TENSILE AND BENDING MOMENT RESISTANCES OF T-SHAPED JOINTS IN RATTAN CHAIRS

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Abstract. Effects of inner fastener type, wrapping pattern and material type, and member material type on ultimate tensile and bending moment resistances of T-shaped joints in rattan chair construction were investigated based on the L9 (3^4) orthogonal array experimental design. The range analyses indicated that the order of impact on ultimate tensile loads of four factors was inner fastener type > wrapping pattern > member material type > wrapping material type, whereas the order of impact on ultimate bending moment was inner fastener type > wrapping material type > wrapping pattern > member material type. Analysis of variance indicated that inner fastener type affected ultimate tensile and bending moment the most among the four factors with percentages of contribution of 51.19 and 47.06 to tensile and bending moment, respectively. Optimal combinations of factors and their levels that yielded the highest ultimate tensile and bending moment resistances were identified for T-shaped, end-to-side joints in rattan materials.

Keywords: Tensile test, bending test, T-shaped joint, rattan chairs, orthogonal array experimental design.

INTRODUCTION

Furniture made from natural rattan materials only and combined with wood, metal, and plastic is experiencing a revival as a diversified product that satisfies natural and personalized requirements. Natural rattan, a versatile material, has the distinct property of being easily twisted and bent into almost any shape ranging from rustic to ornate. Currently, natural rattan furniture is mainly produced in Asia but is mostly consumed in Europe, North America, Japan, and some other industrialized countries. Consumers pay a great deal of attention to the quality of rattan furniture, such as appearance and mechanical and physiochemical performances.

Early in 1976, the Philippines issued a standard for performance evaluation of rattan and wicker furniture. Performance tests such as the level test and static and impact load tests are used to determine if a rattan furniture product, specifically load-bearing members and joints, can reasonably withstand normal use (UNIDO 1996).

Even now, as a traditional rattan furniture production and export country, China has no unified standard for testing and assessing rattan furniture quality. Yuan (2006) studied the physical and

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mechanical properties of T-shaped and L-shaped joints in rattan cane materials connected by inner mechanical connectors such as dowels and screws without external wrapping materials. To develop a unified standard for rattan furniture quality testing and assessment, a research program has been carried out at Nanjing Forestry University, China, since 2005. Gu (2008) analyzed and summarized the standard for rattan furniture quality testing and assessment from three aspects: appearance quality, mechanical properties, and physiochemical performances. Also, moisture content, axial tensile strength, and mildew resistance of rattan bast and core of *Calamus simplicfoilius* Wei. were evaluated. Furthermore, fatigue and static load performance tests of rattan chairs were performed. The results from these tests indicated that tensile load and bending moment resistance capacities of joints are extremely important for overall rattan chair strength performance. The joints in rattan chairs are of particularly complex constructions that consist of an inner mechanical fastener and external wrapping materials. There are various

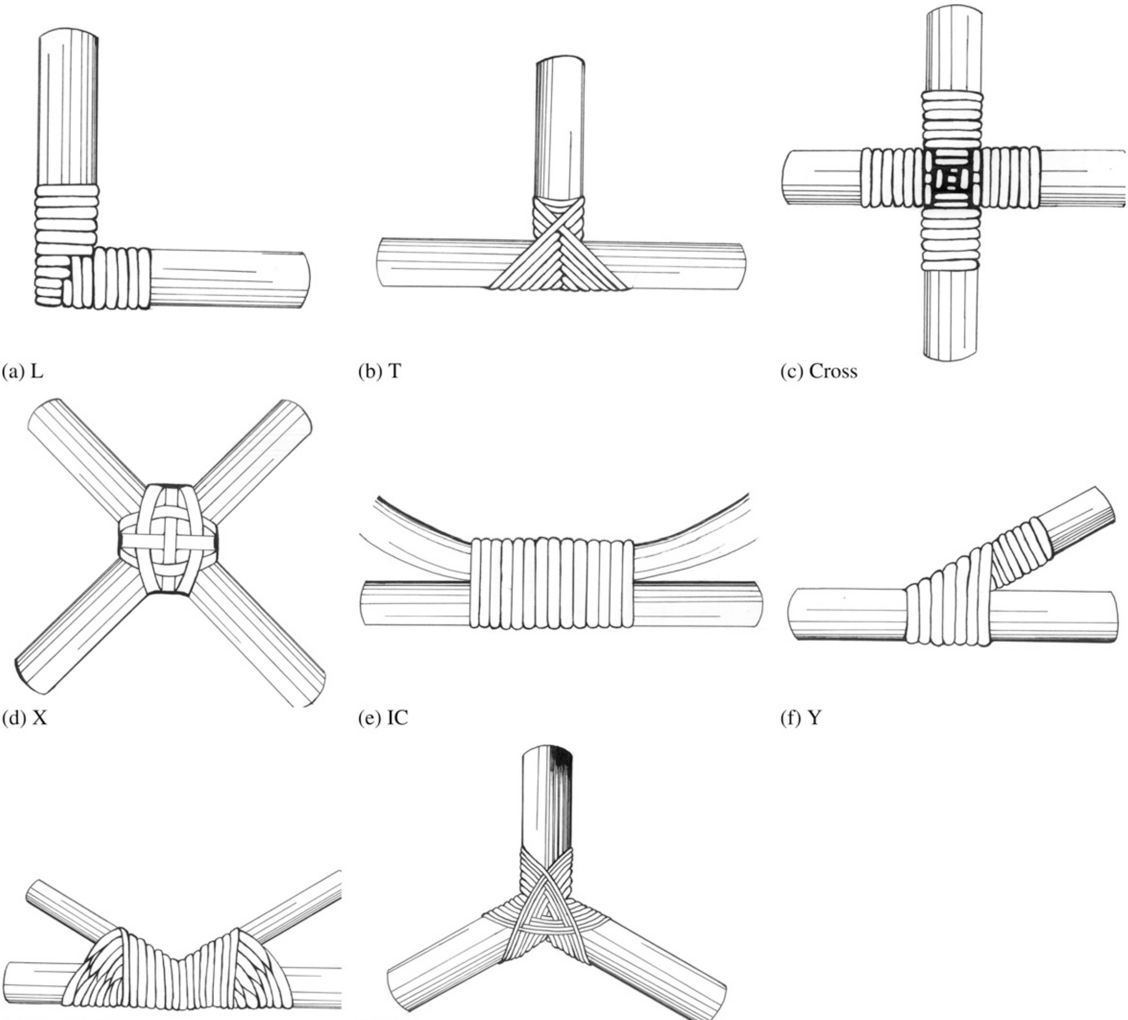


Figure 1. Configurations of differently shaped joints commonly seen in rattan chairs: (a) L, (b) T, (c) Cross, (d) X, (e) IC, (f) Y, (g) Double Y, (h) 3D cross. (a) through (g) are 2D configurations.

configurations of joints in rattan chairs such as L, T, cross, and X, Y, double Y, IC, and 3D cross (Fig 1) (ATTC 1991; Yuan et al 2007). Among them, the T-shaped joint is the typical construction in a rattan chair. The joint failure mode from the study (Gu 2008) indicated that the main factors on mechanical properties of T-shaped joints in rattan chair construction include inner fastener type, external wrapping pattern, member material type, and wrapping material type.

In rattan chairs, T-shaped joints are commonly jointed by inner fasteners such as wooden dowels along with adhesive, nails, or screws and external rattan wrapping material such as rattan bast or a flat core. Wrapping materials are used for decoration but also add strength to the joints. There are many kinds of wrapping patterns, mainly three types (ATTC 1991): around, cross, and cross and parallel (Fig 2).

The joint member material type for rattan chairs can be various species such as rattan, ivy, kudzu, and wisteria. Among them, rattan palm (Palmae), Calamus subfamily (Calamoideae), and Calamus family (Calameae) plants are the most commonly used high-quality rattan species. These rattan plants naturally grow in tropical Asia. Indonesia produces the most rattan materials followed by Malaysia, the Philippines, Laos, Vietnam, and Burma. There are about 13 known genera worldwide and 600 species of rattan, but less than 10% of these rattans (mainly in Calamus family) have economic value (Jiang 2002; Xu et al 2002).

Two species of rattan commonly used in China to construct furniture are Rattan manau (*Calamus manan* Miq.) and Baden cane (*Calamus zollingeri* Becc.). R. manau is the best material for rattan furniture. It is mainly produced from Indonesia's Sumatra Island, Peninsular Malaysia, southern Thailand, and Kalimantan (Li et al 2003). Cane diameter is between 20 and 80 mm, and length can be more than 107 m. Therefore, it is also called "Great Calamus." It is of high quality, has few surface defects, has bright and even color, has an internode spacing of 0.4 m, is uniform in thickness, and is compact in structure and flexibility. It deserves the title "King of the Vine." Its bast often is used together with cane and results in a beautiful appearance that is also strong (Jiang 2002).

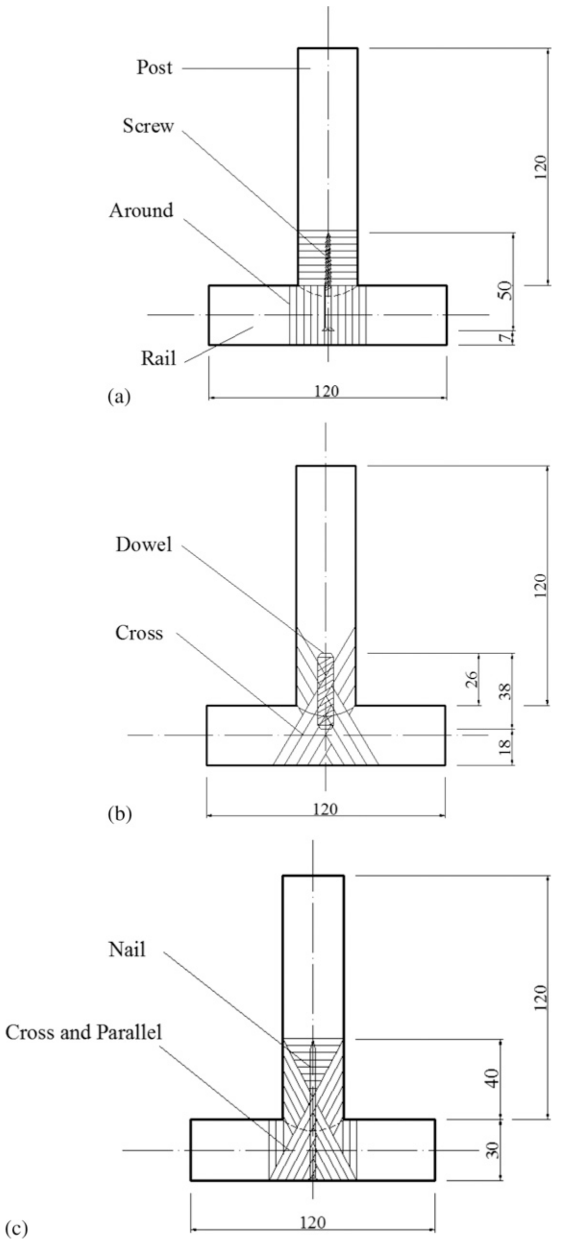


Figure 2. Configurations of T-shaped, end-to-side, tensile-load-resisting joints connected with three outer wrapping patterns of (a) around, (b) cross, and (c) cross and parallel and three inner fastener types of (a) screws, (b) dowels, and (c) nails. All dimension units are millimeters.

Baden cane (*Calamus zollingeri* Becc.) mainly grows in southern Sulawesi, Indonesia (South Sulawesi), Moluccas Islands (Moluccas), and West Java (Li et al 2003). The quality of its bast is not as good as R. manau and also the material itself is not high in economic value. Therefore, usually Baden is used without its bark. After polishing the Baden peeled rattan cane, all aspects of its performance are comparable with R. manau and it is lower in price than R. manau. These factors are helping Baden to become the most cost-effective cane rattan material.

Li cane (*Calamus simplicfoilius* Wei., commonly known as Calamus) is a species of small-diameter rattan commonly used in China's rattan furniture industry, largely for weaving and wrapping. It grows naturally at 300-1100 m above sea level in eastern and central China's Hainan Island. Also there are artificial cultivation sites in the south of Guangdong, Guangxi, and Fujian provinces in China. The bast color is white to slightly yellow. The diameter of rattan cane (without bark) is between 8 and 20 mm, and internode spacing is 0.15-0.3 m (Xu 2002). Because rattan cane does not have a secondary layer, the thickness of the stem is even. With its superior tensile strength and flexibility, the rattan bast and flat core are both fine materials for weaving and wrapping (Cai 1992).

Limited literature was found for tensile and bending moment resistance loads of typical joints constructed with these rattan materials in rattan chairs. The objectives of this study were to evaluate the effects of inner fastener type, wrapping pattern, member material type, and wrapping material type on the tensile and bending moment resistance loads of T-shaped, end-to-side joints in rattan materials commonly used in rattan chair construction and to identify the optimal combinations of these four factors with their levels that yield the highest tensile and bending moment resistance loads.

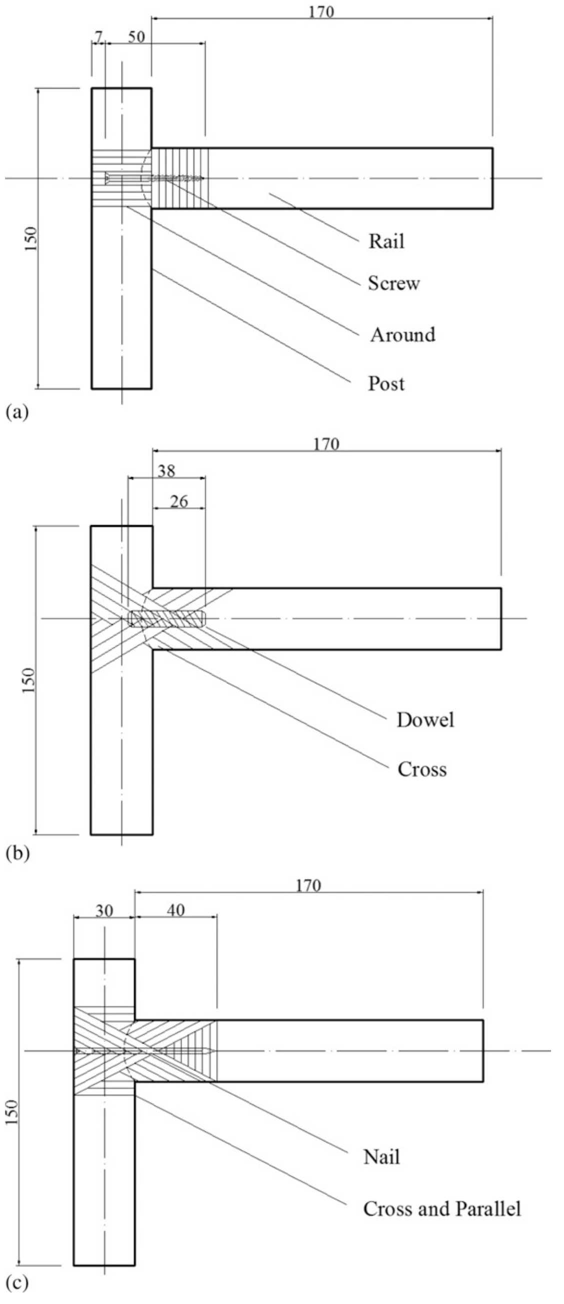


Figure 3. Configurations of T-shaped, end-to-side, bending-moment-resisting joints connected with three outer wrapping patters of (a) around, (b) cross, and (c) cross and parallel and three inner fastener types of (a) screws, (b) dowels, and (c) nails. All dimension units are millimeters.

MATERIALS AND METHODS

Specimen Configuration and Materials

Configurations of T-shaped, end-to-side, tensile and bending joint specimens in this study are

Table 1. Specifications of fasteners used in this study.

Type	Diameter (mm)	Length (mm)	Penetration depth in rail (mm)	Penetration depth in post (mm)
Screws	Head: 6 Root: 3	Shank: 18 Thread: 30	23	27
Bright smooth wire nails	Head: 5 Wire: 2.5	70	30	40
Dowel (with adhesive)	8	38	12	26

shown in Figs 2 and 3, respectively. Both tensile and bending specimens consisted of two principal structural members, a post and a rail, joined together by an inner mechanical fastener and an outer wrapping material. Both joint members were constructed of the same type of rattan material. Both members of the tensile joint specimens had normal dimensions of 120 mm long × 30 mm in diameter. The rail of the bending joint specimens had normal dimensions of 170 mm long × 30 mm in diameter, whereas the post had normal dimensions of 150 mm long × 30 mm in diameter. Rattan canes of two species, *Calamus zollingeri* Becc. and *Calamus manan* Miq., were considered for joint structural members in the study. The outer wrapping materials were rattan (Calamus) flat core and bast. The inner mechanical fasteners were wood screws, nails, and dowels (Table 1).

Experimental Design

The L9 (3^4) orthogonal array experimental design with four three-level factors was considered for each of two joint properties, tensile and bending moment resistances, evaluated in this study. For the experiment with four factors at three levels each, the traditional complete factorial design would require performing 3^4 or 81 combinations of experiments, which would be a time-consuming full-scale testing process, but the L9 orthogonal array design requires only nine experiments and proved to be a cost-effective optimization strategy that could obtain the optimal experimental combination with limited experimental trials.

Table 2 summarizes the factors, their codes, and selected levels in this study. The four three-level factors were the inner mechanical fastener type (coded as factor A), pattern (factor B), joint structural member material type (factor C), and outer wrapping material type (factor D). Inner mechanical fastener types were wood screw, nails, and dowels. Outer wrapping material types were a rattan flat core 3.5 mm wide × 1.5 mm thick, rattan flat bast I 3 mm wide × 0.5 mm thick, and rattan flat bast II 5 mm wide × 1 mm thick. The three different wrapping patterns were around, cross, and cross and parallel (Figs 1a, b, and c, respectively). Joint member material types were *Calamus zollingeri* Becc. without bark, *Calamus manan* Miq. without bark, and *Calamus manan* Miq. with bark.

Table 3 shows the experimental design plan of this study using the L9 orthogonal array method. Each row of the orthogonal array from 1 to 9 represents an experimental run with a different

Table 2. Factors and their levels used in the L9 (3^4) orthogonal array experiment for evaluation of ultimate tensile and bending moment loads of T-shaped, end-to-side joints in rattan materials.

Factors	Code	Levels		
		1	2	3
Inner fastener type	A	Screw	Nail	Dowel
Wrapping pattern	B	Around	Cross and parallel	Cross
Member material type	C	Calamus zollingeri Becc. without bark	Calamus manan Miq. without bark	Calamus manan Miq. with bark
Wrapping material type	D	Rattan flat core	Rattan flat bast I	Rattan flat bast II

Table 3. L9 (3^4) orthogonal array experimental design for evaluating the significance of factors on ultimate tensile and bending moment loads of T-shaped, end-to-side joints in rattan materials.

	Factors and levels			
Experiments	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

combination of factor levels. Six replications were tested for each of nine experimental runs performed with a randomized sequence. Therefore, a total of 54 specimens were tested in this study.

Specimen Preparation and Test

All joint member materials were free of defects such as knots, insect holes, and mildew. All joint sample connections were hand-wrapped by a worker with 8 yr of rattan furniture wrapping assembly experience. All screws and nails were driven through the post side into the rail end without predrilled pilot holes in rails, but 6-mm-diameter, 7-mm-deep pilot holes were drilled in posts. A polyvinyl acetate emulsion adhesive with 45% solid content was used for the dowel joint. For tensile specimens, two 8-mm-diameter holes were drilled on both sides of posts symmetrically for attaching the testing fixture with bolts. Prior to joint construction, all cut joint materials were conditioned in a chamber set to maintain 8% equilibrium moisture content. All specimens were tested right after completion of joint assembly except the doweled specimens, which were allowed at least 48 h of adhesive curing.

All tensile and bending specimens were tested on a CMT6104 universal testing machine. Figures 4 and 5 show the setups for evaluating tensile and bending moment resistances of T-shaped, end-to-side joints in rattan materials, respectively. Figure 5 shows anchorage location of the lead-

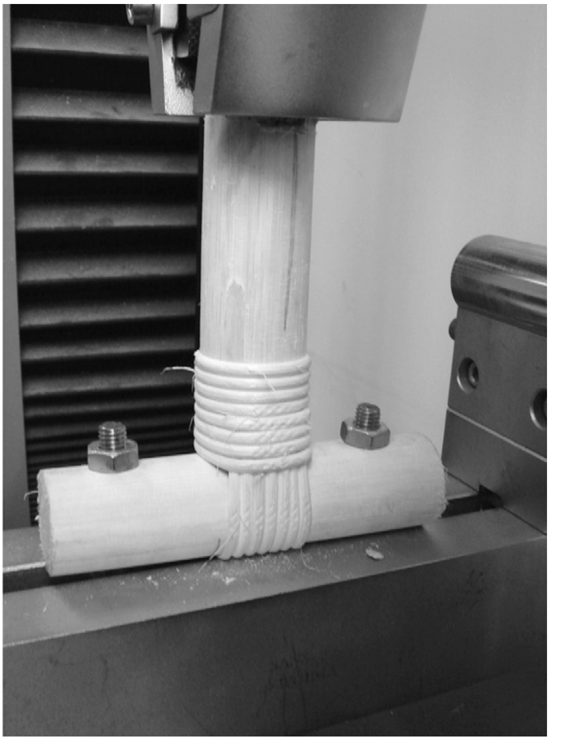


Figure 4. Test setup used to evaluate tensile load of T-shaped, end-to-side joints in rattan materials.

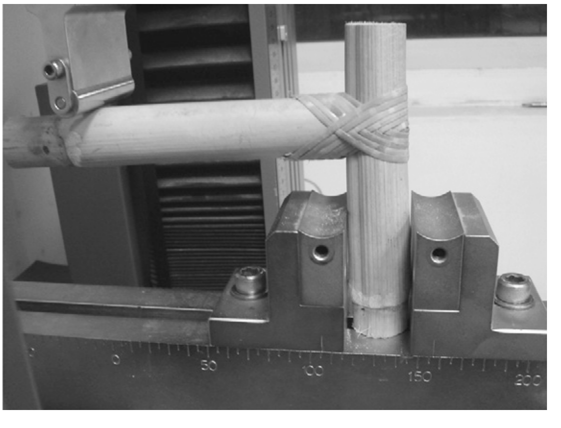


Figure 5. Test setup used to evaluate bending moment load of T-shaped, end-to-side joints in rattan materials. The moment arm was 120 mm.

ing bore used to fasten the T-shaped, end-to-side joints in rattan materials with support. For the bending test, loads were applied to the rail 120 mm in front of the post, ie the moment arm was 120 mm. In both tensile and bending tests, the loading rate was 10 mm/min. The ultimate tensile and bending moment loads and all joint failure modes were recorded.

RESULTS AND DISCUSSION

Tensile Test

Three typical failure modes occurred in the tests. Type I was external wrapping material loosened and dowel or nail withdrawal from joint members (Fig 6a). Type II was external wrapping material broken and dowel or nail withdrawal from joint members (Fig 6b). Type III was external wrapping material broken and fastener (screw or nail) head pulled out from the post accompanied with the post material fractured (Fig 6c).

Table 4 summarizes mean results of ultimate tensile loads of T-shaped, end-to-side joints based on the orthogonal array experimental design and their range analysis results. Each value in the column “Mean 1” within each of the nine experiments represents the mean ultimate tensile load of the first three specimens among the six tested joint specimens in the same row, and the mean ultimate tensile load of the remaining three specimens is in the column “Mean 2.” The values in the column “Sum” represent the sum of two values of the same row in columns “Mean 1” and “Mean 2.”

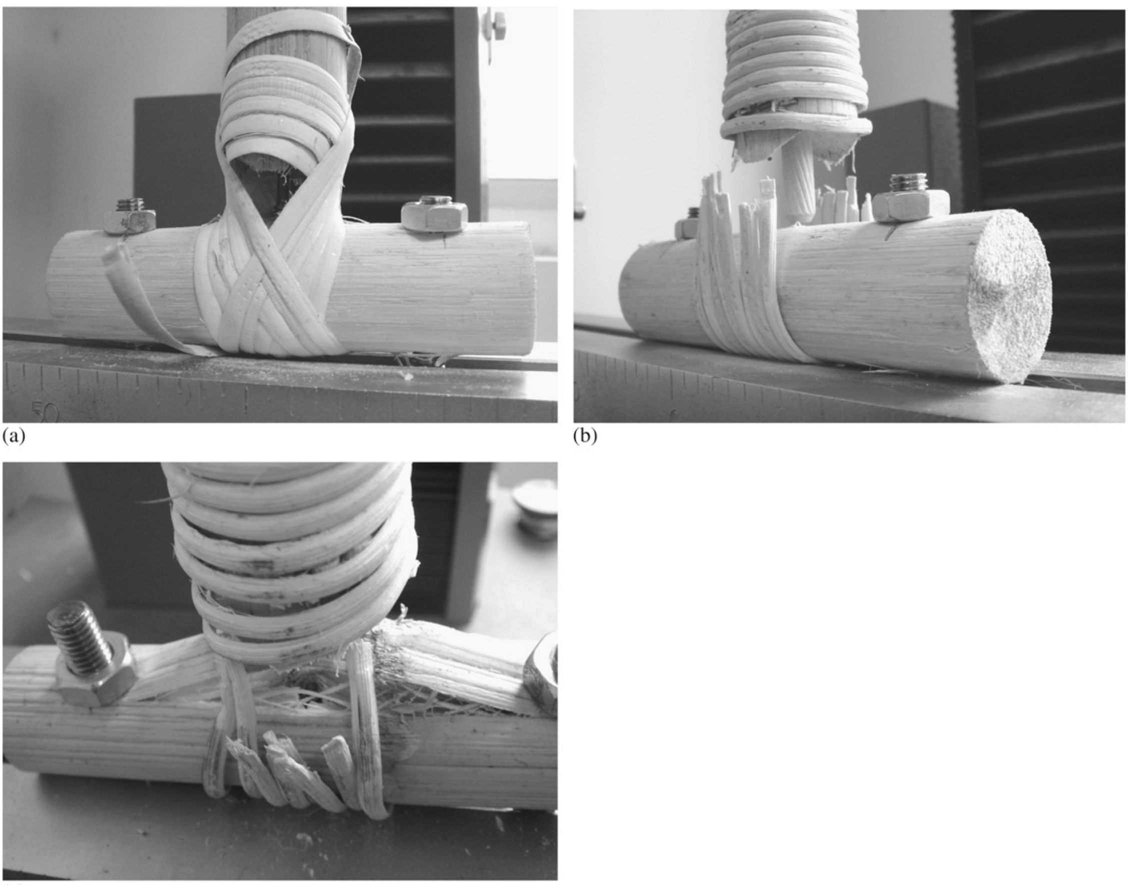


Figure 6. Three types of failure modes in tensile tests of T-shaped joints in rattan materials: (a) external wrapping materials loosened, (b) external wrapping materials broken and fastener withdrawn from rail or post, and (c) wrapping materials broken and fastener (nail or screw) withdrawn from rail with rail surface fracture.

Table 4. Results of mean ultimate tensile loads and their range analyses of T-shaped, end-to-side joints in rattan materials based on L9 (3^4) orthogonal array experimental design.

	Factors				Ultimate tensile load (N)		
Experiments	A	B	C	D	Mean 1	Mean 2	Sum
1	1	1	1	1	1,700	1,650	3,350
2	1	2	2	2	2,985	2,990	5,975
3	1	3	3	3	3,314	3,270	6,584
4	2	1	2	3	1,007	1,240	2,247
5	2	2	3	1	1,925	2,050	3,975
6	2	3	1	2	1,497	1,310	2,807
7	3	1	3	2	2,020	2,580	4,600
8	3	2	1	3	2,647	2,550	5,197
9	3	3	2	1	2,423	2,230	4,653
K_{ij}							
K_{1j}	15,909	10,197	11,354	11,978			
K_{2j}	9,029	15,147	12,875	13,382			
K_{3j}	14,450	14,044	15,159	14,028			
$K_{1j}/6$							
$K_{1j}/6$	2,652	1,700	1,892	1,996			
$K_{2j}/6$	1,505	2,525	2,146	2,230			
$K_{3j}/6$	2,408	2,341	2,527	2,338			
R_j	1,147	825	634	342			

The value of K_{ij} represents the sum of three values in the column "Sum" corresponding to the i^{th} level (1, 2, 3) within each of four factors (A, B, C, D) represented by j. For instance, the value of 15,909 is K_{1A} representing the sum of three values of 3350, 5975, and 6584 in the "Sum" column for the combination of factor A and level 1, whereas the value of 10,197 is K_{1B} representing the sum of the three values of 3350, 2247, and 4600 for the combination of factor B and level 1.

The value of $K_{ij}/6$ is the mean value of K_{ij} that can be used to determine the optimal level and the optimal combination of factors. The optimal level of each factor has the highest value of $K_{ij}/6$ among the three values within each factor column. For instance, the highest value of 2652 N in the column of factor A indicates that level 1 of factor A is the optimal level among the three levels of 1, 2, and 3 (Fig 7a), and it should be selected for the optimal combination of four factors. It is also concluded that the optimal levels for factors B, C, and D are 2, 3, and 3, respectively (Figs 7b, c, and d). Therefore, the optimal combination of factors and their levels that yields the highest ultimate tensile load is level 1 of factor A by level 2 of factor B by level 3 of factor C by level 3 of factor D, ie the highest ultimate tensile load of a T-shaped, end-to-side joint can be obtained if the joint is constructed with *Calamus manan* Miq. materials with bark as the joint structural rail and post members connected with a screw and wrapped with rattan flat bast II using a cross and parallel pattern.

In Table 4, the value of R_j is defined as the difference between the maximum and minimum values among three values of $K_{ij}/6$ within the j^{th} column (j = A, B, C, D). For instance, $R_A = K_{1A}/6 - K_{2A}/6 = 2652 - 1505 = 1147\ N$. The R_j value is used to evaluate the order of each of four factors on the ultimate tensile load of T-shaped, end-to-side joints, ie the higher the R_j value, the more impact the factor has on the ultimate tensile load. Inner fastener type (factor A) had the highest R_j value of 1147 N among the four factors. Therefore, the order of impact on the ultimate tensile load of four factors is inner fastener type > wrapping pattern > member material type > wrapping material type (Fig 8).

Analysis of variance (ANOVA) was also performed to quantify the contribution of each factor on the ultimate tensile load because of the fact that the range analysis method lacks the

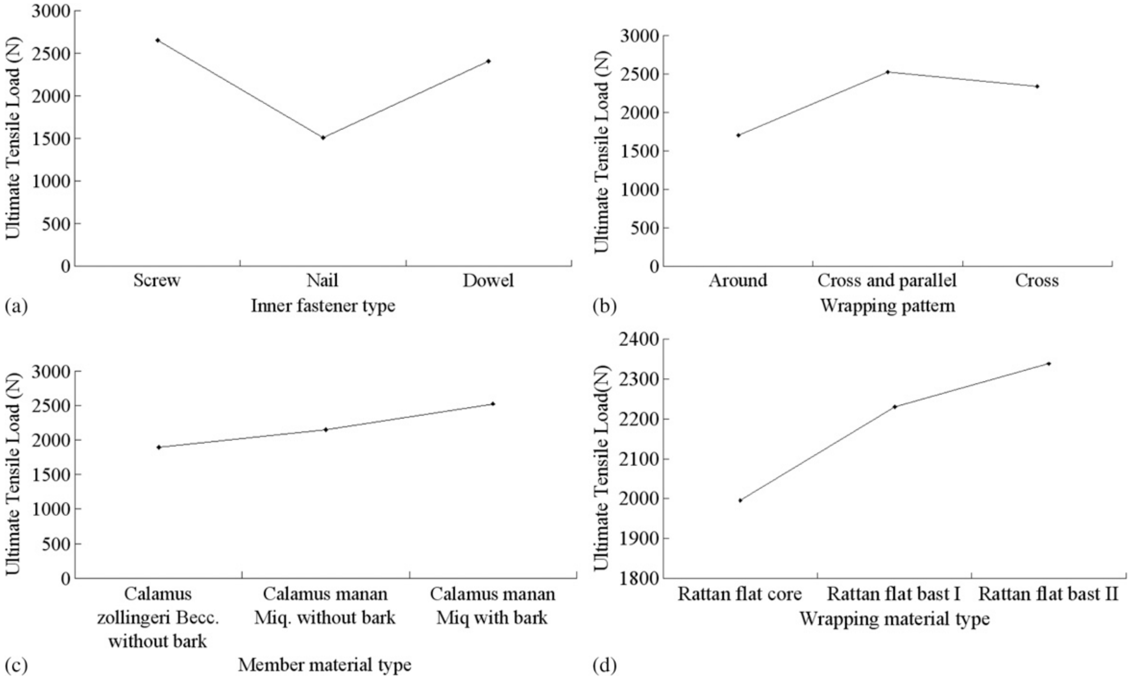


Figure 7. Ultimate tensile loads vs (a) inner fastener type, (b) wrapping pattern, (c) member material type, and (d) wrapping material type.

ability to quantify each factor contribution to the response variable. Table 5 summarizes the ANOVA results. The purified sum of squares for each factor (SS_j') is (Wu and Leung 2011):

$$SS_j{}' = SS_j - MS \times df_j \qquad (1)$$

where SS_j is the sum of square, *MS* is the mean square, *df* is the degrees of freedom, and *j* is the index for factors A, B, C, and D.

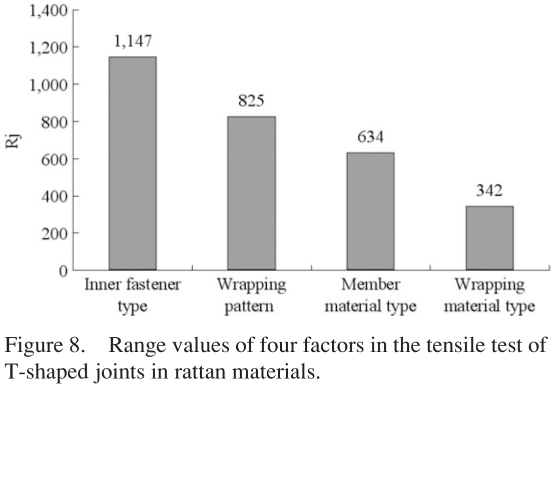


Figure 8. Range values of four factors in the tensile test of T-shaped joints in rattan materials.

The percentage contribution of each factor (P_j) is

$$P_J = \left(SS_j{}' / SS_T \right) \times 100\% \qquad (2)$$

where SS_T is the total sum of squares.

The percentage of contribution to the total sum of squares caused by experimental error is 5.25%, which is less than 15%. This indicates that the experimental data from evaluating ultimate tensile loads of the joints constructed in this study are reliable and no important factor will be misinterpreted. At the 1% significance level, the critical value of $F_{0.01}$ was found to be 8.02, ie $F_{0.01}$ (2, 9) = 8.02. The computed values of F_A, F_B, and F_C were 84.0, 43.1, and 23.4 (Table 5), respectively, and all exceeded the critical value. The computed value of F_D was 7.0, which was less than $F_{0.01}$ but greater than the critical value of $F_{0.05}$ (2, 9) = 4.26 at the 5% significance level. This indicates that the inner fastener type, the wrapping pattern, and member material type were significant factors affecting the ultimate tensile load of T-shaped, end-to-side

Table 5. Analysis of variance of ultimate tensile loads of T-shaped, end-to-side joints in rattan materials based on L9 (3^4) orthogonal array experimental design.

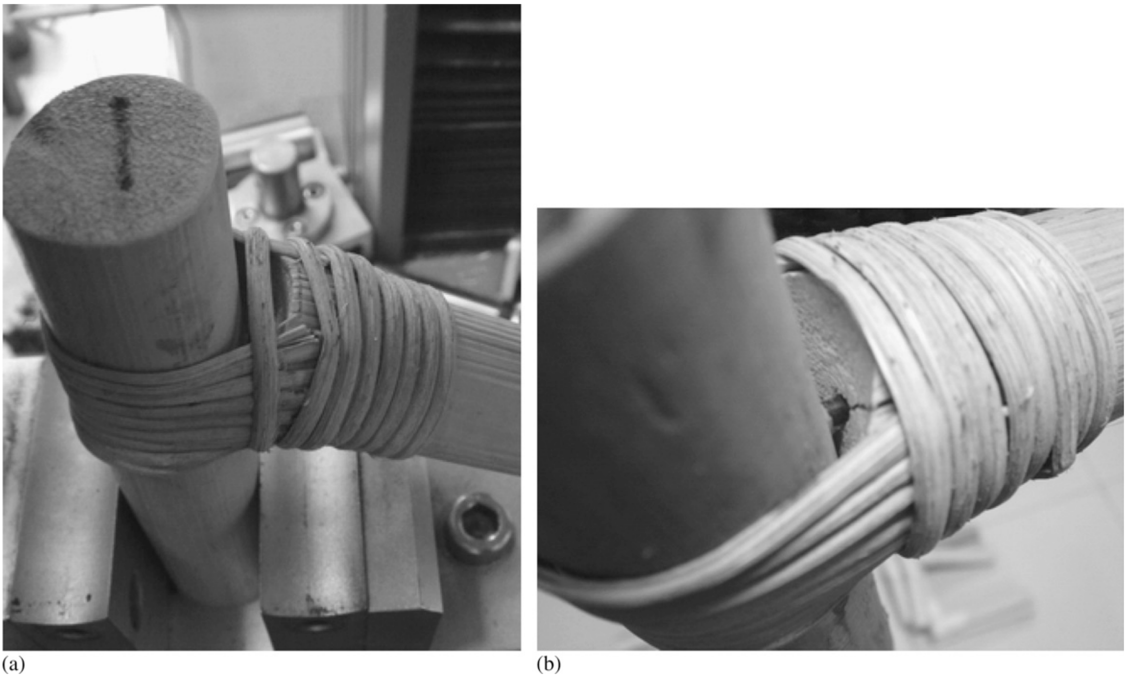
Sources (j)	SS_j	df_j	MS_j	F_j	$F_{0.01}$ (2, 9) = 8.02	$F_{0.05}$ (2, 9) = 4.26	SS_j'	P_j (%)
A	4,380,573	2	2,190,287	84.0	>	>	4,328,395	51.19
B	2,251,028	2	1,125,515	43.1	>	>	2,198,851	26.01
C	1,222,673	2	611,337	23.4	>	>	1,170,495	13.84
D	366,168	2	183,084	7.0	<	>	313,990	3.71
Error	234,801	9	26,089				443,514	5.25
Total	8,455,245	17					8,455,245	100.0

joints in rattan materials, but the wrapping material type was not a significant factor at the 1% significance level. All four factors were significant at the 5% significance level. The percentage contribution values were 51.19, 26.01, 13.84, and 3.71 for inner fastener type, wrapping pattern, member material type, and wrapping material type, respectively. This indicates that inner fastener type contributed to the ultimate tensile load of T-shaped, end-to-side joints in rattan materials the most with the percentage of contribution being 51.19 among the four factors.

Bending Test

Two typical failure modes occurred in the tests. Type I was external wrapping material loosened or broken (Fig 9a). Type II was rail end splitting (Fig 9b).

Table 6 summarizes mean results of ultimate bending moment of T-shaped, end-to-side joints in rattan materials based on the orthogonal array experimental design and their range analysis results. The value of bending moment of T-shaped joints is multiplied by ultimate bending moment load and length of moment arm (ie 120 mm).



(a) (b)

Figure 9. Two types of failure modes in bending tests of T-shaped joints in rattan materials: (a) external wrapping materials loosened or broken, and (b) rail end splitting.

Table 6. Results of ultimate bending moment and their range analyses of T-shaped, end-to-side joints in rattan materials based on L9 (3^4) orthogonal array experimental design.

	Factors				Ultimate bending moment (N·m)		
Experiments	A	B	C	D	Mean 1	Mean 2	Sum
1	1	1	1	1	21.24	21.60	42.84
2	1	2	2	2	22.80	21.60	44.40
3	1	3	3	3	19.56	20.40	39.96
4	2	1	2	3	8.40	10.80	19.20
5	2	2	3	1	21.72	19.32	41.04
6	2	3	1	2	13.56	14.40	27.96
7	3	1	3	2	15.96	14.40	30.36
8	3	2	1	3	13.20	15.60	28.80
9	3	3	2	1	18.36	18.00	36.36
K_{1j}							
K_{1j}	127.20	92.40	99.60	120.24			
K_{2j}	88.20	114.24	99.96	102.72			
K_{3j}	95.52	104.28	111.36	87.96			
$K_{1j}/6$							
$K_{1j}/6$	21.20	15.40	16.60	20.04			
$K_{2j}/6$	14.70	19.04	16.66	17.12			
$K_{3j}/6$	15.92	17.38	18.56	14.66			
R_j	6.50	3.64	1.96	5.38			

Based on the criteria of finding the highest $K_{ij}/6$ value among the three levels of each factor, it is concluded that the optimal levels for factors A, B, C, and D are 1, 2, 3, and 1 (Fig 10), respectively. Therefore, the optimal combination of factors and their levels that yields the highest ultimate bending moment is level 1 of factor A by level 2 of factor B by level 3 of factor C by level 1 of

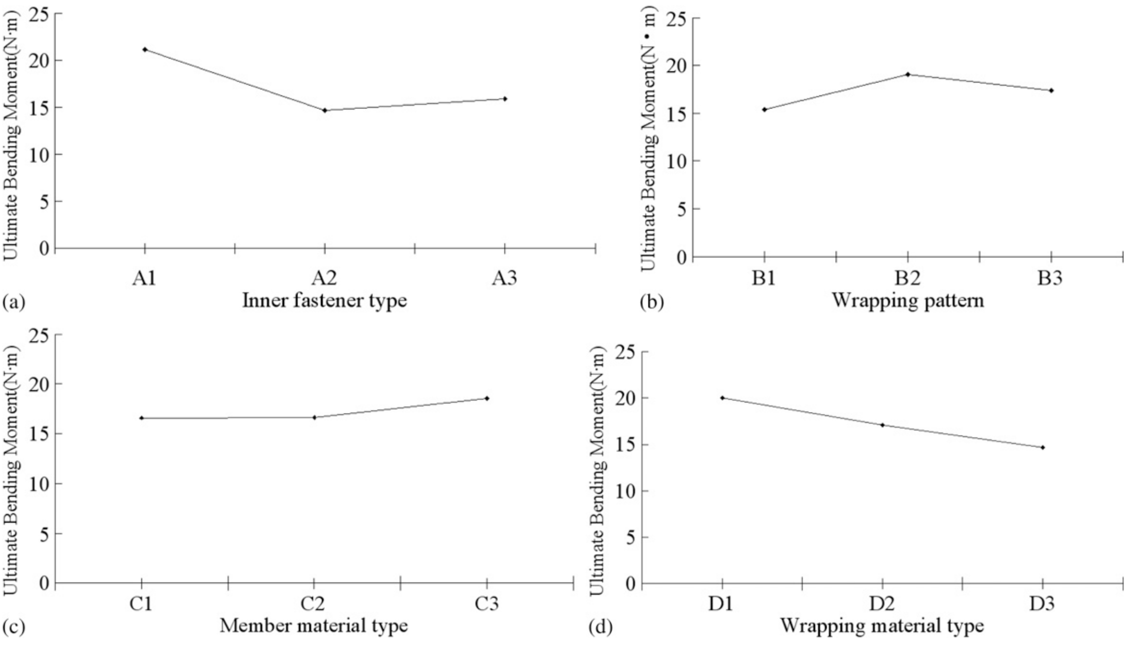


Figure 10. Ultimate bending moments vs (a) inner fastener type, (b) wrapping pattern, (c) member material type, and (d) wrapping material type.

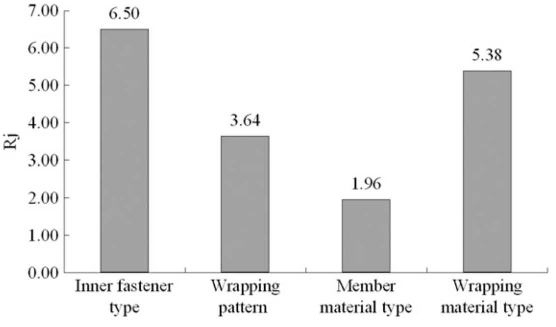


Figure 11. Range values of the four factors in the bending tests of T-shaped joints in rattan materials.

factor D. The highest ultimate bending moment of a T-shaped, end-to-side joint in rattan materials can be obtained if the joint is constructed with *Calamus manan* Miq. materials with bark as the joint structural rail and post members connected with a screw and wrapped with a rattan flat core using a cross and parallel pattern.

Factor A (inner fastener type) had the highest R_j value of 6.50 (N·m) among the four factors (Fig 11) followed by factor D (wrapping material type) with an R_j value of 5.38 (N·m), then factor B (wrapping pattern) with an R_j value of 3.64 (N·m), and then factor C (member material type) with an R_j value of 1.96 (N·m). Therefore, the order of impact on the ultimate bending moment load of the four factors was inner fastener type > wrapping material type > wrapping pattern > member material type.

Table 7 summarizes ANOVA results of ultimate bending moment. The percentage of contribution to the total sum of squares caused by experimental error was 7.27%, which is less than 15%. This indicates that the experimental data from bending tests were reliable and no important factor would be misinterpreted. At the 1% significance level, the computed values of F_A, F_B, and F_D were 56.4, 15.7, and 34.3, respectively, which exceeded the critical value $F_{0.01}$. The computed value of F_C was 5.9, which is less than $F_{0.01}$ but greater than the critical value of $F_{0.05}$. These results indicate that inner fastener type and wrapping pattern and material type are significant factors affecting the ultimate bending moment of T-shaped, end-to-side joints in rattan materials and that member material type is not a significant factor at the 1% significance level. All four factors were significant at the 5% significance level. The percentage contribution values were 47.46, 28.51, 12.59, and 4.17% for inner fastener type, wrapping material type, wrapping pattern, and member material type, respectively.

CONCLUSIONS

The effects of inner fastener type, wrapping pattern and material type, and member material type on the ultimate tensile and bending moment of T-shaped joints in rattan chair construction were investigated based on the L9 (3^4) orthogonal array experimental design. The range analyses indicated that the order of impact on ultimate tensile loads of four factors was inner fastener type > wrapping pattern > member material type > wrapping material type, whereas the order of impact on ultimate bending moment was inner fastener type > wrapping material type > wrapping pattern > member material type. The highest ultimate tensile load of a T-shaped, end-to-side joint in rattan materials is that constructed with the optimal combination of *Calamus manan* Miq. with bark as the joint structural rail and post

Table 7. Analysis of variance of ultimate bending moment of T-shaped, end-to-side joints in rattan materials based on L9 (3^4) orthogonal array experimental design.

Sources (j)	SS_j	df_j	MS_j	F_j	$F_{0.01}$ (2, 9) = 8.02	$F_{0.05}$ (2, 9) = 4.26	SS_j'	P_j (%)
A	143	2	72	56.4	>	>	141	47.46
B	40	2	20	15.7	>	>	37	12.59
C	15	2	7	5.9	<	>	12	4.17
D	87	2	44	34.3	>	>	85	28.51
Error	11	9	1				1497	7.27
Total	296	17					296	100.0

members connected with a screw and wrapped with rattan flat bast II using a cross and parallel pattern. The highest ultimate bending moment of a T-shaped, end-to-side joint in rattan materials is that constructed with the optimal combination of *Calamus manan* Miq. with bark as the joint structural rail and post members connected with a screw and wrapped with a rattan flat core using cross and parallel pattern.

ANOVA indicated that inner fastener type affected ultimate tensile and bending moment the most among the four factors with percentages of contribution of 51.19 and 47.06 to tensile and bending moment loads, respectively. The factor that ranked second on ultimate tensile load based on the magnitude of percentage of contribution (26.01) was wrapping pattern, whereas the one that ranked second on ultimate bending moment was wrapping material type with percentage of contribution of 28.51. The factor ranked third on ultimate tensile load was member material type, whereas the one that ranked third on ultimate bending moment was wrapping pattern. The factor wrapping material type was ranked last for its impact on ultimate tensile load, and member material type was ranked last for ultimate bending moment.

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