Double Shear Load Carrying Capacity of Kempas and GFRP Dowelled Connections

P.E.H Ab. Rahman, N. J. Abd.Malek, R. Hassan

Abstract**: *Glass fibre reinforcement polymers (GFRP) application for reinforcement of wood, concrete and steel member is relatively becoming more variety in construction applications. Although it is possible to build large monolithic structures with composite materials, there are still several reasons for the structure to fail. One of the main reasons that contribute to this failure is the connection performance due to its function in carrying load across the structure. Thus having the right fundamental data for connection design purposes according to the specific and technological upgraded materials is very important. One of the basic methodologies in gaining the design data is through experimental double shear test which can be verified by European Yield Model (EYM) theory. Therefore, the objective of this research is to determine the load carrying capacity of double shear strength behaviour connections made of Kempas timber species as the main member and dowelled by the GFRP or the Kempas rod. The specimens were tested under the shear load with 2mm/min rate and tested until failure. From the experiment, it was found that the average ultimate shear strength of member dowelled with GFRP rod is 21.36% higher compared to one doweled with Kempas rod. According to mode of failure between two types of bolt, GFRP dowelled performs well (Mode I& IV) rather than Kempas dowelled (Mode IV).***

Keywords **: *Double Shear, Timber Dowelled,Kempas, GFRP.***

I. INTRODUCTION

Connections are used to transfer load from one element to another structural element. Improper design of connection may cause to structural failure. Common application of engineering connection is to join members together such as in trusses and lattice girders, stiffeners and plate girder to form built-up members, beam to beam, column to column, bracing, beam to column, column splices and others. According to BS 5950-1:2000, connection can be described as position where the member is attached to the supporting member or to other supports, including bolts, welds, other fastener materials used for load transfer. Connection should be design according to the loads that the connection will carry during their service life.

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For the pass new decades, the use of glass fibre reinforced polymer (GFRP) as a construction material, conventional materials such as concrete, steel and timber were not intended to be replaced or compared. The usage is as reinforcing method to strengthen the connection capacity. Chew et. al. stated that GFRP is suitable for rectify and strengthen timber connection. It also could upgrade the performance of connection. [1]. The use of GFRP in structure engineering applications has been rather limited compare to the use of steel and concrete[2]. In fact, there are some attractive and special features of GFRP which have lower specific gravities, higher strength, resilience, resistance to marine environment, capability to resist low temperatures, flexibility over a wide range of temperatures, high internal damping that could lead to better absorption of vibration energy and electrical transparency of the materials.

In ensuring the increment of load capacity of a connection and their structural elements, timber structures that require repairs need reinforcement to render variety of applications and situations. In recent years, much attention has been focused on new developed materials for reinforcement and structural recovery, and many researchers were dedicated to apply fibre reinforced polymer (FRP) as the alternatives. This material has high strength, low weight, corrosion resistance and electromagnetic neutrality making FRP an appropriate alternative material for many structural applications, including the restoration and reinforcement of new wood products Triantafillou & Deskovic (1992) develop a technique for stabilizing members of timber with external FRP sheets that bind to their stress zones. An empirical model that establishes a relationship between timber stress and strain is established in this report. This model takes into account wood under elastic-linear tensile and elastic-plastic compression. The fiber is known as a linear elastic material [3]. Hay et. al.'s research shows that GFRP sheets are better that vertical sheets used in the test [4]. The field assembly of structural timber members is most easily and economically accomplished by bolting compare to GFRP as fastener. However, with the disadvantages as corrosive and heavier in weight for the bolts has given an opportunity to GFRP to be further studied as an alternative connector for timbers. GFRP has been widely used in various industries because low cost compare to aramid and carbon. At the same time, the advantages of GFRP are high tensile strength, high chemical resistance and excellent electrical insulating properties. Additional advantage of GFRP is a good dimensional stability and ease to fabricate. GFRP reinforced polymers are widely used in the chemical and marine industries applications because of its advantages, which often have superior resistance to environmental attack [5].

In this research, a theory is believed to have been proposed by [6] that includes non-linear compression behaviour and brittle tension of wood.

II. EUROPEAN YIELD MODEL

McLain (1983) found that the EYM projected relation yielding was stronger than the proportional limit theory used in development. [7]. Bolted link study on aspects of bolts that are not addressed by the EYM has also been performed. An important aspect is conservation. The bolt retention impact are quantified by Gattesco (1998) on timber joints and discovered that retention increases connection resilience by approximately 10% parallel-to-grain and 40% perpendicular-to-grain. The second factor that affects timber connections is loading rate [8].

From the test data, Trayer developed an empirically based design formulae for bound, double-shear joints and proposed proper boulder spacing, end length, alignment and diameter choice. It was within this work that the term proportional limit stress was initially introduced “as the average stress under the bolt when the slip in the joint ceases to be proportional to the load”, [9].

Johansen (1949) developed a Yield Limit Model at the late 1940’s [10]. The researcher studies used fundamental mechanics to forecast the yield strength of a single dowel-type fastener’s resilience to bending and the experimental and yield design verified by McLain and Thangjtham (1983) and Soltis et al (1986) decided that the model of yield could be accepted precision, forecast the bolted timber yield capacity connections loaded parallel to grain. Nonetheless, the onset of yielding in timber is not well determine point on the load-deflection curve. Based on the investigation, Harding and Fowkes (1984), came up with conclusion that the 15% offset yield was implemented and became the base for the description of upward strength in a single fastener connection. The 5% offset yield is defined as the point where the load-deflection curve is crossed by a line parallel to the linear region, but offset 5% of the dowel diameter. The yield capacity is estimated on the basis of the presume brilliantly elastic-plastic behavior of both wood components and fasteners. Understanding of the dowel embedment capacity, fastener strength and basic link geometry leads to a projected yield mode and the strength of the lateral relation with this criterion. Yield types explain the system that deforms the elements of a wood link beyond the elastic region [11]. They are defined as follow [12]:

- Yield Mode I - Wood crushing in either the main member or side members. The strength of the fastener is greater than the strength of the timber.
- Yield Mode II- Localized wood crushing near the wood members ' faces based on pivoting the shear plane with a rigid fastener.
- Yield Mode III- Fastener yield per shear plane and related wood crushing in bending at one plastic hinge point.•

Yield Mode IV- Fastener yield per shear plane and related wood crushing in bending at two plastic hinge points.

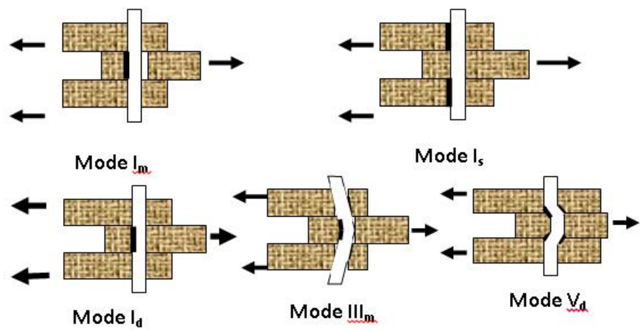

Fig. 1: Proposed joint failure modes [12]

As prescribed by Schwartz, 1992, the structural efficiency of a connector can be defined as the load which can be transferred divided by the connector area provided. It can be shown that the most effective connectors are the nails or dowels in pre-drilled holes from steel plates. Bolts, toothed-ring connectors and broken rings accompany these. Nails are twice as efficient in pre-drilled holes as any of the other connectors. The choice of connector will depend on the connection and aesthetics space available. The most effective connectors are the end-grain connectors, where the load transfer is through direct tension. The shorter the load path, the more effective the connector will be. [14] (Fig.2).

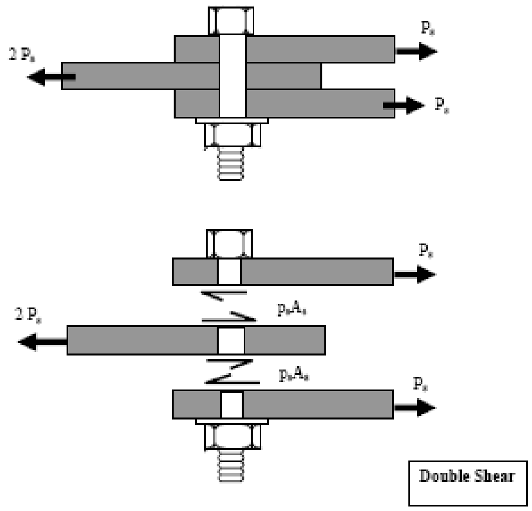

Fig. 2: Double shear Connection Showing the Convoluted Load Path for The Transfer of Forces. [14]

III. DOUBLE SHEAR TEST COMPARISON

The samples were ready for the double shear in line with the ASTM D 5652 – 95 (reapproved 2007) Details of the specimens is shown in Fig. 2. Six (6) numbers of double shear joints specimens were prepared. Kempas timber species was used as the base material (i.e. main and side). Three (3) joints were fastened using GFRP dowel and Kempas wood dowels respectively. Every wood samples used was made sured that free from any defect and with straight-grained directions.

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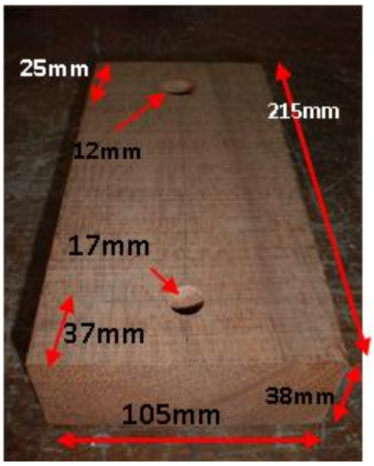
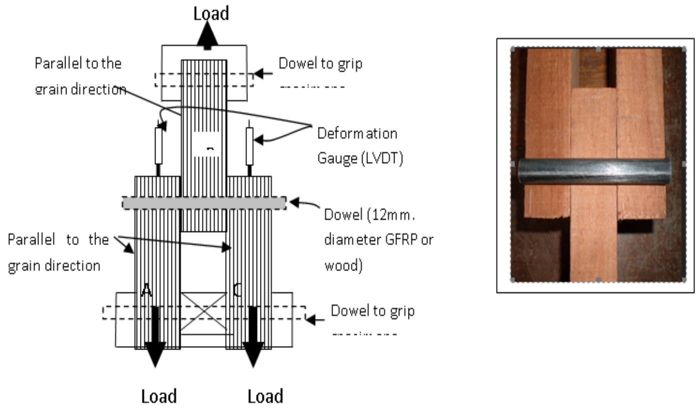


Fig.3: Detail configurations of sample

For the testing, a joint was drilled for the end grip-hole at each end of the three specimen parts (member A, B and C) (Fig. 4). Instead, with sufficient pressure, the 3 parts are clamped together to maintain contact between eyes. Hole was then drilled with a hole slightly smaller than the diameter of the dowel between the three bits. The hole size is drilled based on the available diameter of the hand driller relative to the dowel length. Both dowel diameters are closed to the available 12 mm GFRP shelve diameter as close as possible. The dowel and the pre-drill hole were allowed a gap within 1mm on the basis of the common industrial practice. Then removed the clamps and inserted the dowel into the hole. The middle member was then clamped on the testing machine using the U-shaped steel jigs followed by the clamping of the side members on both ends as well as the U-shaped jigs. A wood block was placed at the middle of the side members to prevent member side movement during testing. The Double shear joint and dowel diameter dimensions of the main and side components are the fixed parameters of this connection.



(a) (b)

Fig.4: Double shear connections loaded in tensile (a) Configuration (b) Actual

The double shear test was tested using Universal Testing Machine with the capacity of 500 kN where the specimen was testing under tensile stress. The shear tests were pulled under tensile load at 2mm/min rate. Digital moisture meter were used in order to measure the moisture content reading.

IV. DOUBLE SHEAR TEST RESULT

A. Load Carrying Capacity

From the results of moisture content test, the average of moisture content of the specimens was at 13.45%. The summary of the double shear load carrying capacity test result is shown in Table I.

Table I: Double Shear load carrying capacity for GFRP and Kempas Rod

Type of Dowel	Sample	Failure Mode	Ultimate Load (kN)	Yield Mode (kN)	Displacement (mm)
GFRP	GFRP 1	Mode I	10.59	10.59	7.00
	GFRP 2	Mode IV	14.04	12.27	15.80
	GFRP 3	Mode I	15.08	13.21	10.40
Avg. Value			**13.24**	**11.41**	**11.07**
Kempas	Kps 1	Mode IV	8.99	7.47	9.20
Avg. Value					
	Kps 2	Mode IV	7.53	5.89	22.20
	Kps 3	Mode IV	9.22	6.63	10.70
			8.58	**6.66**	**14.03**

From the experiment, the average ultimate shear strength is 13.24kN and 8.58kN for GFRP and Kempas rod respectively. This result shows that the load carrying capacity of 12 mm diameter GFRP dowelled is 54.3% higher than the Kempas dowelled connections. The yield load is 11.41kN and 6.66kN for the GFRP and Kempas connections. The yield point is the results of non-elastic where the connection shall no longer return to its original shape. The performance of load versus displacement for all 3 tests of GFRP and Kempas dowelled are shown in Fig. 3 and Fig. 4 respectively. The typical performance comparison between GFRP and Kempas dowelled connections is shown in Fig. 5.

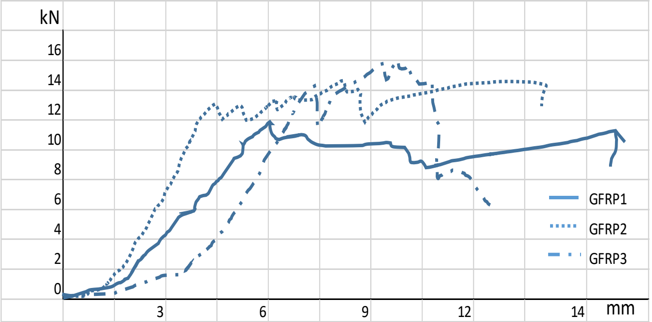


Fig.5 : Load versus displacement for GFRP dowelled connections

The failure characteristics of each joint were described in combination with load versus displacement graph (Fig. 5) and observation made on the specimens under loading. The changes in load versus displacement graph were noted in correspondence with changes in the mode of failure in the specimens. Load-displacement characteristics are almost similar for each repeatness of test and generally feature a higher yield with a staggered failure before it reached the maximum value and totally fracture. This typical responses marked in connections dowelled with GFRP rod.

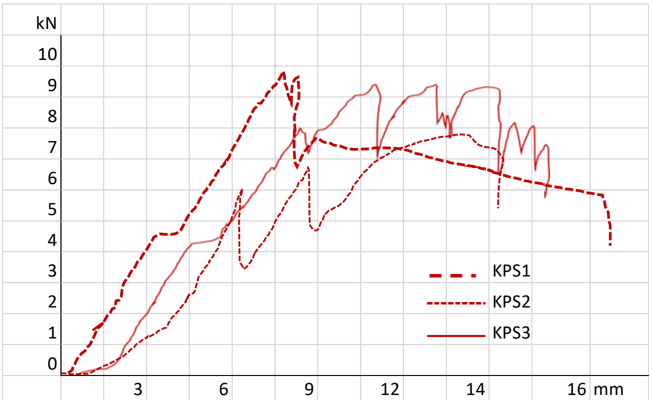


Fig. 6 : Load versus displacement for Kempas dowelled connections

Fig. 6 shows a pattern of load versus displacement for the connections dowelled with Kempas rod. It shows that the brittleness in the member is high during the process. The brittle failure might occur due to the failure of the main or side member; or the rod itself.

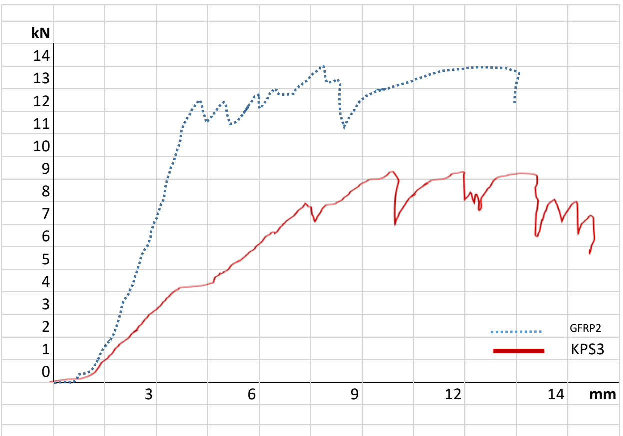


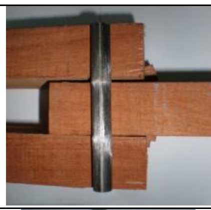
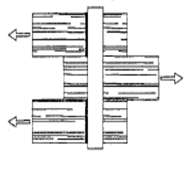
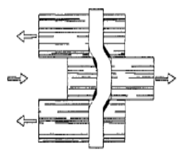
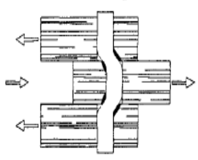
Fig. 7 : Typical load versus displacement for GFRP and Kempas dowelled connections

Fig. 7 shows the typical load versus displacement for GFRP and Kempas dowelled connections. Between the two connections performance, the deflection of the Kempas dowelled to reach its maximum capacity is extended compared to the GFRP dowelled connections. Though the load carrying capacity of GFRP dowelled connections is higher, Kempas dowelled connection is allowing an extended displacement before failure.

B. Failure Mode Behaviour

The failure mode behaviour of the joints were summarised in tabulated form followed by the reports on the experimental physical observations. Typical behaviour of the joints after the tests was reported according to the type of dowel started with the behaviour of joint dowelled with GFRP followed wood.

Table II: Failure Mode behaviour for Wood Connections dowelled using GFRP and Kempas

Type of Dowel	Specimens After Test	Theoretical (EYM) Mode of Failure
GFRP		 **MODE I**
		 **MODE IV**
Kempas		 **MODE IV**

From the failure mode observations, the two tests for GRFP failed in Mode I (Wood crushing in either the main member or side members). It shows that fastener stiffness is greater than wood strength. Only one sample failed in Mode IV (Fastener yield in bending at two plastic hinge points per shear plane and associated wood crushing). All 3 samples for Kempas dowelled failed in Mode IV. It is clearly shown that GFRP rod is stronger than Kempas rod according to the mode of failure and the physical behaviour of the material. Every connection failed in tension through the member cross section at the bolt hole due to concentrated stress. The higher ultimate load reflected to the lowest displacement at failure.

V. CONCLUSIONS AND RECOMMENDATIONS

Upon the experimental investigations on comparison of double shear strength of dowel connection between GFRP and Kempas rod, the following conclusions are drawn:

1) The average ultimate shear strength is 13.24kN and 8.58kN for GFRP rod and Kempas rod respectively
2) The ultimate double shear strength of GFRP dowelled is 21.36% higher than Kempas dowelled

The failure modes of double shear GFRP dowelled are in mode I, mode IV and mode I while failure mode for Kempas dowelled is all in mode IV.

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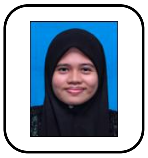

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