Equations of the Sum of Shear Connector on the Double Shear Connection Strength using Different Connector Materials

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Abstract

Mangium wood from the timber estate have been developed continuously in an effort to reach the fulfilling of wood fiber and construction material needs to replace role of timber from the natural forests which has been decreased. Timber connection requires a connector such as bolt that can distribute both the load of wood to wood and the compression or tensile stress through all the connections. Bearing slip is a connector that is inserted into a hole in the wood, which bears pressure and shear. Bolted connection is the most commonly used because it is easy to apply, even though it is less efficient due to the shear forces will be retained by the bolts and wood only on the cross-sectional area of the bolt. This research trying to find the equations of the sum of bearing slip connector to the strength of double shear connection which composed of 17 years old mangium. The connector was made from different materials that consisted of the same mangium, compressed mangium, ironwood and steel. The bearing slip connector consisted of two forms (dowel and rectangular) and arranged on one until three pairs of connector. The size and placement of the double-shear component based on Anonymous (2002), each form of the sample was made in 4 replications and all of them have been tested using a 35-ton Baldwin UTM. The result showed that the rectangular steel bearing slip connector has the highest equation ($y = 5322e^{0.329x}$) meanwhile the lowest equation was the ironwood materials ($y = 3164e^{0.405x}$). All of equations give high correlations (R^2 between 0.743 to 0.947). Bearing slip connector can improve the ability of the connection in load-bearing. Densified of mangium able to raise the connection system's ability however not significantly, both in strength and displacement. Ironwood connector are not well used as a retaining shear pin because of easy to split and significantly much below in capacity than mangium wood. Steel connector resulted the higher load-bearing significantly than mangium and ironwood. Dowel do not differ in terms of strength as compared with rectangle, and each additional number of connector producing an increase in load-bearing ability significantly. Observation on the displacement value shows that for the value which applied usually in Indonesia reach the strength ratio (SR) as 92.21% to the proportion limit and 44.91% to the maximum load. This value was in below position of the US standard (24.17 and 11.77%) and of the Australian standard (51.46 and 25.06%) to the proportional limit and maximum load respectively. Displacement achievement at the proportional limit varies from 1.1 to 2.2 mm, so that the minimum requirement of 1.5 mm displacement is not fulfilled by some treatments, however all of the connection system have passed the 1 mm displacement.

Keywords: bearing slip connector, displacement, double shear connection, equation, strength ratio.

Introduction

Timber connections require connection tool (connector) which are distinguished by traditional connector and the modern ones. Traditional wood connections is divided into two types namely the type of peg connection (shank joint, dowel-type joint) where the load of both compression or tensile supplied between component through along the connection. This type like a round peg (drift pins, dowel), bolts, screws and nails, while the other type is an outside connection (skin type connector) where the load is transmitted from the timber to the joint primarily by shearing action. Some examples are shear plate or split ring. In many cases the bolts applied as a fastener that was coupled but do not take part in the load transmission, merely to keep the connection still in place or the real component of the connection will not stretched due to the working of the moment. In other case, the modern connection method using glulam rivets, glued-in bolts and glued-in rods (Madsen 1992).

Peg is the object that is inserted partly in connection areas to transfer the load from one part to another (Yap 1984). PKKI (1961) explain that the peg is a connector that is inserted into the notch in the wood and are loaded with the compression and shear. Pegs mounted in a hole that has the same size or without leeway, so if there is swelling or shrinkage of wood, pegs still can be fixed retained in the hole. Therefore the moisture content of the peg must be same as the moisture content of wood at the time of installation if the pegs are made of wood (Faherty and Williamson 1999). Connection with wooden peg can be performed as rectangular, round (dowel) and Kubler peg (round peg like a thick ring with small holes for mounting bolts fasteners). Wooden connector has advantages over the bolt, which is wood capable of supporting a large force, higher efficiency and smaller deformations. Round peg connection is better than the square peg because although both are burdened with shear and pressure loads, the round pegs have not a tipping moment (Wiriyomartono 1977; Yap 1984). Perkins and Suddarth (1958) mentions the advantage of peg as a connector, such are the connection

is strong and rigid (stiff) axially, easily under construction, and it is the most rigid connection between the mechanical connection despite all the peg holes have been loose but still able to survive.

The addition of shear connectors will give better results in a connection which weighed a considerable axial force, this shear connectors are placed between layers of wood perpendicular to the direction of force. Shear areas detention will be greater than without shear connectors (Williamson *et al.* 2002). However, the shear connectors also have suffering damage possibility due to inter-fiber shear modulus force which called rolling shear. Neuhamer *in* Fellmoser and Blaß (2004) record rolling shear modulus of spruce wood by 48 N/mm², while Aicher *et al.* *in* Fellmoser and Blaß (2004) describe that the rolling shear modulus on the growth ring orientation is between 50 to 200 N/mm².

Test of connection system on variation of shapes and materials in the differences of the shear connector number arrangement, has been done in this study. The shape of the connector varied in round (dowel) and rectangular shapes, while its material consists of the same mangium wood as the connection component, densified mangium, ironwood and steel. Data obtained in connection system includes the load-bearing ability on the maximum and at the proportional limit, and noted the displacement that occurred at the two points.

Materials and Methods

The research was conducted in laboratories within the Department of Forest Products, Forestry Faculty Bogor Agriculture University since December 2009 - August 2011. The 17 years-old mangium wood as research material was obtained from forest concession area PT ITCI Hutani Manunggal (IHM) in East Kalimantan, with 15% moisture content during testing, while dowels making was carried out by PT Era Sumpindo Sejati at Cikupa, Tangerang. Other materials were the ironwood peg, compressed wood, round and steel plate and bolt as fastener.

Double shear connection for this research treats three connector factors consist of the shape (dowel and rectangle), number (one, two and three pairs), and materials (connector from the same mangium wood as the connection component, densified mangium by 10.7% reduction in compression thickness, ironwood and steel). The samples were prepared for four replications so that the amount of entire samples was $2 \times 3 \times 4 \times 4 = 96$ units. The length of the component and the number of fastener follow the number of peg installed on each unit, with the fixed size on the thickness and width. So for a pair, two and three pairs of peg will have 240, 320 and 400 mm length unit respectively.

UTM Baldwin equipped by dial gauge and computerized equipment used for recording load and

deflection value that occurs that can be described later in the load and deflection curve.

Figure 1. Size of double shear connection with a pair of dowel shear connector.

Remark: Dowel: $\varnothing = 20$ mm, $l = 80$ mm

Fastener: $\varnothing = \frac{1}{2}" = 12.7$ mm,

$l = 6" = 152.4$ mm

Fastener hole: $\varnothing = D + 1.6 = 14.3$ mm

Edge distance: $l_m/D \leq 6 \rightarrow 80/20 \leq 6$

min. $1.5D \rightarrow$ taken $2D = 40$ mm

Edge distance, Compression component:

$4D = 4 \times 20 = 80$ mm

Spacing between lines: $1.5D < 127$ mm

taken $3D = 60$ mm

Results and Discussion

Moisture content (MC) and specific gravity (SG) of the connection component are found as 17.7% and 0.6. The dowel's MC ranged 11 ~ 17% with SG of mangium wood 0.69, densified mangium 0.74, ironwood 0.97 and 7.51 for the steel. On SG rectangular peg of mangium is 0.69, densified mangium 0.75, ironwood 1.06 and for steel is 7.66.

Wood connection using a pair of ironwood dowel has the lowest on maximum strength ability which only 4,265 kg, while the highest value generated by a three pairs of steel pin connection on rectangular shape arrangement which has 15,686 kg strength. The following histogram described the connection system ability for retaining load and deflection at maximum and proportional limit point.

Figure 2 shows that addition amount of connector will enhance the ability of connection, and steel connector provide the highest value of load-bearing capability in each group of connector type (Figure 2a). However, on the value of displacement at maximum load, increasing the number of connectors did not give the same effect as shown in Figure 2b.

Figure 3 shows the average of load-bearing capacity based on the factors that influence the treatment done such as shape, number and material of connectors. Figure 3a

shows connection with a rectangular connector having ability of 1,226 kg which was higher than dowel connector. Meanwhile addition of the number of connector pairs which used in connection system will increase the maximum load ability. As shown at Figure 3b, it increases each 2,511 kg and 3,627 kg for the addition of one and two pairs on the connection respectively. The connection ability on maximum load-bearing also depends on the material which used. Figure 3c shows the difference from the lowest was

ironwood connector, mangium wood connector, densified mangium and the highest achieved by steel connector.

Increasing number of connector will have positive influence on the ability of the maximum load bearing connection. Such influence can be described in exponential regression equation, which reviewed from the type of material connector, shape of connector, or as a connection unit as described in Table 1 with good coefficient of determination.

Figure 2. Maximum load ($\times 10^3$ kg, Fig. 2a), and its displacement (mm, Fig. 2b) for each treatment.

Figure 3. Maximum load (kg) of the connection based on (a) shape, (b) number of pairs and (c) connector material.

Table 1. Exponential equation on relation between the number of connector to the maximum strength of connection load-bearing

No	Connector Type	Equation	Determination Coef. (R^2)
1.	Mangium without treatment	$y = 3667e^{0.391x}$	$R^2 = 0.947$
2.	Densified mangium	$y = 4280e^{0.303x}$	$R^2 = 0.743$
3.	Ironwood	$y = 3164e^{0.405x}$	$R^2 = 0.921$
4.	Steel	$y = 5322e^{0.329x}$	$R^2 = 0.924$
5.	Dowel	$y = 4000e^{0.335x}$	$R^2 = 0.776$
6.	Rectangular	$y = 4171e^{0.379x}$	$R^2 = 0.827$
7.	Connection using connector	$y = 4085e^{0.357x}$	$R^2 = 0.770$

Note: y = value of maximum load-bearing capacity (kg), x = number of connector (in pairs).

ANOVA and Honestly Significant Difference (HSD)

Determining the influence of the some factors of connector which consist of shape, number and the material of connector on the strength value of connection system, data is processed based on the analysis of variance (ANOVA). Statistical calculation proves that the maximum load-bearing strength of the connection is not influenced by the shape of the connector, but it is influenced by number of connector and the type of connector material. HSD-test has been done to the both -number of connector and type of connector material factor- and prepared as Table 2 below.

Table 2 shows that each additional of connector producing load-bearing capacity increases significantly. Beside that, viewed on the kind of connector material suggests that the densification is not effective in improving the ability of maximum load-bearing connections strength, it increases the average capacity of 95 kg only, and the value is not significant. Similarly for ironwood connectors, turned out to be significantly much below than mangium wood capacity, even though that is not densified. Meanwhile for the steel connectors, load-bearing strength ability is significantly far above the mangium and ironwood connectors. Differences effect between treatments on the ability of the system connection at the proportional limit points will clearly shown in Figure 4 below.

Figure 4 shows that the treatment that produces the greatest ability at proportional limit is the connection with 3 pairs of connectors made of round steel which reach 7,290 kg, while the lowest is a pair of ironwood dowel (2,246 kg). Displacements which occur at proportional limit are not different in high value, with the densified connector reach higher amongst others. Three pairs of densified mangium connector reach highest displacement yield (2.20 mm) while the lowest is a pair of ironwood (1.10 mm). If we following Wiryomartono (1977) and Yap (1984) which made limitation on using wood construction which requires a connection maximum displacement 1.5 mm, then the Figure 4b proves the inability of the achievement requirements. Displacement happens very varied even if the connector are made of steel though, but all sample are able through the displacement limitation of 1 mm. Sucahyo (2009) has suggested the same value, that in using a nail connection the maximum displacement is 1 mm.

The load-bearing ability of connection system reach the proportional limit was calculated by ANOVA. It has prove that connector shape factor is not significant, meaning there is no effect difference between round and square connector, while the sum of connector and type of materials have a significant effect respectively.

Table 2. Significance of the connector number influence and connector material influence on maximum load-bearing strength of connection.

Connector number	Average (kg)	Connector materials	Average (kg)
1 Pair	5,937 _a	Mangium without treatment	8,474 _p
2 Pairs	8,448 _b	Densified mangium	8,569 _p
3 Pairs	12,075 _c	Ironwood	7,540 _q
		Steel	10,697 _r

Note: The average value which has same *subscript* means not significant, otherwise is significant. HSD (69; 3) at 0.05 = 8.30 and at 0.01 = 93.33. HSD (69; 4) at 0.05 = 114.79 and at 0.01 = 140.88.

Figure 4. Average load ($\times 10^3$ kg, Fig. 4a) and displacement (mm, Fig. 4b) at the proportional limit.

Strength of Each Connector

Proximity the ratio between the standard with the actual ability of the connection systems vary widely depending on the user's state standards. Ratio prevailing in the United States is very small (24% and 11% of the proportional limit and maximum strength ability respectively), while Australia and Indonesia (Wiryomartono 1977; Yap 1984) is higher. When used Anonymous (1961) then the strength of the connection system, there is at 89% of the proportional limit capacity and 43% of the capability at the maximum strength, while when used maximum displacement value (1.5 mm) then the connection is at a 92% of capacity at proportional limit and 44% of the maximum strength capability. Ratio values which obtained did not differ much between the maximum boundary strength (allowable strength = maximum strength/2.3) to the maximum allowable displacement (1.5 mm). Compared to some other standard, the allowable strength of the connection system can be described as Table 3 below.

Table 3 illustrate the strength resulted by connection which have reduced by safety factor. Anonymous (1961) mentions that the safety factor of the double shear

connection is 1/(2.3). Furthermore calculation for each connector ability on each connection system and the decreasing curve of each connector ability in a number of connector arrangement, as described in Figure 5.

Figure 5 describes the ability of each connector on any variation treatment of the system connections. In terms of the material units, steel connector has the greatest strength value, while the ironwood connector has the lowest between all systems that made.

The strength of connection using untreated mangium and densified mangium each excels in some systems, but both are still in strength range between the steel and ironwood connectors. Decreasing per-connector ability can be written in regression equation as described in Table 4.

All values demonstrate the decreasing of strength value which occurs in a single connector calculation, in any addition of the sum of connector in a connection system unit. It means that the increasing of the connection strength caused by connector addition is not a geometrical progression following the sum addition of connector, but it's appropriate the regression function as Table 4.

Table 3. Mangium wood connection allowable strength based on several standard.

Standard	US	Australia	Indonesia	Max Load	PL Load	Max Load
Parameter(mm)	0.38	0.8	1.5	2.3	1.66	4.6
Load (kg)	1,035	2,203	3,948	3,822	4,281	8,790
SR to PL(%)	24.17	51.46	92.21	89.27	100.00	-
SR to Max(%)	11.77	25.06	44.91	43.48	48.70	100.00

Note: Allowable Strength = Max Load/2.3 (kg), Anonymous (1961), SR= Strength Ratio. Average displacement on proportional limit (1.66 mm) and at maximum point (4.6 mm) obtained from this research. Displacement Standard for US and Australia according to Suchyo (2009). Indonesian maximum displacement (1.5 mm) according to Wiryomartono (1977) and Yap (1984).

Figure 5. Strength of each connector (Fig. 5a) and the ability decreased curves appropriate to the treatment in a number of connector arrangement (Fig. 5b).

Table 4. Regression of the decreasing strength.

Connector type in the connection system	Exponential regression		Linear regression	
	Equation	R ²	Equation	R ²
Untreatment dowel mangium	$y = 3008 e^{-0.09x}$	0.760	$y = 2928-208.5x$	0.758
Densified dowel mangium	$y = 3837 e^{-0.14x}$	0.966	$y = 3519-325.1x$	0.937
Dowel ironwood	$y = 2558 e^{-0.08x}$	0.978	$y = 2454-152x$	0.989
Dowel steel	$y = 4027 e^{-0.10x}$	0.908	$y = 3856-289.5x$	0.886
Untreatment rectangular mangium	$y = 3046 e^{-0.06x}$	0.654	$y = 3018-157.85x$	0.667
Densified rectangular mangium	$y = 3610 e^{-0.10x}$	0.705	$y = 3516-264.45x$	0.714
Rectangular ironwood	$y = 2667 e^{-0.06x}$	0.832	$y = 2631-129.9x$	0.824
Rectangular steel	$y = 4793 e^{-0.11x}$	0.699	$y = 4637-384.4x$	0.710

Note: y = value of maximum load-bearing capacity (kg), x = number of connector (pcs)

Conclusions

Shear connector can improve the connection system in regarding load-bearing strength ability. Densification of mangium was able to raise the ability of connection system ability though not significantly, both in strength and displacement. Ironwood connector has low quality when being used as retaining shear connector due its easy sliding and split properties, that significantly below the capacity of mangium wood. Steel connector is capable of retaining the load significantly far above mangium and ironwood connector. Dowel connector type does not differ in terms of strength as compared to the rectangular shape, and each additional increase in the pair-sum of connector producing significant load-bearing ability. Achievement of displacement in the proportion limit of the connections varies from 1.1 to 2.2 mm, so that the requirement of minimal displacement 1.5 mm is not reached, although all of the system could pass 1 mm displacement. There are some exponential equations between the number of connector to the maximum strength of connection load-bearing with the coefficient of determination are more than 0.7. Beside that, strength decreased regression on each connector ability in each connector type and connection have determination coefficient more than 0.7 also.

Further research is needed using different wood species, addition of the number of test sample and other material types in order to obtain the more comprehensive data.

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