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Fatigue Performance of Natural and Synthetic Rattan Strips Subjected to Cyclic Tensile Loading

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Abstract: Tensile fatigue performances of selected natural rattan strips (NRSs) and synthetic rattan strips (SRSs) were evaluated by subjecting them to zero-to-maximum constant amplitude cyclic tensile loading. Experimental results indicated that a fatigue life of 25,000 cycles began at the stress level of 50% of rattan material ultimate tensile strength (UTS) value for NRSs evaluated. Rattan core strips' fatigue life of 100,000 cycles started at the stress level of 30% of its UTS value. Rattan bast strips could start a fatigue life of 100,000 cycles at a stress level below 30% of material UTS value. SRSs didn't reach the fatigue life of 25,000 cycles until the applied stress level reduced to 40% of material UTS value and reached the fatigue life of 100,000 cycles at the stress level of 40% of material UTS value. It was found that NRSs' S-N curves (applied nominal stress versus log number of cycles to failure) could be approximated by $S = \sigma_{ou}(1 - H \times \log_{10} \cdot N_f)$. The constant H values in the equation were 0.10 and 0.08 for bast and core materials, respectively.

Keywords: rattan bast strips; rattan core strips; synthetic rattan strips; tensile strength; fatigue life; cyclic loading

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1. Introduction

A rattan seating furniture consists of woven seat foundation and back support surfaces with natural rattan strips (NRSs) and frames made of natural rattan stem, wood, or metal materials with their connections wrapped with rattan strips as external structural reinforcement and decoration as well [1–5]. As surface supporting and joint reinforcement materials, NRSs can be subjected to tensile stresses. Therefore, the static tensile properties [6], especially the fatigue performance of natural rattan materials as a seating furniture structural material should be investigated because most service failures of woven surfaces of rattan seating furniture appear to be fatigue related. In addition to NRSs as rattan furniture weaving materials, furniture manufacturers continue to seek new materials like synthetic rattan strips (SRSs) [6] in order to enrich their products and alleviate the shortage in supply of natural rattan resources.

Limited literature has been found in related to investigate the fatigue performance of NRSs as furniture structural materials. Gu et al. [1] investigated the fatigue performance of seat foundations of natural rattan chairs subjected to vertical loads, observed that in general rattan strips were broken in tension, and suggested that tensile strength properties need to be investigated. To fill these knowledge gaps, we have been carrying out a systematic study on the investigation of static, fatigue, and creep behaviors of NRS and SRS materials as seating furniture structural components subjected to tensile loading. The static tensile performance of rattan materials was published [6]. This paper reports our

findings in evaluating the fatigue performance of rattan materials as seating furniture structural components.

In engineering, the term fatigue is defined as the progressive damage that occurs in a material subjected to cyclic loading [7]. There are three major approaches to analyzing and designing against fatigue failures: the stress-based, the strain-based, and the fracture mechanics [8]. The stress-based approach is to experimentally obtain the S-N curve (applied nominal stress versus log number of cycles to failure) of a researched material. This experimental method has been used in analyzing the bending fatigue property of wood-based composites such as plywood, oriented strandboard (OSB), and particleboard as furniture frame stock [9–11]. The Adkins' method, $S = \sigma_{ou}\ (E - H \times \log_{10} \cdot N_f)$, where σ_{ou} was material ultimate bending strength, N_f was the number of cycles-to-failure, was also applied to derive the fitting constants E and H for investigated wood-based composites. General findings from these studies indicated that larger variations of fatigue life were observed in terms of the coefficients of variation ranging from 97 to 185%. It was found that S = MOR $(1 - H \times \log_{10} \cdot N_f)$, where MOR is the modulus of rupture of tested materials, can be used to approximate S-N curves of wood-based composites in bending. The fitting constants E and H values summarized in Table 1 indicated that the constant H was correlated with basic wood element sizes of composite raw material such as veneer and particles.

Table 1. The fitting constants E and H values of estimated equations for wood composite S-N curves.

Material Type	Adkins		Reference
	E	H	
Plywood	0.9	0.05	Zhang et al., 2005 [9]
Particleboard	1	0.09	Zhang et al., 2005 [9]
OSB#1	0.9	0.07	Zhang et al., 2005 [9]
OSB#2	1	0.07	Dai et al., 2007 [10]
OSB#3	0.9	0.06	Dai et al., 2007 [10]
OSB#4	0.9	0.06	Dai et al., 2007 [10]

The primary objective of this study was to evaluate the fatigue performance of selected NRSs and SRSs subjected to zero-to-maximum constant amplitude tensile cyclic loading using the stress-based approach. The specific objectives were to: (1) obtain S-N curves of NRSs and SRSs and (2) explore different methods of deriving estimated S-N curves for rattan materials used in seating furniture construction. It is believed that this systematic research effort on the investigation of static, fatigue, and creep properties of rattan materials as furniture frame construction materials will provide a knowledge base that eventually can help furniture designers in their product design process with the consideration of material strength factors.

2. Materials and Methods

2.1. Approach

This experiment used the stress-based approach to analyze fatigue behavior of NRSs and SRSs subjected to zero-to-maximum constant amplitude tensile cyclic loading. The S-N curves, i.e., applied nominal stress versus the logarithm number of cyclic-to-failure of evaluated strips, were considered for describing the fatigue properties of NRSs and SRSs subjected to zero-to-maximum constant amplitude tensile cyclic loading.

Static tensile strength properties of NRSs and SRSs were evaluated first to obtain mean values of their ultimate tensile strength (UTS) values, followed by obtaining stress-life curves of three evaluated rattan strips through subjecting them to zero-to maximum constant amplitude tensile cyclic loading. The Adkins method [10–12] was considered in deriving the estimated S-N curves for evaluated rattan materials in this study.

2.2. Materials

The species of NRSs used in this study was *Rattan manau* (*Calamus manan Miq.*), provided by Boxuan Rattan Furniture Co., Ltd. (Nanjing, China). Specifically, two types of NRSs, rattan bast and core strips, were considered. Rattan bast strips were cut from the outer edge of rattan stems without their epidermis removed, and rattan core strips were cut from the pith portion of rattan stems using cane cutter (Figure 1a). NRSs had their dimensions measured 6 mm wide by 1 mm thick and 9 mm wide by 2 mm thick in their cross-sections, respectively. These NRSs are originally from Indonesia, and commercially available in Asian markets. SRSs measured 8 mm wide by 1 mm thick in their cross-section (Figure 1b) were purchased from Hongbo Plastic Industry Co., Ltd. (Hangzhou, China). These SRSs were fabricated through the extrusion technology at two-stage processing temperatures of 170 °C and 200 °C using plastics' mixtures of low-density polyethylene, propylene (5502), and polyethylene (linear 7042) with their mass ratio of 5:3:2.



Figure 1. Physical appearance of evaluated natural (**a**) and synthetic rattan (**b**) strips.

2.3. Experimental Design

Figure 2 showed the cutting pattern designed for the preparation of NRSs, evaluated in this experiment for their static and cyclic tensile strength performances.

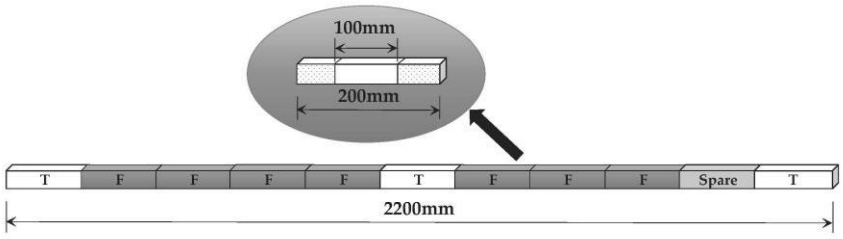


Figure 2. Sampling method and code number for static and fatigue tensile test of natural rattan.

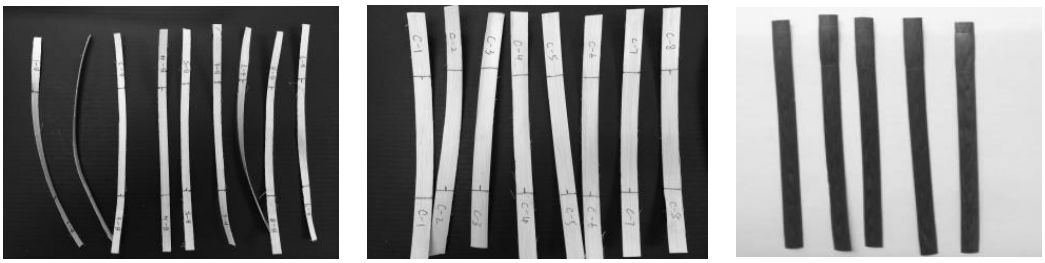
NRSs measured 200 mm long with their gauge length measured 100 mm, i.e., the length between two gripping heads. The three strips, labeled as T for a given rattan strip length of 2200 mm, were subjected to static tensile loading for obtaining the mean UTS value of this specific rattan strip. This mean UTS value was used to represent the UTS of all strips labeled as F that were subjected to constant amplitude cyclic loading, i.e., the strips labeled as F on this specific rattan strip were randomly selected to nominal cyclic stress levels at 90, 80, 70, 60, 50, 40, and 30% of its UTS value, respectively. Stress-life curves (S-N curves) of evaluated rattan strips were obtained based on constant amplitude cyclic tests. Ten replicates were tested for each of seven nominal cyclic stress levels for each of three types of rattan strip materials. Therefore, for each of natural bast and core rattan materials, in total, 70 strips were tested under cyclic tensile stresses, while 30 strips were tested under static tensile loading.

For SRSs, ten replicates were randomly selected from the prepared supply to obtain its mean UTS values. Ten replicates were randomly picked from the prepared supply for each

of seven nominal cyclic stress levels of 70, 65, 60, 55, 50, 45, and 40% of its corresponding static mean UTS value. Therefore, in total, 70 SRSs were tested under cyclic tensile stresses, while 10 SRSs were tested under static tensile loading. All SRSs also measured 200 mm long with their gauge length measured 100 mm.

2.4. Experimental Preparation and Testing

For each of natural bast and core rattan materials evaluated in this experiment, ten 2200 mm long strips were randomly cut from their rolls first, respectively, followed by cutting each of long strips into 200 mm long testing strips per the cutting pattern (Figure 2). A 200-mm long SRS supplier was prepared through cutting SRS rolls first, followed by randomly selected 10 strips from the supplier for static tensile testing and 70 strips for cyclic tensile testing. Figure 3 showed NRSs and SRSs cut for each of three types of rattan strips evaluated. All testing strips were free of visible defects such as cracks, scratches, and burrs.



(**a**) (**b**) (**c**)

Figure 3. Testing bast (**a**), core (**b**), and synthetic (**c**) rattan strips.

All testing rattan strips were conditioned in an environment with an ambient temperature of 25 ± 2 °C and relative humidity of 40 ± 2% for over 48 h prior to testing. The cross-section of NRSs and SRSs had a flat long side and an arc-shape on the opposite side (Figure 4). The cross-sectional area was equal to the sum of the area of the rectangular cross-section and the area of the circular segment. Moreover, the area of the circular segment can be presented as the area of the circular sector minus the area of the triangle. Width (2α) and thickness (β) of NRSs and SRSs were measured at three locations within the gauge length using an electronic digital caliper right before static tensile test. The average cross-sectional area, S (mm^2), can be calculated using the following formulas:

$$S = \alpha(\beta + \gamma) + \frac{\pi(90 - \arccos\frac{\alpha}{\beta-\gamma})\left[\alpha^2 + (\beta-\gamma)^2\right]}{360\cos^2\arccos\frac{\alpha}{\beta-\gamma}} - \frac{\alpha\sqrt{\alpha^2 + (\beta-\gamma)^2}}{2\cos\cdot\arccos\frac{\alpha}{\beta-\gamma}} \quad (1)$$

where α is half the width of a rattan strip (mm); β is the overall thickness of a rattan strip (mm); γ is the thickness of the rectangular cross-section of a rattan strip (mm).

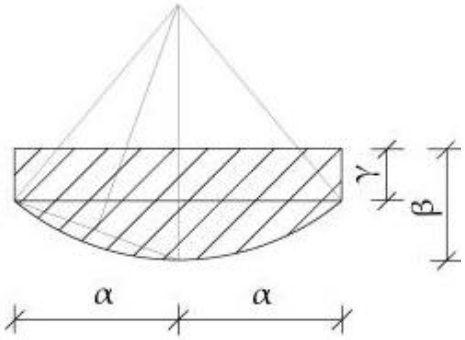


Figure 4. Cross-section geometry of tested natural and synthetic rattan strips.

2.4.1. Static Test

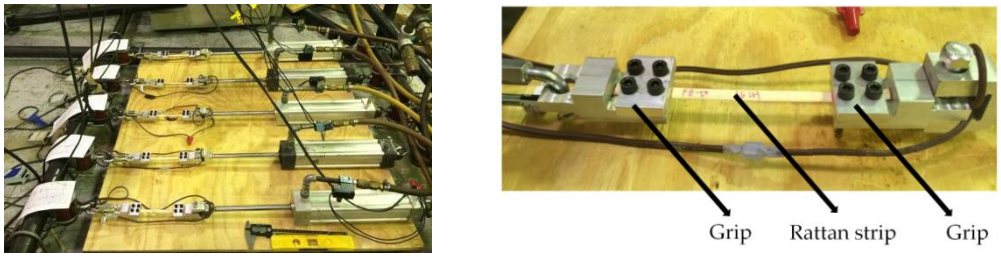
All static tensile tests were performed on a universal-testing machine (INSTRON 5566, Instron Corp., Norwood, MA, USA) in accordance with the procedures outlined in Chinese National Standards (CNS) GB/T 1938–2009 [13] and GB/T 15780–1995 [14] for NRSs, and American Society of Testing Materials (ASTM) D882-2012 [15] for SRSs, respectively. The loading rates of NRSs and SRSs were 30 and 40 mm per minute, respectively [6]. All NRSs were loaded until a fracture breakage occurred to the strips, while all SRSs were tested till reaching a strain level of 20% (since it was observed that, the stress-strain curve of a tested SRS became flatten after reaching this strain level without a fracture breakage occurring in general) [6]. Failure modes and load-deflection data of all tested strips were recorded. UTS values of all tested rattan strips, σ_u (MPa) were calculated using the following formulas:

$$\sigma_u = {}^P/_S \quad (2)$$

where P is the test tensile load at the ultimate point determined from load-elongation curves (N); S is the average cross-sectional area (mm^2) of a tested rattan strip.

2.4.2. Fatigue Test

Zero-to-maximum constant amplitude cyclic tensile tests were conducted on a specially designed air cylinder and pipe rack system as shown in Figure 5. This set-up allowed five strips to be tested simultaneously. Each tested rattan strip was clamped at each of two gripping heads with the grip length of 100 mm. In general, zero-to-maximum cyclic tensile loads were applied to rattan strips by air cylinders for each loading level at a rate of 20 cycles per minute [16]. Specifically, the cyclic tensile load starts with zero load, then the load reaches its maximum value for 0.75 s, drops to zero and retains zero for 0.75 s until the next load cycle starts. A Programmable Logic Controller and electrical re-settable counter system recorded the number of cycles completed. Limit switcher actuated and stopped the test when the tested strip broke completely into two pieces, or until 100,000 cycles were reached for NRSs, and 20% strain was reached for SRSs. The maximum number of cycles, 100,000, considered was mainly because 100,000 cycles (Table 2) were selected as heavy-service acceptance level for testing the durability of seat surface of chair, according to Chinese National Standards (CNS) GB/T 10357.3–1989 [17]. All rattan strips were tested in the lab room maintained at the temperature of 25 ± 2 °C and 40 ± 2% relative humidity. Failure modes and the numbers of cycles-to-failure of all tested rattan strips were recorded.



(**a**) (**b**)

Figure 5. Overview of a specially designed air cylinder and pine rack system for constant amplitude cyclic testing of rattan strips (**a**), and a close look at the set-up for testing a single rattan strip (**b**).

Table 2. Cyclic loading schedule for testing the durability of a chair seat surface.

P	Cumulative Cycles	Service Acceptance Level
950N	25,000	Light duty service
950N	50,000	Medium duty service
950N	100,000	Heavy duty service

3. Results and Discussion

3.1. Static Tests

Table 3 summarized mean values of UTS of NRSs evaluated. The mean value of UTS of SRSs was 10.37 MPa with its CV value of 4%. NRSs failed with three typical modes: splintering tension, brash tension, and combined splintering and brash tension (Figure 6a–c). Percentage distributions of these failure modes of NRSs were summarized in Table 4. Detailed discussion can be found in our first report [6]. No fracture failure modes were observed in SRSs, but a localized yield necking mode was observed for all SRSs (Figure 6d).

Table 3. Mean values of ultimate tensile strength of tested natural rattan strips.

Rattan Type.	Group #										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Overall Avg. (σ_{ou})**
	- - - - - - - - - - - - (MPa) - - - - - - - - - - -										
Bast	27.29 (2) [a]	34.48 (16)	21.12 (12)	21.17 (12)	30.13 (12)	36.74 (1)	37.73 (3)	49.37 (6)	27.85 (0)	35.27 (14)	32.12
Core	21.88 (3)	25.99 (8)	22.71 (11)	22.48 (8)	21.76 (6)	21.76 (6)	24.53 (8)	24.53 (8)	23.61 (6)	22.96 (4)	23.22

[a] Values in parentheses are coefficients of variation in percentage.



(**a**) (**b**) (**c**) (**d**)

Figure 6. Typical failure modes of natural rattan strips observed in static and fatigue tests: splintering tension (**a**), brash tension (**b**), and combined splintering and brash tension (**c**), and typical failure mode of synthetic rattan strips: yield necking (**d**).

Table 4. Percentage distribution of failure modes for natural rattan strips subjected to static and fatigue tensile loadings.

Test	Rattan Type	Percentage Distribution of Failure Modes (%)		
		Splintering	**Brash**	**Combination**
Static	Bast	35	57	8
	Core	7	80	13
Fatigue	Bast	27	69	4
	Core	18	68	14

3.2. Fatigue Tests

Table 4 indicated that the majority of bast and core strips failed in brash tension when subjected to zero-to-maximum constant amplitude tensile cyclic loading. The general trend of percentage distribution of NRS failure modes when subjected to fatigue tensile loading is similar to the one to static tensile loading.

The range, mean values, and CVs of fatigue life (number of cycles to failure) of NRSs and SRSs were summarized in Tables 5 and 6, respectively. The CVs of fatigue life averaged 113, 116, and 7% for bast strips, core strips, and SRSs, respectively. In general, larger variations in fatigue life were observed in NRSs, and the variation tended to decrease as the normal stress level decreased (Table 5), and this observation is similar to the one published in the previous study on the fatigue performance of wood-based composites [10]. All core strips can reach 100,000 cycles without breaking into pieces when subjected to its nominal stress level at 30% of its average UTS value. Meanwhile, bast strips were still in the averaged 60,000-cycles level when subjected to its nominal stress level at 30% of its average UTS value. If compared these results to ones published in the previous study on fatigue life of wood-based composite study [10] that indicated there was significant jump from average fatigue life of 100,000-cycles level to higher numbers occurred at nominal stress levels of 65, 60, and 45% of their average UTS values of plywood, OSB, and particleboard, respectively. For instance, in case of particleboard, its fatigue life jumped from 95,160 cycles to 497,282 cycles when the nominal stress level was reduced from 45% to 35% of its average UTS value. This jump fatigue life was not observed in NRS materials even at 30% of their average UTS values (Table 5). This indicated that further study on the fatigue life of NRS materials with the consideration of lowing the nominal stress level below 30% of their average UTS values is necessary. All SRSs subjected to 40% of its UTS value reached 100,000 cycles without reaching its 20% strain limit. It was noticed that the fatigue life SRSs only reached to 1,678 cycles when subjected to 45% of its average UTS value, while NRSs can reached 38,170 cycles when subjected to 50% of its average UTS value. Overall, SRSs had significantly lower variation in fatigue life if compared with NRSs.

Table 5. Results of fatigue life (number of cycles to failure) at each of applied stress levels for natural rattan strips subjected to zero-to-maximum constant amplitude cyclic tensile loading.

Stress Levels	Rattan Type					
	Bast			Core		
	Range	Mean	CV	Range	Mean	CV
(%)	(Cycles)	(Cycles)	(%)	(Cycles)	(Cycles)	(%)
90	1–15	5	118	1–925	184	185
80	1–133	32	144	1–4819	856	181
70	11–4525	1336	119	18–52,017	8658	184
60	99–56,556	19,357	119	447–90,881	24,486	136
50	568–100,000	38,170	106	1104–100,000	41,170	88
40	2245–100,000	52,536	97	23,419–100,000	85,594	36
30	2561–100,000	61,772	85	100,000	100,000	0
Avg.			113			116

Table 6. Results of fatigue life (number of cycles to failure) at each of applied stress levels for synthetic rattan strips subjected to zero-to-maximum constant amplitude cyclic tensile loading.

Stress Levels	Range	Mean	CV
(%)	(Cycles)	(Cycles)	(%)
70	1	1	0
60	1–2	2	25
55	3	3	0
50	415–476	460	6
45	1533–1839	1678	9
40	100,000	100,000	0
Avg.			7

Bast strips had its average fatigue lives of 38,170; 52,536; and 61,772 cycles when subjected to nominal stresses equal to 50, 40, and 30% of their average UTS values, respectively. This could suggest that light duty service acceptance level (Table 2) could be met when bast strips were designed as weaving surface to resist zero-to-maximum constant amplitude cyclic tensile stresses equal to 50% of its average UTS value, while passing medium duty service acceptance level (Table 2) if a strength design value is set to 40 and 30% of its average UTS value. For passing heavy duty service acceptance level (Table 2), the strength design value should be below 30% of its average UTS value.

Core strips had its average fatigue lives of 41,170; 85,594; and 100,000 cycles when subjected to nominal stress equal to 50, 40, and 30% of their average UTS values, respectively. This could suggest that light duty service acceptance level could be met when core strips were designed as weaving surface to resist zero-to-maximum constant amplitude cyclic tensile stresses equal to 50% of its average UTS value, while passing medium heavy duty service acceptance level if a strength design value is set to 40% of its average UTS value, and a strength value of 30% of its average UTS value can yield core strips as weaving surface passing heavy duty service acceptance level.

When using SRSs as the weaving surface for seat supporting of a chair, a strength value of 40% of its average UTS can yield its performance passing 10,000 minimum loading cycles required.

The fatigue behavior of rattan strips subjected to zero-to-maximum constant amplitude cyclic tensile loading was described using their S-N curves. Figure 7 plotted individual data points of applied nominal stress, S, versus fatigue life (the number of cycles-to-failure), N_f, in linear-log coordinate system for all three rattan strips evaluated in this study. The analysis of correlation coefficient, r, indicated that there is a strong linear relationship between the applied nominal stress and the number of cycles-to-failure (Table 7) for each tested rattan strip group. Therefore, the following equation was employed to fit individual data points using the least square regression method for each of three material data sets [8]:

$$S = C - D \times \log_{10} \cdot N_f \quad (3)$$

where S is the applied nominal stress (MPa); N_f is the number of cycles-to-failure; C, D are fitting constants.

Table 7. Constants of derived equations for S-N curves of evaluated rattan strips.

Rattan Type	σ_{ou} (MPa)	Linear Regression					
		C	D	r	r^2	E	H
Bast	32.12 (27) [a]	27.82	2.99	−0.93	0.87	0.9	0.1
Core	23.22 (6)	19.93	1.46	−0.94	0.88	0.9	0.08
Synthetic	10.37 (5)	6.55	0.55	−0.88	0.76	0.6	0.05

[a] Values in parentheses are coefficients of variation in percentage.

Linear regression analyses resulted in three regression equations for three rattan materials. The regression fitting constant values of C, D, and coefficient of determination r^2 values of derived equations for each of three materials were given in Table 7.

The following Adkins' equation was derived through setting $C = \sigma_{ou} \times E$ and $D = \sigma_{ou} \times H$ for each of three rattan materials:

$$S = \sigma_{ou} \times (E - H \times \log_{10} \cdot N_f) \quad (4)$$

where S is the applied nominal stress (MPa); σ_{ou} is the overall average ultimate tensile strength of tested rattan strips (MPa); N_f is the number of cycles to failure; E is equal to C/σ_{ou}; H is equal to D/σ_{ou}.

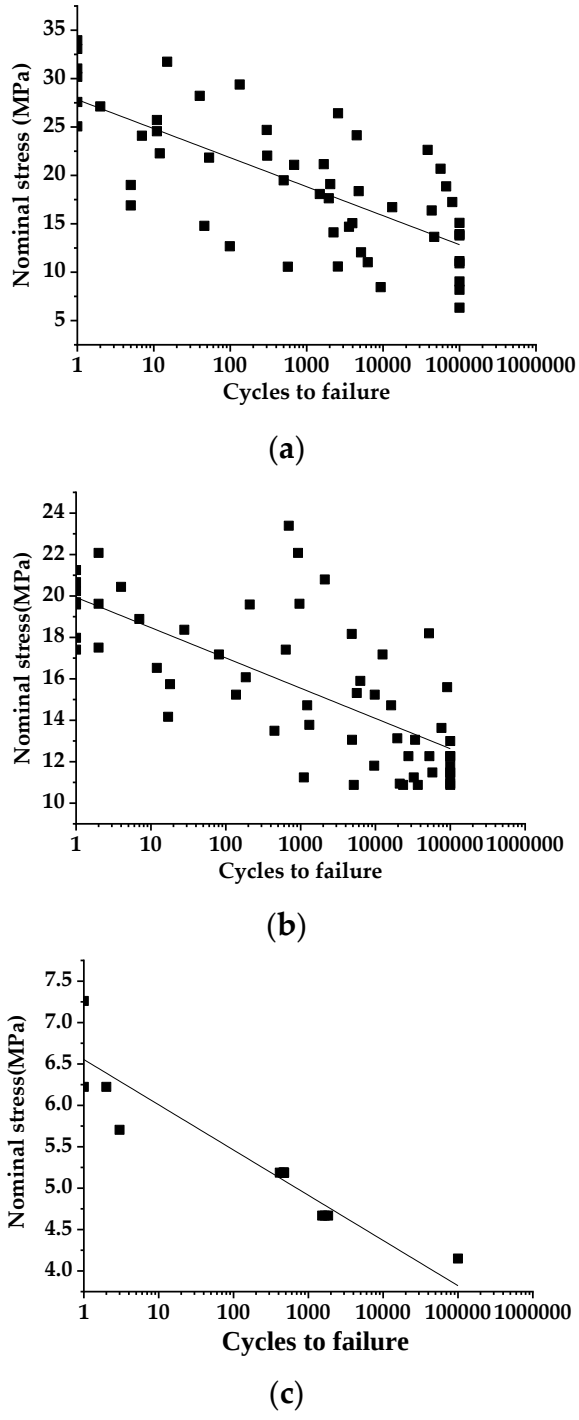


Figure 7. S-N curves of three evaluated rattan materials in this study: rattan bast strips (**a**), rattan core strips (**b**), and synthetic rattan strips(**c**). Individual data points of each evaluated rattan strip were plotted on linear-log coordinate system.

The calculated constants E and H were summarized in Table 7 under the Adkins columns. The constant E value of NRS materials all equaled to 0.9 that is close to 1, but the one of SRS materials is 0.6. These results might suggest that S-N curves of NRS materials could be approximated with Adkins formula, i.e., approximating E value as 1, but the ones of SRS materials could not be. The constant H was 0.10, 0.08, and 0.05 for bast, core, and synthetic rattan materials, respectively, implying that the constant H is somehow correlated to the geometry characteristics of basic building block of rattan strips [10], such

as fiber length of rattan strips. In general, the length (or fiber aspect ratio) of fibers that are basic building blocks of bast rattan materials is larger than the one in core rattan materials [18]. Therefore, our experimental results indicated that the effect of basic building blocks of rattan materials on its constant H in a different way if compared to the observation presented in previous study [10]. In other words, the observation in the study [10] indicated a negative trend of the constant H value decreasing as the size of basic building blocks of man-made wood-based composites increasing. Meanwhile, experimental results from this rattan material study indicated a positive trend of the constant H value increasing as the length of basic building blocks increasing. One possible explanation of this difference could be that the bonding among fibers in NRS materials or molecules chain of SRS materials is better than the one among building blocks of man-made composites such as plywood, OSB, and particleboard. Therefore, the bonding performance among basic building blocks of a composite could be a factor on its fatigue performance.

4. Conclusions

The major findings of this experimental investigation on fatigue life of NRSs and SRSs when subjected to zero-to-maximum constant amplitude cyclic tensile loadings are the following:

1. A fatigue life of 25,000 cycles started at the stress level of 50% of UTS values for the natural rattan strips evaluated. Rattan core strips started its fatigue life of 100,000 cycles at the stress level of 30% of its UTS value, while rattan bast strips could start its fatigue life of 100,000 cycles at a stress level below 30% of its UTS value. SRSs didn't reach its fatigue life of 25,000 cycles until the stress level reduced to 40% of its UTS value and reached its fatigue life of 100,000 cycles at the stress level of 40% of its UTS value.
2. The CVs of fatigue life averaged 113, 116, and 7% for bast strips, core strips, and SRSs, respectively. The CVs in tested NRSs tended to decrease as applied stress level decreased.
3. The functional relationship between the fatigue stress and the log number of cycles to failure can be expressed with the linear equation $S = C - D \times \log_{10} \cdot N_f$ for rattan strips evaluated in this study. By incorporating the average UTS value of each of the evaluated rattan strips, it was found that the S-N curves of NRSs could be approximated by $S = \sigma_{ou}(1 - H \times \log_{10} \cdot N_f)$, reflecting the relationship between natural rattan material static strength and fatigue life. The constant H values in the equation were 0.10 and 0.08 for bast and core materials, respectively.
4. These experimental results and functional relationships derived are limited to the rattan materials investigated in this study. The conclusions are limited to theoretical development stage and not ready for practical design usage yet. General conclusions than can be applied for practical application usage should be made when a comprehensive study on all types of rattan materials has completed. It is believed that our systematic research effort on the investigation of static, fatigue, and creep properties of rattan materials as furniture frame construction materials will provide a knowledge base that eventually can help furniture designers in their product design process with the consideration of material strength factors.
5. Future studies should be considered in the direction of investigating fatigue life of rattan materials subjected to nominal stress level that is lower than 30% of their materials' UTS values. Furthermore, the effects of the size of material building blocks and other factors such as bonding performance among material building blocks on the constants in the functional relationship between fatigue stress level and fatigue life of natural fiber-based composites should be further investigated.

Author Contributions: Conceptualization, J.Z. and Y.G.; methodology, J.Z. and Y.G.; software, Y.G.; validation, J.Z.; investigation, Y.G.; resources, J.Z.; data curation, Y.G.; writing—original draft preparation, Y.G.; writing—review and editing, J.Z. and Y.G. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to their complexity.

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References

1. Gu, Y.T.; Wu, Z.H.; Zhang, Z.L. Load-deflection behavior of rattan chair seats. *Wood Fiber Sci.* **2016**, *48*, 1–12.
2. Gu, Y.T.; Wu, Z.H.; Zhang, Z.L. Tensile and Bending Moment Resistances of T-Shaped Joints in Rattan Chairs. *Wood Fiber Sci.* **2013**, *45*, 429–441.
3. Desmond, P.C. The Rattan Plant. In *Manual on the Production of Rattan Furniture*; United National Industrial Development Organization: New York, NY, USA, 1983; pp. 5–6.
4. Miller, B.W.; Widess, J. *The Caner's Handbook*; Lark Books: New York, NY, USA, 1991; pp. 13–20.
5. Widess, J. *The Complete Guide to Chair Caning: Restoring Cane, Rush, Split, Wicker, and Rattan Furniture*; Sterling Publishing: New York, NY, USA, 2006; pp. 6–15.
6. Gu, Y.T.; Zhang, Z.L. Tensile Properties of Natural and Synthetic Rattan Strips Used as Furniture Woven Materials. *Forests* **2020**, *11*, 1299. [CrossRef]
7. Forest Products Laboratory. *Wood Handbook—Wood as an Engineering Material. General Technical Report FPL-GTR-282*; U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA, 2021; 543p.
8. Dowling, N.E. *Mechanical Behavior of Materials*; Prentice Hall: Hoboken, NJ, USA, 1999; pp. 401–411.
9. Bao, Z.; Eckelman, C.A. Fatigue life and design stresses for wood composites used in furniture. *Forest Prod. J.* **1995**, *45*, 59–63.
10. Zhang, J.L.; Chen, B.Z.; Daniewicz, S.R. Fatigue performance of wood-based composites as upholstered furniture frame stock. *Forest Prod. J.* **2005**, *55*, 53–59.
11. Dai, L.; Zhang, J.L. Fatigue performance of wood composites subjected to edgewise bending stress. *Forest Prod. J.* **2007**, *57*, 44–51.
12. Adkins, D.W.; Kander, R.G. Fatigue performance of glass reinforced thermoplastics. Paper No.8808-010. In Proceedings of the 4th International Conference on Advanced Composite Materials in Bridges and Structures, Calgary, AB, Canada, 20–23 July 2004; ASM International: Russell Township, OH, USA, 1988.
13. *GB/T 1938-2009*; Method of Testing in Tensile Strength Parallel to Grain of Wood. China National Standard: Beijing, China, 2009.
14. *GB/T 15780-1995*; Testing Methods of Physical and Mechanical Properties of Bamboos. China National Standard: Beijing, China, 1995.
15. *ASTM D882-2012*; Standard Test Method for Tensile Properties of Thin Plastic Sheeting. American Society for Testing and Materials: West Consholocken, PA, USA, 2012.
16. *FNAE-80-214A*; Upholstered Furniture Test Method. Furniture Commodity Center, Federal Supply Services, General Service Administration: Washington, DC, USA, 1998.
17. *GB/T 10357.3–1989*; Test of Mechanical Properties of Furniture Strength and Durability of Chairs and Stools. China National Standard: Beijing, China, 1989.
18. Wang, Y.B. Studies on Wood Properties of Plantation Rattan. Master's Thesis, Nanjing Forestry University, Nanjing, China, 1 June 2006.