an average of 20.8mm displacement.

It is found that Bintangor species is 29% stronger compared to the Yellow Meranti species. This result reflected to the strength group of the selected timber species, which the lower strength group shows a stronger capacity of timber species. This performance is expected since Bintangor from strength group 5 is stronger than Yellow Meranti from strength group 6.

For the connection with the GFRP wrap, the average of 5% offset load and ultimate tensile strength for 5 Bintangor specimens is 11.3kN and 25.2kN, respectively. The specimens were displaced at an average of 28.1mm (Table 1). While for Yellow Meranti, the average 5% offset load and ultimate tensile strength is 10.3kN and 23kN respectively. The ultimate tensile strengths are in the range of 20.9kN to 26.2kN. The connections can withstand an average of 32mm displacement.

The load-displacement pattern of failure for the connection without and with the GFRP wrapping between Bintangor and Yellow Meranti is shows in Figure 4 and 5 accordingly.

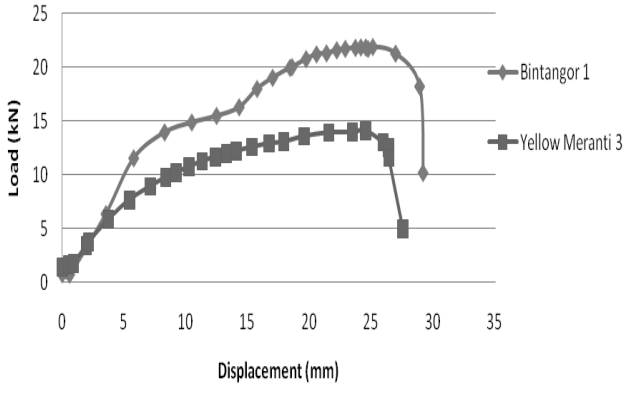


Fig 4: Comparison between Bintangor and Yellow Meranti timber connection without GFRP Wrapping.

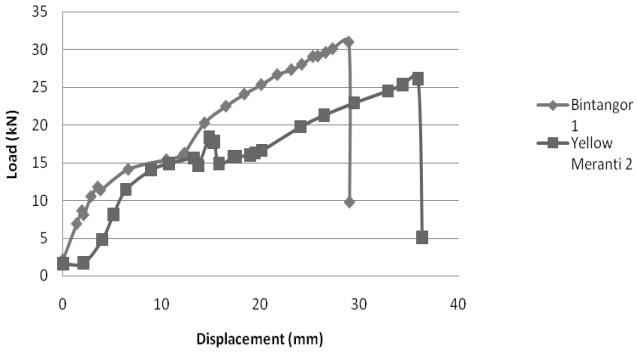


Fig 5: Comparison between Bintangor and Yellow Meranti half-lap timber connection with GFRP Wrapping.

Both connection showing brittle failures compared to ductile failure modes occur for both connections of without the GFRP wrapping (Figure 4). It is found that Bintangor half-lap timber connection is 8.7% stronger compared to the Yellow Meranti half-lap timber connection. Figure 6 shows that timber connection from both species with GFRP wrapping contributes to a higher load carrying capacity compared to the timber connection without GFRP wrapping.

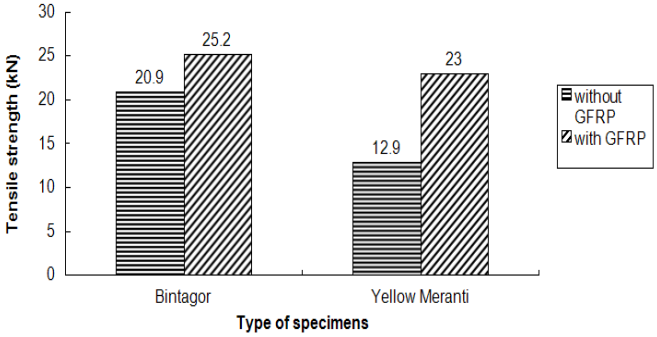


Fig 6: Comparison between Bintangor and Yellow Meranti timber connection with and without GFRP wrapping.

Bintangor and Yellow Meranti were found having an increment of 17% and 34% of strength respectively when wrapped with the GFRP sheet. Therefore, this finding shows that having GFRP as the strengthening material has significantly contributes to a higher strength of half-lap steel dowelled timber connection.

3.2. Failure Modes Comparison of Connections with and without GFRP Wrapping using EYM

In this study, the mode of failure was analyzed based on EYM (EC5, 2004) guideline.

The mode of failure for Bintangor and Yellow Meranti without GFRP wrapping experienced single shear failure with mode c (1(c)). During the test, it was observed that the steel dowels rotated once the maximum load was achieved, followed by decreasing of strength and reached its fracture in ductile manner. The locations of failure for all specimens are similar which occurs at the joint of the timber connections.

The mode of failures for timber connection with GFRP wrapping shows different pattern of failure where Bintangor fails in mode b. Mode b failure is a bearing failure underneath the steel dowel compressed area of Bintangor wood member. This also means the steel dowel remain its original condition after the connection fractured. The pattern of failure also shows that the fracture is due to the failure of the GFRP sheet through the brittle mode of failure. The extra load sustained higher compared to the connection without the wrapping is also shown that GFRP sheet has lengthen the displacement and increases the overall strength of the wrapped connections. It shows that the strength of GFRP sheet that preserved the timber connection and allow to sustain extra load. For Yellow Meranti connection with GFRP

wrapping, the failure is mode c and all specimens failed at the joint of the connection. For all timber connections for with and wihout GFRP wrapping, the total fracture occurs with an audible cracking. This characteristic has made timber a suitable construction material that shows sign prior to failure.

4. Conclusions

The main aim of this research is to study the tensile resistance composite timber connection fastened using steel dowel with and without GFRP wrapper. The followings are the conclusion of this research:-

1) The average ultimate tensile strength for Bintangor and Yellow Meranti without GFRP wrapper is 20.9kN and 12.9kN respectively. Bintangor is 38.3% stronger than Yellow Meranti for without GFRP. From the tensile test shows the Yellow Meranti without GFRP failed earlier than Bintangor.
2) The average ultimate tensile strength for Bintangor and Yellow Meranti with GFRP wrapper is 25.2kN and 23.0kN respectively. Load carrying capacity of Bintangor is by increased by 8.7% than Yellow Meranti for the timber connections with GFRP.
3) Bintangor without GFRP and Yellow Meranti without GFRP wrapper were at failure mode 1(c). The location fails at the joint of the connection. While, Bintangor with GFRP and Yellow Meranti with GFRP wrapper were at failure modes 1(b) and 1(c) respectively. Therefore, GFRP is suitable material for rectifying work in order to strengthen the timber connection. It can be enhanced the load carrying capacity of timber connection and the performance of the timber connection can be improved. From the result, Bintangor was tougher than Yellow Meranti species.

5. Recommendations

The following are the recommendations for improvement and further study related to this research: -

a) Extended on retrofitting works by using GFRP, CFRP and other types of composite material.
b) More research regarding other connection as their fastener.
c) The scope of this study was limited to dry timber only where the moisture content was maintained to be below 19%. It is suggested that this research should be extended to timber structures exposed to wet conditions.

It is very important to extend or repeat the study to other timber species either among the same group (SG6) or other strength group. The behavior of hardwood, medium wood and softwood is different.

6. Acknowledgement

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