Jurnal
TEKNIK SIPIL

Split Ring Connection of Coconut and Bangkirai Lumber

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Abstrak

Penelitian ini merupakan penelitian lanjutan mengenai kuat tarik sambungan komposit Glugu-Bangkirai yang dilakukan oleh Awaludin & Triwiyono (2003). Hal baru yang dilakukan pada penelitian ini adalah penggunaan cincin belah sebagai alat sambung, sedangkan pada penelitian sebelumnya (Awaludin & Triwiyono, 2003), alat sambung yang digunakan adalah dua baut 15.6 mm (5/8 inchi). Selain kuat tarik sambungan hasil pengujian, kuat tarik sambungan juga dianalisis dengan persamaan dari Euro Code 5 dan Awaludin & Triwiyono (2002). Diameter dan panjang cincin belah yang dipergunakan berturut-turut adalah 40 mm dan 30 mm, sedangkan diameter baut pengaku adalah 12.5 mm (½ inchi). Pada setiap sambungan terdapat dua cincin belah sebagai alat sambungnya.

Hasil penelitian menunjukkan bahwa, kuat tarik sambungan dengan alat sambung cincin belah lebih tinggi 30% dari pada kuat tarik sambungan dengan alat sambung baut. Sesaran pada sambungan dengan alat sambung cincin belah lebih kecil yaitu 67% dari pada sesaran sambungan dengan alat sambung baut. Kuat tarik ultimit sambungan hasil pengujian tersebar disekitar kuat tarik ultimit dari Euro Code 5 dan Awaludin & Triwiyono (2002).

Kata-kata kunci : *cincin belah, kuat tarik, sesaran.*

Abstract

This research was a further research on tensile load of three-member connection of Coconut and Bangkirai lumber (Awaludin & Triwiyono, 2003). The new thing done in this experiment is the use of split ring as the connector of the connection. In the previous research (Awaludin & Triwiyono, 2003), two bolts of 15.6 mm were used as the connectors in each connection. Besides the result from experiment, the ultimate tensile load of split ring connection was also analyzed with equations from Euro Code 5 and Awaludin & Triwiyono (2002). The dimension of split-ring connector was 40 mm in diameter, 30 mm in length, and bolt of 12.5 mm was used to tight the connection. Two split ring connectors were placed in every connection. The result shows that the ultimate tensile load of split-ring connection was thirty percent higher than the bolted connection. The displacement of split ring connection was only 67% of the displacement of bolted connection. The ultimate tensile load of experiment was scattered closely to the result of Euro Code 5 and Awaludin & Triwiyono (2002).

Keywords : *split ring, tensile load, and displacement.*

1. Introduction

1.1 Background

Wood is extensively used for construction especially in rural area where timber can be quite easy to get. Wood is used in truss structures such as roof and bridge besides frame and floor system. Some advantages that would be obtained when wood is used in construction compared with the other materials are: first is the total weight of construction would be smaller, and second is the simplicity in fabrication.

As a natural resources, wood differs in many ways. Two kinds of wood that will be used in this research are Bangkirai and Coconut. According to Awaludin & Triwiyono (2002), and Morisco (1998), the strength of Bangkirai lumber is higher than that of Coconut lumber, so that for structural construction people only use Bangkirai. However, since not all elements of structural construction sustain equal load, the strength grade of lumber in a structural construction can be varied. This combination lumbers in a construction is called composite structure. In composite structure,

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woods of high grade, middle grade, and low grade can be used optimally and wisely to conserve wood sustainability.

Bolt has been used in wood joint or connection since long time ago. Bolt is one of the mechanical connector where the connection strength is determined by the bending strength of bolt and the bearing or shear stress of wood. Joint in wood structure is known as the weakest part. The increase in connection strength will give significant benefit to whole structure. Many research have done to find out wood jointing methods and wood connectors.

In the previous research, Awaludin & Triwiyono (2002), three-member connection of Coconut and Bangkirai lumber were tested in several angles of load to grain. Two bolts of 15.6 mm (5/8 inchi) were used as the connectors. Because the need to increase the tensile load and to decrease the displacement, split ring will be used in this experiment. In addition to that, the ultimate tensile load of connection of experiment also will be evaluated with some theoretical formulae.

2. Objectives

The objectives of this research were:
1. to find out the load-slip curve of three-member connection of Coconut and Bangkirai lumber with split ring connector,
2. to find out the advantage of using split ring connectors compared with bolt connector in three-member connection of Coconut and Bangkirai lumber, and
3. to evaluate the ultimate tensile load of split ring connection with some theoretical formula.
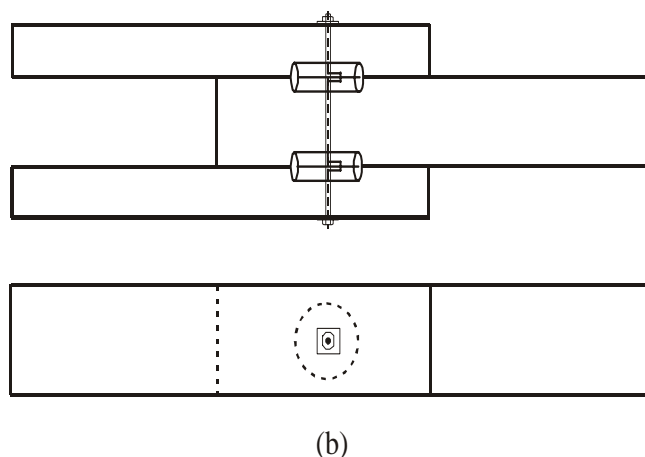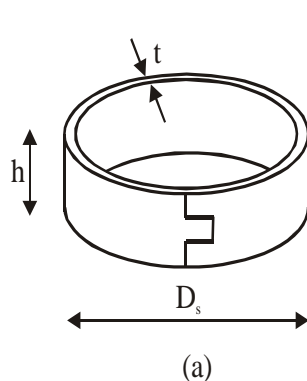
3. Literature Cited

Because wood is a natural resource, the structural properties of wood vary from one species to another species and even in one trunk: the bottom, the middle, and the upper part. Two things that are potentially controlled the strength of wood are moisture content and density or specific gravity. Water exists in wood in two ways: in the cell cavities as free water and in the cell wall as bound water. There are three common conditions in describing water content in wood: green water, fiber saturation point, and air-dry condition. For structural purposes, it is recommended to use lumber at air-dry condition (the water content is about 12 to 15%). The strength of wood increases as the water content decreases. But the water content decrease should be made gradually to avoid crack or split. Density can be used to predict the strength of a specific wood. Wood with high density will also have high strength grade.

Ring (split ring) is used laterally loaded timber to timber connection and generally in combination with bolt (see Figure 1). Ring is available in a variety of shape and size. The common shape of ring are double bevel and flat, and the common size are 2½ inchi (64 mm) and 4 inchi (100 mm). Diameter of bolt which is used in 2½ inchi and 4 inchi ring are ½ inchi and ¾ inchi respectively. This bolt is used to tight the connection so that the ring connector worked optimally. According to Blass in Blass et al (1995), rings are always circular because they are placed into precut grooves produced by rotary cutters and are made from aluminum cast alloy, steel or cast iron.
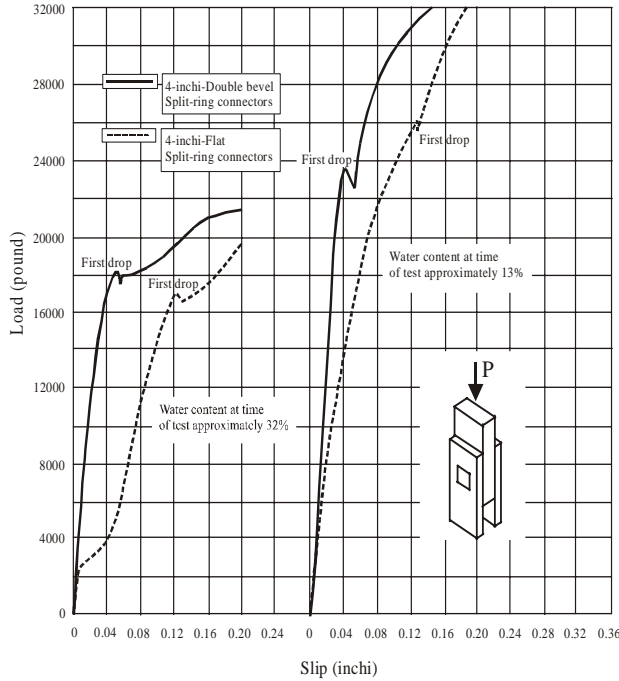

Figure 1. Flat split-ring (a) and split-ring connection (b)

Figure 2. Load-slip curve of 4 inchi split-ring connections at 13% and 32% water content

The tensile load of split ring connection is determined not only by the diameter and the length of ring, but also the water content of members as shown in Figure 2. Tensile load of double bevel ring is higher than that of the flat ring, while the displacement of double bevel ring is smaller than that of flat ring. The failure mode of ring connection can be studied in Figure 2. According to Faherty (in ASCE, 1996), at the proportional limit, wood between the ring and bolt begin to crush, then followed by the bent of bolt. After that, the final failure of wood splitting parallel to grain occurs until its ultimate tensile load. Beyond the proportional limit, depending on the thickness of the members, wood splitting may occur rather abruptly (in thin member) or additional compression of wood fiber takes place and the bolt begins to bend (thick member).

Euro Code 5 in Blass et al (1995) introduce Equation 1 and Equation 2 to analyze the tensile load of split ring connection (P_{sr}). The least value of these two equation is used as the design value. The tensile load which is sustained by the bolt is neglected. These equations give good prediction at 13% of water content. Equation 3 is used to obtained tensile load of split ring connection when the load direction to grain is not parallel.

$$P_{sr} = 20 A_s^{0.75} \tag{1}$$

$$P_{sr} = 0.09 . \rho . D_s . h \tag{2}$$

$$P_{sr\theta} = \frac{P_{sr //}}{k . \sin^2 \theta + \cos^2 \theta} \tag{3}$$

where, $k = 1.3 + 0.001 D_s$ and $A_s = (D_s + h)a - \frac{\pi D_s^2}{8}$

According to Awaludin & Triwiyono (2002), the ultimate tensile load of split ring connection is the total tensile load that is developed by the ring and the bolt. The tensile load that is developed by the ring is a combination between shear and compression strength. Equation 4 is recommended formula by Awaludin & Triwiyono (2002) to obtain the ultimate tensile load of split ring connection. Tensile load which is developed by bolt (P_b) is similar to the nominal strength of bolt (Z).

$$P_{sr} = P_b + \lambda_s P_s + \lambda_c P_c \tag{4}$$

$$P_{s //} = m \frac{\pi D_s^2}{2} \tau_{//} (1 - 0.6 \sin \theta) \tag{5}$$

$$P_{c //} = m \frac{\pi D_s h}{2} F_{e //} (1 - 0.6 \sin \theta) \tag{6}$$

The nominal strength for one bolt (Z) of three-member connection is the least value which is obtained from Equation 5 to Equation 8 in Table 1. Yield mode in Table 1 describes the failure mode of bolted connection. The yield modes I_s and I_m are the result of wood fiber crushing in side member and main member respectively. Yield mode III_s is the result of bolt yielding with one plastic hinge at the shear plane along with the wood fiber crushing in side member. Yield mode IV is the result of bolt yielding in many plastic hinges.

Table 1. Connection yield load of three-member bolted connection

Connection yield modes	Nominal strength for one bolt (Z)	
I_s	$Z = \dfrac{1.66 D t_s F_{es}}{K_\theta}$	(7)
I_m	$Z = \dfrac{0.83 D t_m F_{em}}{K_\theta}$	(8)
III_s	$Z = \dfrac{2.08 k_3 D t_s F_{em}}{(2 + R_e) K_\theta}$	(9)
IV	$Z = \dfrac{2.08 D^2}{K_\theta} \sqrt{\dfrac{2 F_{em} F_{yb}}{3(1 + R_e)}}$	(10)

$$k_3 = -1 + \sqrt{\frac{2(1+R_e)}{R_e} + \frac{2F_{yb}(2+R_e)D^2}{3F_{em}t_s^2}}$$

$$R_e = \frac{F_{em}}{F_{es}}$$

$$K_\theta = 1 + \frac{\theta}{360}$$

4. Material

Twelve three-member connections of Coconut and Bangkirai lumber were made in this research. The side members of connection were two Coconut lumber of 40/150 mm^2, and the main member was one Bangkirai lumber of 60/150 mm^2. The angle of load to grain is varied into 90°, 60°, 45°, and 0° (parallel) to side members. Two split rings of 40 mm in diameter, 30 mm in length and two bolts of 12.5 mm (½ inchi) in diameter were used in every connection.

Preliminary tests such as water content test, dowel bearing strength, and mechanical properties of Coconut and Bangkirai lumber were conducted. Drying process is also conducted to obtained air-dry lumber. The connection specimens were tested until its ultimate tensile load. Failure mode and displacement were also observed to obtain load-slip curve of connection.

5. Result and Discussion

Three-member connections were assembled and tested in air-dry condition. The water content at time of test of Coconut and Bangkirai lumber were 15.86% and 17.95% respectively. The result of tensile test which is presented in load-slip curve showed that: The load-slip curve of split-ring connection is steeper than that of bolted connection, and the ultimate tensile load of split ring connection was higher than that of bolted connection especially when the angles of load to grain were 45° and 60°. The average ratio between the ultimate tensile load of split ring connection to the ultimate tensile load of bolted connection (P_{sr}/P_b) was 1.30 as shown in Table 2. Furthermore, the displacement of split ring connection was smaller than the displacement of bolted connection. For instance, when the tensile load was parallel to grain, the displacement of split ring connection was only 67% of the displacement of bolted connection. The yield mode of connection was initiated by the crush of wood between ring and bolt, followed by the bent of bolt until the ultimate tensile load. The deformation on ring connectors was observed after the connections were dismantled. There

is no significant deformation on ring connectors. But all ring connectors and bolts became so rusty around the Coconut lumber (side members).

The ultimate tensile load of split ring connection can be evaluated with Equation 1 to Equation 3 of Euro Code 5 and Equation 4 to Equation 6 of Awaludin & Triwiyono (2002). Data from experiment which were used to evaluate the ultimate tensile load of connection were listed below. Density (ρ) of Coconut lumber was taken from Morisco et al (1998). Bending strength of bolt was taken 320 N/mm^2 as it is suggested by National Design and Specification (NDS) of USA for timber construction (ASCE, 1996). The ultimate tensile load of split ring connection which was evaluated with Euro Code 5 was presented in Table 4.

Table 2. Ultimate tensile load of connection

Angle of connection (θ)	Bolted connection (P_b) (kg)	Split-ring connection (P_{sr}) (kg)	P_{sr}/P_b
0°	45783	50688	1.11
45°	28096	39446	1.40
60°	23672	34698	1.46
90°	24133	29224	1.21
Average			**1.30**

Table 3. Maximum slip of connection with tensile loaded parallel to grain

Bolted connection (δ_b) (mm)	Split ring connection (δ_{sr}) (mm)	δ_{sr}/δ_b
40.78	31.45	0.77
22.35	15.25	0.68
22.60	12.75	0.56
Average		**0.67**

$\rho = 0.0065$ N/m^3 $D = 12.5$ mm $D_s = 40$ mm

$m = 2$ $h = 30$ mm $a = 147$ mm

$t_s = 40$ mm $t_m = 60$ mm $F_{es} = 14.25$ N/mm^2

$F_{em} = 58.69$ N/mm^2 $F_{yb} = 320$ N/mm^2 $\tau_{//} = 2.32$ N/mm^2

Table 4. Ultimate tensile load connection according to Euro Code 5

Angle of connection (θ)	Equation 1 (N)	Equation 2 (N)	Ultimate tensile load (N)
0°	38982	70200	38982
45°	33322	60007	33322
60°	31065	55943	31065
90°	29091	52388	29091

The failure mode of split ring connection was a combination between the strength of bolt, the shear strength and dowel bearing strength of wood around the ring. Since the shear strength of Coconut lumber was lower than its dowel bearing strength, so the strength reduction factor (λ_s) will be equal to one and the compressive strength reduction factor (λ_c) will lay between nil to one. Some modification was made to Equation 5 and Equation 6. This modification was written in Equation 11 to Equation 14. The ultimate tensile load of split ring connection was obtained from Equation 4 and step by step described in Table 5. The compressive reduction factors of 0, 0.5, and 1.0 were applied to analyze the ultimate tensile load, while the shear strength reduction factor was 1.0.

$$P_{s//} = m \frac{\pi D_s^2}{2} \tau_{//} \quad (11)$$

$$P_{s\theta} = \frac{0.4 P_{s//}^2}{P_{s//}(\sin^2\theta + 0.4\cos^2\theta)} \quad (12)$$

$$P_{c//} = m \frac{\pi D_s h}{2} F_e \quad (13)$$

$$P_{c\theta} = \frac{0.4 P_{c//}^2}{P_{c//}(\sin^2\theta + 0.4\cos^2\theta)} \quad (14)$$

The ultimate tensile load of Awaludin & Triwiyono (2002) with $\lambda_c = 0.5$, of experiment, and of Euro Code 5 were plotted in Figure 3. It can be seen in Figure 3 that the ultimate tensile load of experiment were scattered closely to both Euro Code 5 and Awaludin & Triwiyono (2002) curves, except for one data of 45° of connection angle. The ultimate tensile load curve of Euro Code 5 intersects with the curve of Awaludin & Triwiyono (2002) in connection angle from 45° to 60°. The ultimate tensile load of Euro Code 5 at connection angle below 45° was lower than that of Awaludin & Triwiyono (2002). While at connection angle from 60° to 90°, the ultimate tensile load of Euro Code 5 was higher than that of Awaludin & Triwoyono (2002). For analysis, equation of Euro Code 5 can be used instead of that of Awaludin & Triwiyono (2002).

Two questions arise in the equation which was suggested by Awaludin & Triwoyono (2002) are: (1). the value of compressive reduction factor (λ_c) will be equal to 0.5 or will be not if the size of split-ring changes, and (2). If the diameter of bolt higher than 12.5 mm, will the ultimate tensile strength of connection increases?. To answer these questions, future research on split ring connection which various value of diameter, length of split ring connector, and diameter of bolt should be conducted.

Table 5. Ultimate tensile load connection according to Awaludin & Triwiyono (2002)

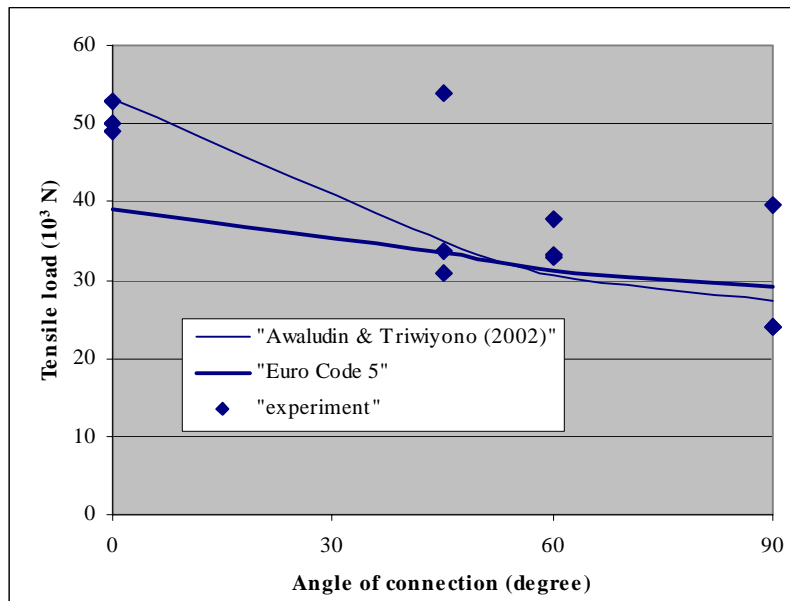| Angle of connection (θ)	Load contribution from 2 bolts (N)		Load contribution from 2 split rings (N)		Ultimate tensile load (P_{sr}) (N)		
	(P_b)	Yield mode	(P_s)	(P_c)	$\lambda_c = 0.0$	$\lambda_c = 0.5$	$\lambda_c = 1.0$
0°	15021	I_s	11656	52677	26677	53015	79353
45°	13352	I_s	6663	30111	20015	35070	50126
60°	12875	I_s	5487	24797	18362	30760	43155
90°	12017	I_s	4662	21071	16679	27215	37750

Figure 3. Ultimate tensile load of connection; Experiment and Theoretic

6. Conclusion

1. The load-slip curve of split-ring connection is steeper than the load-slip curve of bolted connection.

2. The ultimate tensile load of split-ring connection was 30% higher than the bolted connection.

3. The displacement of split ring connection was only 67% of the displacement of bolted connection.

4. The ultimate tensile load of experiment was scattered closely to the result of Euro Code 5 and Awaludin & Triwiyono (2002).

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Notation

t_s = width of side member (mm)

t_m = width of main member (mm)

D = diameter of bolt (mm)

D_s = diameter of split-ring connector (mm)

h = length of split-ring connector (mm)

a = end distance of split-ring connection (mm)

ρ = wood density (kg/m^3)

λ_s = shear strength reduction factor

λ_c = compression strength reduction factor

θ = angle of load to grain

P_b = Z = nominal strength of bolt (N)

P_s = shear strength of split ring connection (N)

P_c = compressive strength of split ring connection (N)

P_{sr} = ultimate tensile load of split-ring connection

F_{es} = dowel bearing of side member (N/mm^2)

F_{em} = dowel bearing of main member (N/mm^2)

F_{yb} = bending strength of bolt (N/mm^2)