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Stiffness and strength properties of rattan furniture joints subjected to lateral load

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Abstract: A study was conducted to investigate the stiffness and strength properties of various types of joints in rattan furniture subjected to lateral load. Four types of joints commonly found in rattan furniture, *i.e.*, nailed, nailed and bound with rattan rope, screwed, screwed and bound, were tested. Initial stiffness, secondary stiffness and ultimate strength properties of the joints were studied. The results showed that, in general, the lateral stiffness and strength properties of the screwed joints were not significantly different from those of the nailed joints. Binding had significantly improved the secondary stiffness and strength for the nailed joints, but not for the screwed joints. Moreover, binding was not able to increase the initial stiffness of both types of joints. It was found that stiffer and stronger rattan joints could be produced by using denser rattan.

Key words: Rattan furniture joints, lateral stiffness and strength, binding material.

INTRODUCTION

Rattan furniture components are normally jointed to each other by nails or screws. Most of the joints, especially those fastened by nails, are wrapped with binding materials made from rattan skin, peel or flat core. Other binding materials such as leather raw-hide and strips of parchment may also be used to advantage (Cody, 1983). There are many patterns of binding and these can dictate the price of the furniture (Husain and Wan Tarmeze, 1991).

Information on strength and stiffness properties of rattan furniture joints is very scarce, or does not exist at all. The lack of knowledge often leads rattan furniture manufacturers to use rattan, fasteners and binding materials of uncertain properties. As a result, in service performance of the furniture cannot be predicted. Guidelines pertaining to the joint stiffness and strength properties, if available, could be useful to rattan furniture manufacturers to ensure furniture life. With this in mind, a series of studies were conducted with an overall goal to generate information on how the joint behaves

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when subjected to various types of loads, *i.e.*, withdrawal, lateral and bending. Moreover, the effects of different fastener types and rattan specific gravity on the strength and stiffness properties were also studied.

The withdrawal strength of the rattan joints has been studied by Wan Tarmeze (2001). The study discusses how the different fasteners and binding materials react to the withdrawal load. The present paper deals with the lateral loading and its impact on the strength and stiffness of joints.

Lateral load in a joint is the load that acts perpendicularly to the longitudinal axes of the fastener (Eckelman, 1982). The load tends to slide one joint member over another. In furniture, most of the joints are subjected to lateral load. For instance, as shown in Figure 1, when a chair is sat on, most of the sitter's weight is exerted on the side rails that are connected to the legs and backrest. The fasteners that connect the members are therefore forced to resist any sliding of a member over another.

Lateral tests are done in various ways depending on the design and actual application of the joints (Fig. 2). Among these are single shear (Chu, 1987; Morris and Gajjar, 1989; Pruthi *et al.*, 1989), and double shear (Wilkinson and Laatsch, 1970; Chu, 1978; Akamastu, 1990), and beam-to-column 'T' shape connections of furniture frame (Eckleman *et al.*, 1979).

MATERIALS AND METHODS

Preparation of rattan material

Calamus manan (locally called rotan manau), commercially important rattan species for making furniture frame, was used in the study. Twenty-five poles of 3 m length each were obtained from a local supplier. The poles had been through the usual primary

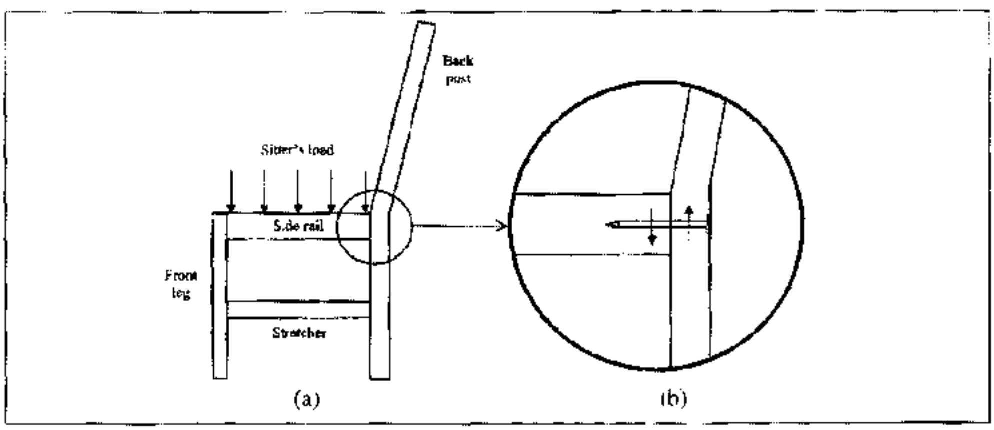

Figure 1. Typical chair side frame: (a) under sitter's load, (b) lateral loading effect at the side rail to backpost.

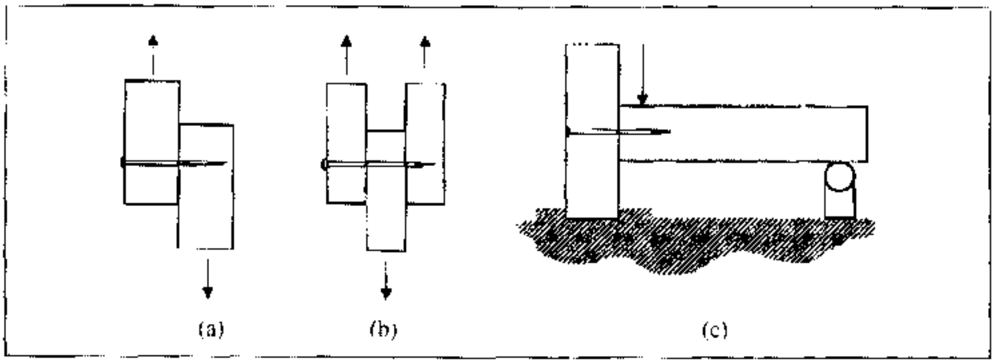

Figure 2. Lateral load test: (a) single shear, (b) double shear, (c) 'T' joint.

processing where they were boiled in diesel oil, air-dried and peeled to certain diameter sizes. For this study, diameter of 33 mm, one of the most common rattan sizes for furniture frame making, was chosen. The poles were cut to 160 mm length and were stored in a conditioning room at 20 °C and 65 per cent relative humidity for 3 to 5 weeks to achieve a uniform moisture content of 12 to 15 per cent (air-dried condition).

Preparation of joint specimen

Two types of fasteners commonly used in rattan furniture, namely, wire-gauge nail and countersunk head screw of almost similar size, were used to connect the poles. The dimensions of the fasteners are shown in Figure 3.

The conditioned rattan poles were connected to their pairs into simple 'T' joints as shown in Figure 4. The joints were divided into four groups namely, nailed (N), screwed (S), nailed and bound (N+B) and screwed and bound (S+B).

The construction of a 'T' joint began with a fastener driven at the middle of the cross bar and through the cross-section centre of its leg. For nailed joint specimen, the nail penetration was made at right angles by using a specially designed jig. For screwed

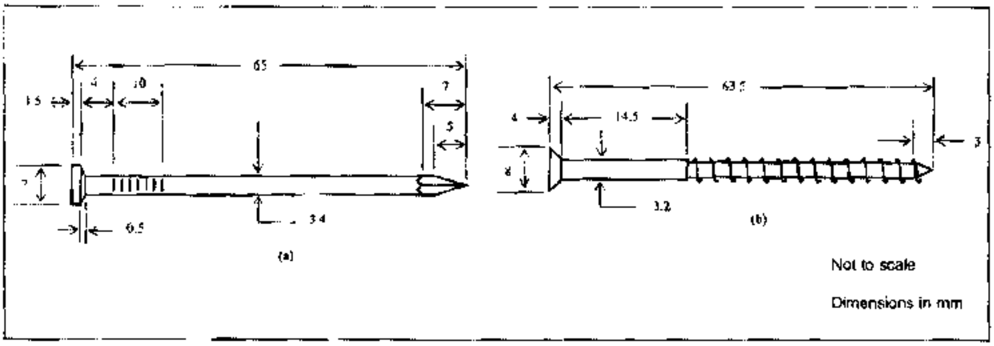

Figure 3. Nail (a) and screw (b) commonly used to fasten rattan furniture joints.

joint specimen, a hole of 0.3 mm diameter was drilled through the middle of the cross bar to provide right angle passage for the screw. Final joint construction was achieved by clamping the cross bar and the leg together, while driving in the nail or screw.

Half of the nailed and screwed joint specimens were bound using 5-6 mm wide peels of *C. caesius* (locally called rotan sega), commonly used in the rattan furniture industry. The binding pattern chosen in this study was the simplest in the craft (Hamdan *et al*., 1997).

Strength testing

Since there is no standard method and suitable jig available for rattan strength testing, the latter had to be designed and fabricated for the study. Its purpose was to clamp and hold the cross bar of the joint vertically leaving the leg to point outward. The clamping was achieved by tightening the bolts at the back of the jig which then pushed against the cross-bar. The end supporter was used to support the flat end of the joining leg during the tests. The joint specimens were subjected to lateral load at the speed of 2.5 mm/min as suggested in the ASTM (ASTM, 1995). A compressive load was applied on the leg at 40 mm away from the cross bar. The leg was supported at the other end by the end supporter placed 100 mm away from the load. The specific gravity was based on the sample oven-dry weight and volume at test (ASTM, 1993).

Statistical analyses

Analysis of variance (ANOVA) was carried out on physical properties and the mechanical properties of the joints between any two groups. Simple (linear) regression was also done to find out the correlation between the specific gravity and the mechanical properties of the joints.

RESULTS AND DISCUSSION

The lateral load-displacement curves of the rattan joints are illustrated in Figures 5-9. The average values of initial slope (S1), secondary slope (S2), first load peak (PA) and second load peak (PB) of the joints are shown in Table 1. The summary of analysis of variance on the sample mechanical properties between groups is shown in Table 2. Results of the regression analysis are given in Table 3.

All the joints shared a similar type of load-displacement characteristic at the early phase of loading, where the load increased linearly in one slope (S1) and then suddenly switched to another less steep slope (S2). The load continued to increase until it reached a peak (PA). For the unbound joints, this peak was the ultimate load (or strength) where the joints failed completely. At failures, cracks occurred in the beam rattan flesh just above the fasteners. The crack formations could be closely related to the shear strength of the rattan and as shown in a previous study by Shahnor and Wan

Table 1. Average stiffness and strength values of rattan joints tested in lateral loading

Types of joint	Rattan diameter (mm)	MC%	SG	S1 kgf/mm	S2 kgf/mm	PA kgf	PB kgf
N*	32.9	13.7	0.472	49.6	11.6	191.2	-
S	33.1	13.8	0.462	41.0	13.5	197.4	-
N+B	32.7	13.8	0.482	50.4	15.4	231.1	222.4
S+B	32.9	13.6	0.470	45.1	20.0	220.5	217.6

* N: Nail; S: Screw; B: Bind; MC: Moisture content; SG: Specific gravity; S1: Slope 1; S2: Slope 2; PA: Peak A; PB: Peak B.

Table 2. Summary of analysis of variance on sample characteristics and lateral stiffness and strength between groups

Groups variation	df	Properties of the joints F-ratios and Statistical significance				
		SG	S1	S2	PA	PB
N vs S	1/48	0.37 (ns)	7.00 (*)	0.81 (ns)	0.24 (ns)	-
N+B vs S+B	1/48	0.30 (ns)	2.31 (ns)	6.17 (*)	0.23 (ns)	0.16 (ns)
N vs N+B	1/48	0.23 (ns)	0.05 (ns)	7.84 (**)	9.35 (**)	-
S vs S+B	1/48	0.46 (ns)	1.80 (ns)	6.53 (*)	3.69 (ns)	-

* NS: Not significantly different at 95% probability level; ** = Significantly different at 99% probability.

Table 3. Summary of Regression Analyses between the specific gravity and the lateral stiffness and strength properties of rattan joints

Group	Regression equation						R^2
N	a.	S1	=	-23.9	+	156SG	0.74
	b.	S2	=	-12.7	+	51.5SG	0.48
	c.	PA	=	-79.3	+	573SG	0.78
S	a.	S1	=	-25.2	+	145SG	0.82
	b.	S2	=	-32.8	+	98.3SG	0.43
	c.	PA	=	-148	+	749SG	0.89
N + B	a.	S1	=	-27.4	+	161SG	0.83
	b.	S2	=	-7.10	+	46.6SG	0.63
	c.	PA	=	-35.3	+	553SG	0.76
	d.	PB	=	88.0	+	281SG	0.36
S + B	a.	S1	=	-14.2	+	126SG	0.73
	b	S2	=	-19.1	+	83.6SG	0.58
	c.	PA	=	-48.9	+	573SG	0.77
	d.	PB	=	83.7	+	285SG	0.33

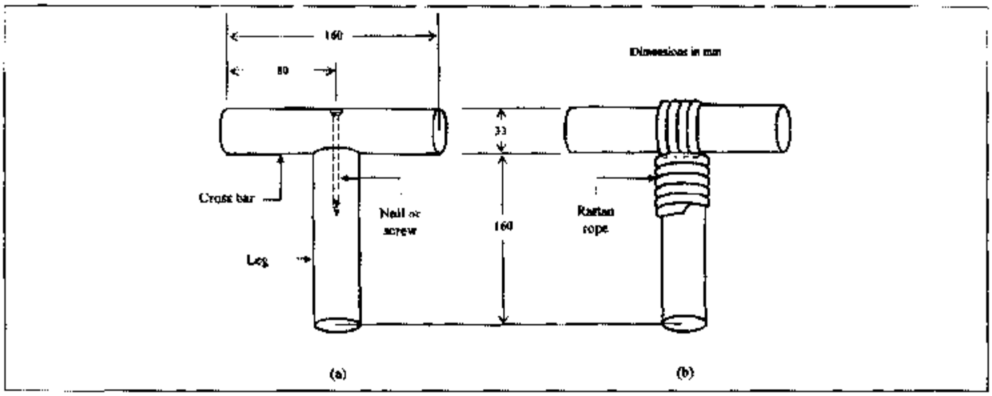

Figure 4. Rattan 'T' joint specimen (a) unbound (b) bound.

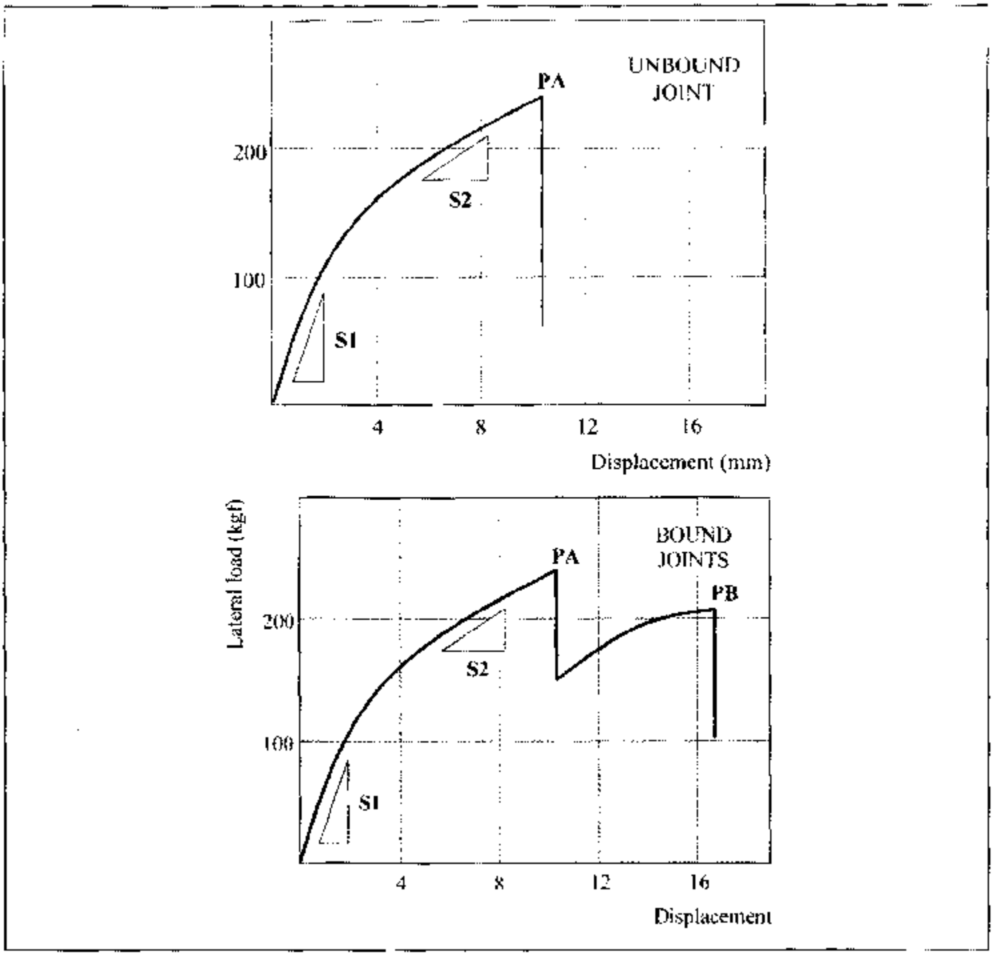

Figure 5. Lateral load-displacement characteristics of some nailed (N) rattan joints; S1: Slope 1; S2: Slope 2; PA: Peak A; PB: Peak B; SG: Specific gravity.

Tarmeze (1993), the shear strength values were positively correlated to rattan specific gravity. This would suggest that the ultimate strength was much influenced by the physical properties of the rattan itself rather than by the type of fastener used. For the bound joints, after the first peak (PA), the load dropped to a certain value and then rose again until it reached another peak (PB) before the joints failed completely. Two types of failures were observed at PB in each of the bound joints, namely, the crack in rattan flesh (as in unbound joints) and the broken binding materials.

The presence of two slopes (S1 and S2) could be due to the following reasons. The first slope (S1) represented the crushing of rattan flesh by the fastener. The fastener continued to crush the soft inner flesh of the rattan upward until it reached the denser and harder epidermal layer and stopped. The increasing load afterwards would be fully exerted on the fastener to gradually bend it (S2) until the rattan flesh cracked. The crushing strength could be associated to the hardness of rattan, where harder rattan would be more difficult to crush. Moreover, rattan hardness values were shown

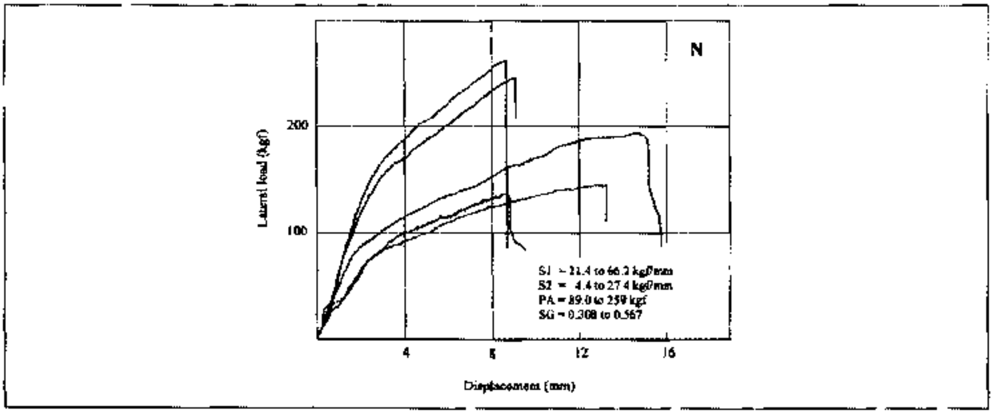

Figure 6. Lateral load-displacement characteristics of some screwed (S) rattan joints.

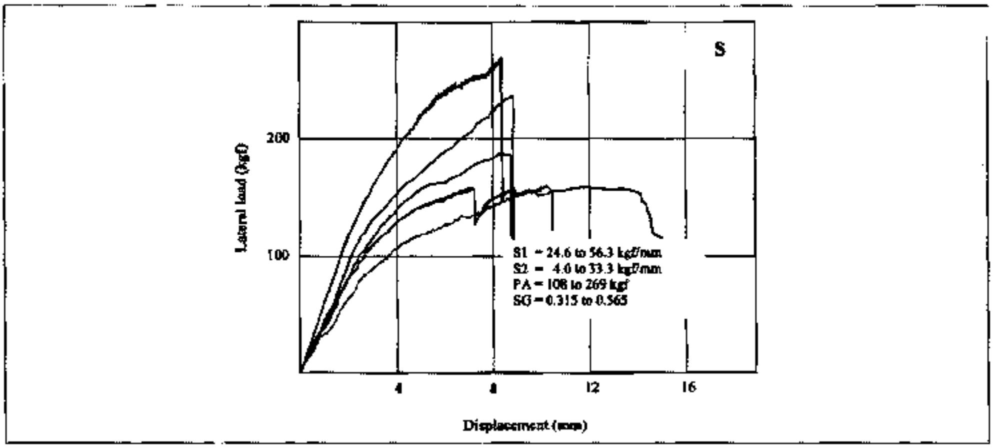

Figure 7. Lateral load-displacement characteristics of some nailed and bound (N+B) rattan joints.

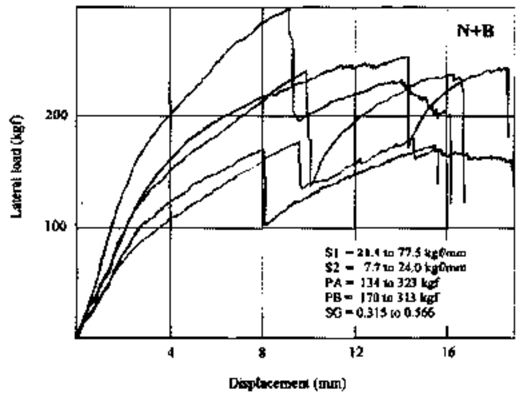

Figure 8. Lateral load-displacement characteristics of some screwed and bound (S+B) rattan joints.

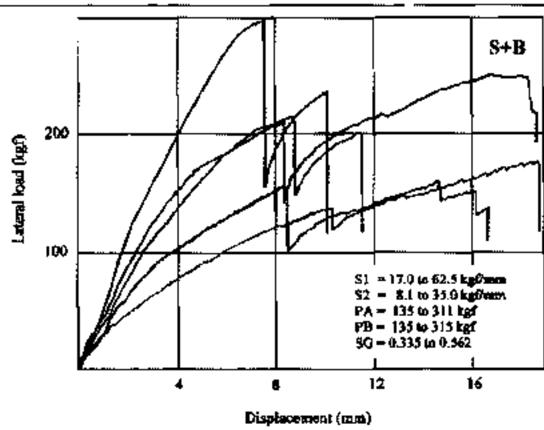

Figure 9. Lateral load-displacement characteristics of some screwed and bound (S+B) rattan joints.

to be highly correlated to the rattan specific gravity (Shahnor and Wan Tarmeze, 1993). Thus, if the "crushing" hypothesis was true, S1 correlated significantly to the rattan specific gravity. The presence of two load peaks (PA and PB) in bound joints suggests that each peak could be associated to either rattan shear (crushing) strength or binding material strength. In other words, the peak would either be followed by the crack in rattan flesh or the breaking of binding materials. As that of the withdrawal strength and stiffness (Wan Tarmeze, 2001), the values of lateral strength and stiffness also varied considerably among the joints in each of the groups. The S1 ranged from 21.4 to 66.2 kgf/mm (N group), 24.6 to 56.3 kgf/mm (S), 21.4 to 77.5 (N+B) and 17.0 to 62.5 kgf/mm (S+B). The S2 varied from 4.4 to 27.4 kgf/mm (N), 4.0 to 33.3 kgf/mm (S), 7.7 to 24.0 kgf/mm (N+B) and 8.1 to 35.0 kgf/mm (S+B). The PA values ranged from 89 to 259 kgf(N), 108 to 269 kgf (S), 134 to 323 kgf (N+B) and 135 to 311 kgf (S+B). For the PB, the values were from 170 to 313 kgf (N+B) and 135 to

315 kgf (S+B). These variations in the strength and stiffness could be closely related to the variation in specific gravity of the rattan samples.

The results of the lateral stiffness and strength (Table 1) and the ANOVA (Table 2) indicate that the SI of almost all the groups for both tests was not significantly different from each other. This would suggest that the initial stiffness of rattan joints was not influenced by the type of fastener used and whether or not the joint was bound. However, the ANOVA test results indicate that the secondary stiffness (S2) of both nailed and screwed joints was significantly improved when the joints were bound. This indicates that binding material also resisted further crushing of the hard epidermal layer by the fastener as described earlier. The ultimate loads (PA) of nailed (N) and screwed (S) joints were not significantly different. This suggests that the fastener type did not influence the ultimate strength values. However, both nailed and screwed joints were stronger (20-30%) when wrapped with the bindings.

As mentioned before, the specific gravity of rattan has a significant influence on most of the lateral stiffness and strength properties. As shown in Table 3, for the unbound joints, the ultimate lateral strength (PA) values were highly correlated (average $R^2 = 0.83$) to specific gravity. This would further prove the hypothesis stated that the ultimate strength values of the joints tested in lateral were much dependant on the physical properties such as the specific gravity.

Furthermore, for the bound joints, the first peak (PA) showed higher correlation (average $R^2 = 0.67$) to specific gravity than the second peak (PB) (average $R^2 = 0.27$). Thus, with the reference to the hypothesis made on the occurrence of two load peaks, it could be concluded that PA represents the crack formations. Moreover, the lack of correlation between PB and the rattan specific gravity suggests that the peak values were related to other material strength properties which could possibly be the tensile strength of the binding materials.

The same approach can also be applied to clarify the hypothesis on the two slope occurrences (S1 and S2) in the load-displacement graph. In all of the joints, regardless of group, S1 correlated, more than S2, to the specific gravity (average $R^2 = 0.78$ and 0.53, respectively). Thus, S1 would more appropriately be considered to represent the crushing of the rattan flesh by the nail or screw. Again, the lower R^2 value of the S2 suggests that deformation mechanism other than the crushing could have happened. The bending of nail or screw by the hard epidermal layer of rattan could most probably be the reason.

CONCLUSION

Generally, the initial stiffness (SI) of rattan furniture joints was not influenced by the type of fastener used and whether or not the joints were bound. The strength (PA and PB) was also not affected by the type of fastener. The secondary stiffness (S2) for both types of joints improved when the joints were bound. However, binding only increased the strength (PA) of nailed joints but not the screwed joints. Specific gravity representing the density of rattan had a significant effect on the initial lateral stiffness (S1) and strength (PA) of the rattan joints. Thus, a rattan manufacturer should properly select dense rattan pole for the furniture components that are regularly subject to lateral load in service.

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