

Research Article

Influence of Four Ageing Methods on the Mechanical Properties of Bamboo Scrimber

Hongyan Wang, Shaofei Yuan, Jian Zhang , and Qin Li

Key Laboratory of Bamboo Research of Zhejiang Province, Zhejiang Academy of Forestry, Hangzhou, Zhejiang 310023, China

Correspondence should be addressed to Jian Zhang; 47207187@qq.com

Received 6 May 2021; Revised 7 July 2021; Accepted 31 July 2021; Published 23 August 2021

Academic Editor: Jingpeng Li

Copyright © 2021 Hongyan Wang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

In this study, the six-cycle accelerated ageing method (method I), the 6 h boiling-freezing-drying method (method II), the wet circulation method (method III), and the boiling-testing method (method IV), which are accelerated ageing testing methods, were used to study the ageing resistance of bamboo scrimber. Changes in the nail-holding power of the plane, the side, and the end face of untreated/treated bamboo scrimber were analyzed systematically, including other changes in mechanical properties, such as the horizontal shear strength, the modulus of rupture (MOR), and the modulus of elasticity (MOE) along the smooth grain, etc. The results show that all mechanical properties decreased after treatment with the four accelerated ageing testing methods: the nail-holding power decreased by 4%~42% on the plane, 8%~40% on the side, and 5%~66% on the end face. The horizontal shear strength decreased by 3.1%~16.7%, the MOR decreased by 15%~27.2%, and the MOE decreased by 2.6%~12.8%. The nail-holding power of the three sides and the MOR were the most affected properties after treatment. So, the nail-holding power and the MOR can be chosen as important indices to evaluate bamboo scrimber's weather resistance. For the four accelerated ageing testing methods, the degree of influence on the nail-holding power was in this sequence: method I > method III > method IV > method II. However, after comprehensive consideration, the degree of influence on the mechanical properties was in this sequence: method I > method IV > method III > method II.

1. Introduction

Bamboo scrimber is China's first independent research and development product with independent intellectual property rights as a major industrialized bamboo product [1, 2]. Its raw material is bamboo, an abundant resource with a short growth cycle and high utilisation rate as well as excellent mechanical properties, which can meet the needs of outdoor building materials [3, 4]. These outdoor building materials include outdoor floors, beams, columns, indoor/outdoor wall panels, and roof panels [1, 5]. Bamboo is a rare biomass material for green buildings.

Compared with natural wood and traditional wood-based panels, bamboo scrimber has better hardness and strength, including water and weather resistance; however, it is prone to decay as well as to mildew and moth attacks with changes in light, temperature, and humidity, which can result in the low performance of bamboo scrimber [3, 6]. According to incomplete statistics, the loss in bamboo

quantity owing to decay, mildew, and moth eating accounts for approximately 10% of the world's bamboo output every year [7–9]. However, the biggest limiting factor for developing bamboo scrimber for use in architecture and outdoor infrastructures is its low weather resistance. Weather resistance is the ability of a material to resist external natural conditions, such as dry, wet, cold, and warm weather; frost; rain; and snow, as well as ultraviolet radiation during use. It is also referred to as ageing resistance. The main factors influencing bamboo scrimber's ageing resistance are as follows: first is the chemical composition and fibrous morphology of the material; second is the adhesive's water and heat resistance used in the production of bamboo scrimber; and third are external environmental conditions, such as temperature and humidity when used [9, 10]. Currently, there is no specialised testing method to evaluate the ageing resistance of bamboo scrimber at home and abroad using some commonly accelerated ageing testing methods. Some researchers previously used the three methods of artificial

accelerated ageing (ASTM D1037, BS EN1087-1, and European AFNOR V313) to study the ageing resistance of outdoor bamboo scrimber [11, 12]. The ASTM D1037 accelerated ageing method is the best method which is able to simulate the harshness of the natural environment, but it is the longest and most time-consuming method which takes more than one week.

In this paper, we used four accelerated ageing testing methods: the six-cycle accelerated ageing method, the 6 h boiling-freezing-drying method, the wet circulation method, and the boiling-testing method, which were used commonly to study the ageing resistance of bamboo scrimber. Changes in the nail-holding power of the plane, the side, and the end face of bamboo scrimber were then analyzed systematically. Changes in mechanical properties, such as the horizontal shear strength, the MOR, and the MOE along the grain, were analyzed as well. Results from this study can provide a reference for the use of bamboo scrimber for outdoor product development, quality evaluation, and standard formulation.

2. Materials and Methods

2.1. Materials. Test specimens of bamboo scrimber were composed of carbonized bamboo and phenol-formaldehyde resin, which were bought from enterprises. The size and density of bamboo scrimber specimens were $2100 \text{ mm} \times 150 \text{ mm} \times 15 \text{ mm}$ and 1.1 g/cm^3 , respectively.

2.2. Major Equipments. Major equipment included a precision panel saw (MJ6116), a universal testing machine for wood-based panels (MWD-W50), a temperature-controlled water bath (GKC218), a programmable temperature and humidity chamber (JW-500T-20), a draught-drying cabinet (DHG-9203A), a digital caliper having a 150 mm range (Shan brand), a spiral micrometer having a 25 mm range (Shan brand), and a refrigerator (Haier brand BCD-196T ADZ).

2.3. Specimens Preparation. The size of the nail-holding-power specimen was $75 \text{ mm} \times 50 \text{ mm} \times 15 \text{ mm}$ (length \times width \times thickness), and six specimens were used in each group. Alternatively, the size of the horizontal shear strength specimen was $110 \text{ mm} \times 50 \text{ mm} \times 15 \text{ mm}$ (length \times width \times thickness), and twelve specimens were used in each group. Moreover, the size of the MOR and the MOE along the grain specimen was $75 \text{ mm} \times 50 \text{ mm} \times 15 \text{ mm}$ (length \times width \times thickness), and similarly, twelve specimens were used in each group.

2.4. Accelerated Ageing Testing Methods. In this paper, bamboo scrimber specimens were treated by the four accelerated ageing testing methods according to their usage and environment: method I—the six-cycle accelerated ageing method of the American standard, ASTM D1037-12 [13]; method II—the 6 h boiling-freezing-drying method of the Chinese standard, JG/T 156-2004 [14]; method III—the wet circulation method of the English standard, BS EN 321 2002 [15]; and method IV—the boiling-testing method of the international standard, ISO 16998-2003 [16].

2.4.1. Method I: The Six-Cycle Accelerated Ageing Method. Before this ageing method treatment was conducted, the specimens were balanced in an environment of $20 \pm 2^\circ\text{C}$ with a relative humidity of $65 \pm 5\%$. The specimens were treated for six cycles, and the specific steps for each cycle were as follows: first, the specimens were soaked in hot water at $49 \pm 2^\circ\text{C}$ for 1 h. Second, the specimens were sprayed with steam at $93 \pm 3^\circ\text{C}$ for 3 h. Third, the specimens were frozen at $-12 \pm 3^\circ\text{C}$ for 20 h, and subsequently dried at $99 \pm 2^\circ\text{C}$ for 3 h in a draught-drying cabinet. The specimens were then sprayed with steam at $93 \pm 3^\circ\text{C}$ for 3 h, and finally dried at $99 \pm 2^\circ\text{C}$ for 18 h.

After the six-cycle accelerated ageing treatment, the specimens were placed in an environment of $20 \pm 2^\circ\text{C}$ and a relative humidity of $65 \pm 5\%$ for at least 48 h [13]. It takes 48 h per cycle and 288 h for the 6 cycles in this treatment. Six groups of bamboo having nail-holding power and horizontal shear strength were used for the MOR and MOE testing. However, 36 specimens were used for the nail-holding power test, and 72 specimens were used for further tests.

2.4.2. Method II: The 6 h Boiling-Freezing-Drying Method. The specific steps followed are as follows: first, the specimens were boiled in boiling water for 6 h, after which surface moisture was wiped off. Then, the specimens were frozen at $-18 \pm 3^\circ\text{C}$ for 24 h, and finally, they were dried at $103 \pm 3^\circ\text{C}$ for 6 h and allowed to cool down at room temperature [14]. It will take at least 36 h for this treatment. Only one group of bamboo scrimber was used in the nail-holding power, horizontal shear strength, MOR, and MOE tests. Six specimens were used for the nail-holding power test, and 12 specimens were used for further tests.

2.4.3. Method III: The Wet Circulation Method. Before this ageing method treatment, the specimens were balanced in an environment of $20 \pm 2^\circ\text{C}$ and relative humidity of $65 \pm 5\%$. The specimens were then treated in three cycles with the following specific steps in each cycle: first, the specimens were soaked in water at $20 \pm 2^\circ\text{C}$ for 72 h, after which surface moisture was wiped off. Second, the specimens were frozen at $-18 \pm 3^\circ\text{C}$ for 24 h and immediately dried at $70 \pm 2^\circ\text{C}$ for 72 h and then cooled down at $20 \pm 2^\circ\text{C}$ for 4 h. Finally, the cooled specimens were balanced at the environment of $20 \pm 2^\circ\text{C}$ and relative humidity of $65 \pm 5\%$. It takes 172 h per cycle and a total of 516 h for the 3 cycles in this treatment. Of note, the specimens were turned vertically 180° before the next cycle treatment [15]. Also, three groups were used in the nail-holding power, horizontal shear strength, MOR, and MOE tests. However, 18 specimens were used for the nail-holding power test, and 36 specimens were used for further tests.

2.4.4. Method IV: The Boiling-Testing Method. Before this ageing method treatment, the specimens were balanced in an environment of $20 \pm 2^\circ\text{C}$ and a relative humidity of $65 \pm 5\%$. The following specific steps were adopted: first, the specimens were placed in water at $20 \pm 2^\circ\text{C}$, heated to 100°C in 90 min, and boiled in boiling water for 2 h. Next, the specimens were soaked in water at $20 \pm 2^\circ\text{C}$ for 60 min, after which surface moisture was wiped off. Finally, the specimens

were dried at $70 \pm 2^\circ\text{C}$ for 16 h and then cooled to room temperature [16]. It will take at least 20.5 h in this treatment. Only one group of specimens was used for nail-holding power and horizontal shear strength tests, including for MOR and MOE testing. Moreover, 6 specimens were used for the nail-holding power test, and 12 specimens were used for further tests.

3. Mechanical Properties Tests

After the ageing method treatment, the mechanical properties of the specimens were tested. The nail-holding power of the plane, side, and end face of bamboo scrimber (showed in Figure 1) was tested according to the Chinese standard, GB/T17657-2013 [17]. The horizontal shear strength, the MOR, and the MOE along the grain of bamboo scrimber were also tested following the Chinese standard, GB/T 21128-2007 [18]. After each cycle, a group of specimens was taken out to test the mechanical properties of the specimens in a multicycle accelerated ageing method treatment. Untreated bamboo scrimber specimens were the control group.

4. Results and Discussion

4.1. Results from the Six-Cycle Accelerated Ageing Method. All specimens were balanced for 48 h before testing ($t = 20 \pm 2^\circ\text{C}$, $R_H = 65 \pm 5\%$). Every data presented in the table were averages of specimens.

Figure 2 shows the specimens treated using the six-cycle accelerated ageing method. As shown, the surface of the specimens remained unchanged after the first and second cycles. However, visible cracks were observed in the third cycle. The cracks of the specimens became increasingly serious as cycles accumulated. Alternatively, as shown in Figure 3, some specimens lacked strength during screw insertion posttreatment. However, followed by drying at $99 \pm 2^\circ\text{C}$ for 18 h, the specimens showed swelling to a great extent when directly subjected to high temperature and high humidity states, resulting in the formation of cracks. Simultaneously, changes in temperature and humidity caused changes in the expansion coefficient of the specimens, which affected the physical and mechanical properties of the tested specimens.

Table 1 shows the results of the mechanical properties after the six-cycle accelerated ageing treatment. As shown in Table 1, the nail-holding power of the bamboo scrimber of the three sides was highest on the plane face, followed by that on the side face and that on the end face. Also, the mechanical properties of the treated bamboo scrimber decreased in different degrees after the six-cycle accelerated ageing treatment. Therefore, results from this study showed that the nail-holding power decreased more (it decreased by 41.8% on the plane, 39.3% on the side, and 65.7% on the end face), while the horizontal shear strength, the MOR, and the MOE decreased by 19.1%, 24.1%, and 10.3%, respectively, which were retained above 75%.

As shown in Figure 4, the mechanical properties of treated bamboo scrimber decreased with treatment cycle accelerated which decreased mostly in the first and second cycles. As the ageing cycle accumulated, the degree of

decrease in mechanical properties gradually slowed down, however, the MOE decreased sharply in the fourth cycle.

4.2. Results of the 6h Boiling-Freezing-Drying Method. Table 2 shows the results of the mechanical properties of bamboo scrimber treated by the 6 h boiling-freezing-drying method. As shown, the nail-holding power levels on the three sides of the treated bamboo scrimber are as follows: 3202 N on the plane, 2525 N on the side, and 1847 N on the end. The horizontal shear strength was 16.2 MPa. The MOR and MOE were 102 MPa and 10747 MPa, respectively.

The mechanical properties were retained above 95% except for the MOR, which decreased by 15%. The nail-holding power levels also decreased by 4.1% on the plane, 8.4% on the side, and 5% on the end face. Moreover, the horizontal shear strength and MOE decreased by 3.1% and 2.6%, respectively. So, the mechanical properties of bamboo scrimber were affected only slightly by the 6 h boiling-freezing-drying method.

In this method, the bamboo scrimber specimens were boiled in boiling water for 6 h, then frozen at $-18 \pm 3^\circ\text{C}$ for 24 h, and finally dried at $103 \pm 3^\circ\text{C}$ for 6 h. The time was not long in boiling, freezing, and drying, and there was no significant damage to the structure of the bamboo scrimber, so the mechanical properties of the treated bamboo scrimber decreased little.

4.3. Results from the Wet Circulation Method. Table 3 shows the results of the mechanical properties of bamboo scrimber treated by the wet circulation method. As shown, the nail-holding power levels on the three sides of the treated bamboo scrimber (treated in three cycles) are as follows: 2989 N on the plane face, 2280 N on the side face, and 996 N on the end face. The horizontal shear strength was 14.4 MPa. The MOR and MOE were 99 MPa and 10275 MPa, respectively.

The nail-holding power levels decreased by 10.5% on the plane, 17.3% on the side, and 48.8% on the end face. Similarly, the horizontal shear strength, the MOR, and the MOE decreased by 11.1%, 17.5%, and 6.9%, respectively. The mechanical properties of the treated bamboo scrimber also decreased by more than 10% except for the MOR, which decreased by 6.9%. So, the mechanical properties of the bamboo scrimber were significantly affected by the wet circulation method, which was most evident in the nail-holding power of the end face, second in the MOR, and third in the MOE.

In this method, the bamboo scrimber specimens were soaked in water at $20 \pm 2^\circ\text{C}$ for 72 h, then frozen at $-18 \pm 3^\circ\text{C}$ for 24 h, and finally dried at $70 \pm 2^\circ\text{C}$ for 72 h. The soaking time was 72 h for the bamboo scrimber specimens saturated with water, which were then frozen and dried. The drying time was 72 h, and the temperature was $70 \pm 2^\circ\text{C}$. In this condition, the structure of bamboo scrimber specimens was damaged easily, so after three cycles, the mechanical properties of the treated bamboo scrimber decreased even more.

As shown in Figure 5, the decrease in mechanical properties increased as the treatment cycle was accelerated. Also, except for the MOR, other mechanical properties declined most in the third cycle.

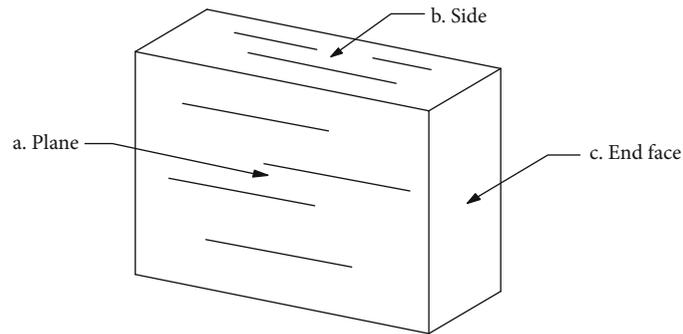


FIGURE 1: Diagram showing the nail-holding power test of specimens.

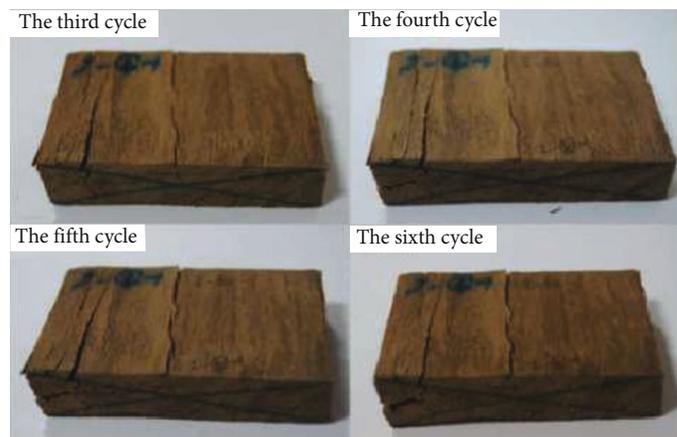


FIGURE 2: Specimens treated using the six-cycle accelerated ageing method.



FIGURE 3: Damaged specimens when made for the nail-holding power testing.

TABLE 1: Results of bamboo scrimber's mechanical properties after the six-cycle accelerated ageing treatment (mean \pm standard deviation).

Cycle	Nail-holding power (N)			Horizontal shear strength (MPa)	MOR (MPa)	MOE (MPa)
	Plane	Side	End face			
Untreated	3339 \pm 166	2756 \pm 140	1945 \pm 100	16.2 \pm 0.15	120 \pm 1.3	11032 \pm 90
First cycle	3032 \pm 130	2143 \pm 125	1263 \pm 60	16.0 \pm 0.2	112 \pm 1	10975 \pm 53
Second cycle	2974 \pm 148	2010 \pm 90	972 \pm 45	14.3 \pm 0.11	99 \pm 0.85	10735 \pm 112
Third cycle	2623 \pm 112	1884 \pm 110	857 \pm 55	14.0 \pm 0.14	96 \pm 1.1	10649 \pm 55
Fourth cycle	2314 \pm 86	1802 \pm 80	876 \pm 40	13.6 \pm 0.16	97 \pm 0.8	10100 \pm 74
Fifth cycle	2184 \pm 109	1769 \pm 120	742 \pm 35	13.5 \pm 0.1	93 \pm 1.2	10060 \pm 80
Sixth cycle	1943 \pm 92	1672 \pm 70	667 \pm 50	13.1 \pm 0.13	91 \pm 0.78	9897 \pm 46

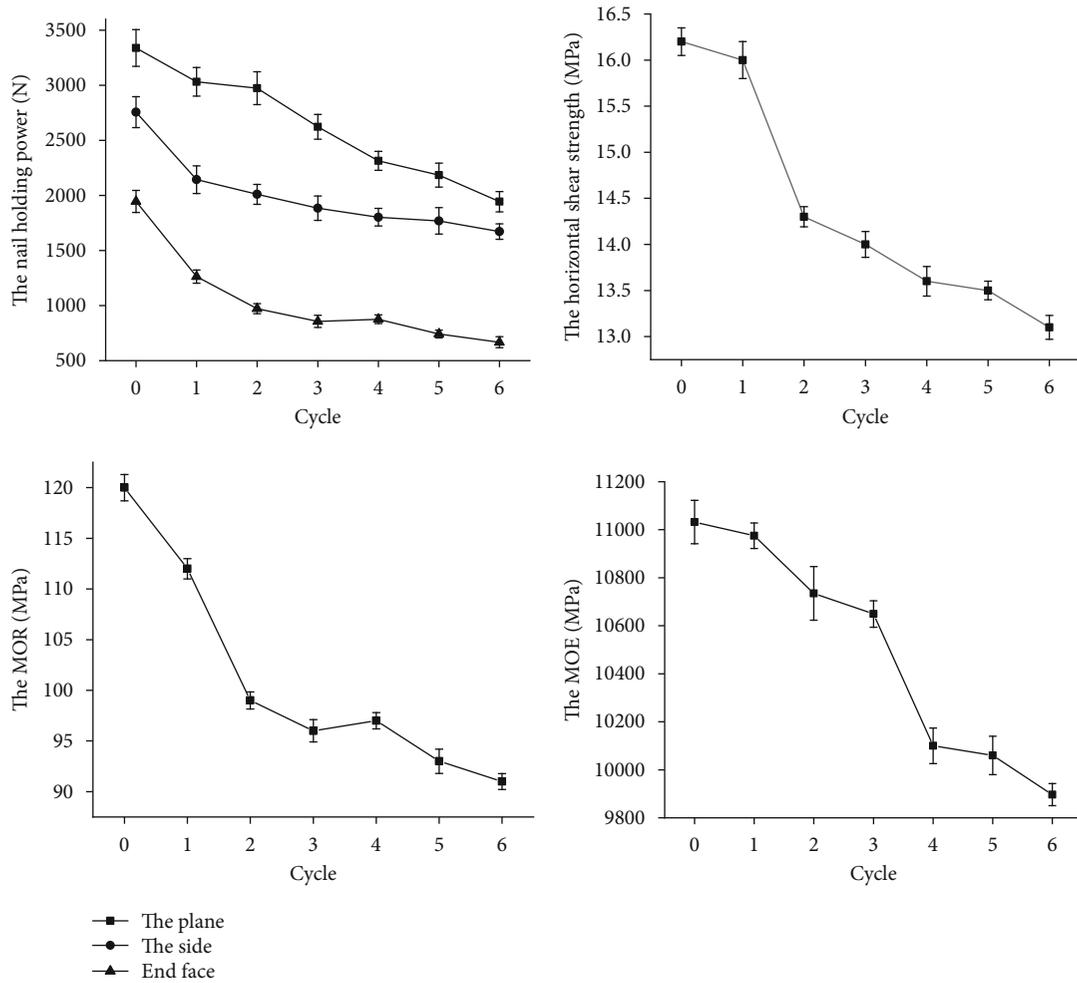


FIGURE 4: Results of the mechanical properties of bamboo scrimber after the six-cycle accelerated ageing treatment.

TABLE 2: Results of the bamboo scrimber’s mechanical properties after the 6 h boiling-freezing-drying treatment (mean ± standard deviation).

Specimens	Nail-holding power (N)			Horizontal shear strength (MPa)	MOR (MPa)	MOE (MPa)
	Plane	Side	End face			
Untreated	3339 ± 83	2756 ± 70	1945 ± 49	16.2 ± 0.05	120 ± 1.3	11032 ± 28
Treated	3202 ± 80	2525 ± 61	1847 ± 43	15.7 ± 0.05	102 ± 0.9	10747 ± 24

TABLE 3: Results of the bamboo scrimber’s mechanical properties after the wet circulation treatment (mean ± standard deviation).

Cycle	Nail-holding power (N)			Horizontal shear strength (MPa)	MOR (MPa)	MOE (MPa)
	Plane	Side	End face			
Untreated	3339 ± 180	2756 ± 160	1945 ± 103	16.2 ± 0.3	120 ± 2	11032 ± 80
First cycle	3142 ± 150	2703 ± 115	1727 ± 66	16.1 ± 0.2	110 ± 1.3	10868 ± 51
Second cycle	3035 ± 120	2576 ± 130	1347 ± 80	15.5 ± 0.13	104 ± 1.6	10762 ± 66
Third cycle	2989 ± 140	2280 ± 105	996 ± 50	14.4 ± 0.16	99 ± 1	10275 ± 40

All specimens were balanced for 48 h before testing ($t = 20 \pm 2^\circ\text{C}$, $R_H = 65 \pm 5\%$). Every data in the table were averages of specimens.

4.4. Results from the Boiling-Testing Method. Table 4 shows the results of the mechanical properties of bamboo scrimber treated by the boiling-testing method. As shown, the nail-

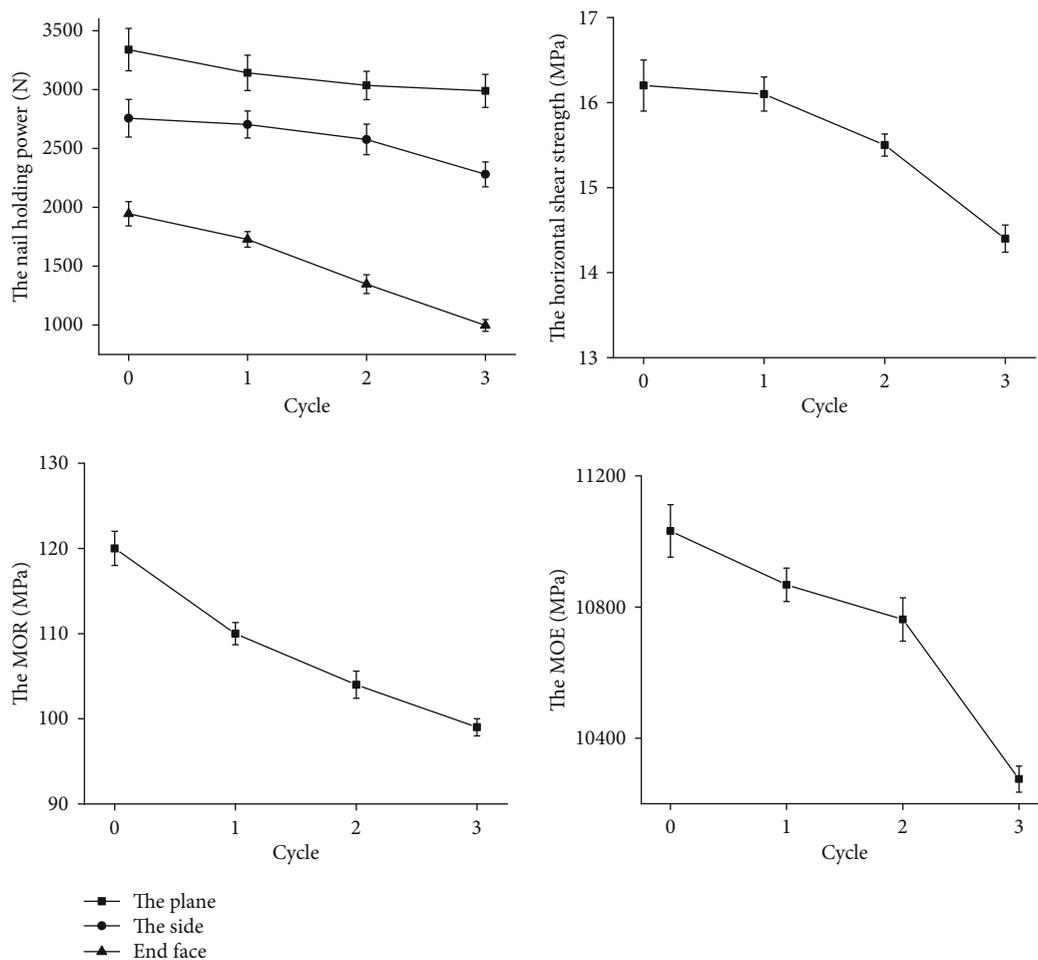


FIGURE 5: Results of the mechanical properties of bamboo scrimber after the wet circulation treatment.

holding power levels on the three sides of the treated bamboo scrimber are as follows: 3008 N on the plane face, 2399 N on the side face, and 1402 N on the end face. The horizontal shear strength was 14.4 MPa. The MOR and MOE were 87 MPa and 9617 MPa, respectively.

The nail-holding power levels decreased by 9.9% on the plane, 13% on the side, and 27.9% on the end face. Similarly, the horizontal shear strength, the MOR, and the MOE were also decreased by 11.1%, 27.2%, and 12.8%, respectively. All of the mechanical properties decreased by more than 9%. So, the mechanical properties of bamboo scrimber were significantly affected by the boiling-testing method as well.

In this method, the bamboo scrimber specimens were boiled in boiling water for 2 h, then soaked in water at $20 \pm 2^\circ\text{C}$ for 60 min, and finally dried at $70 \pm 2^\circ\text{C}$ for 16 h. This accelerated ageing testing method takes the least time, requiring only 4 h, and the boiling and drying time was not long, so there was no significant damage to the structure of the bamboo scrimber; thus, the mechanical properties of the treated bamboo scrimber decreased little.

4.5. Comparison of the Four Accelerated Ageing Testing Methods. Figure 6 shows the mechanical properties of bamboo scrimber specimens treated by the four accelerated

ageing testing methods. All of the mechanical properties decreased after treatment with the four accelerated ageing testing methods, especially with method I. From the results, we know that method I (the six-cycle accelerated ageing method) destroyed the bamboo scrimber specimens most in this paper, while method II (the 6 h boiling-freezing-drying method) destroyed the least.

Table 5 and Figure 7 show the decrease of mechanical properties treated by the above four accelerated ageing testing methods. As shown for the four respective accelerated ageing testing methods, the nail-holding power levels decreased by 4%~42% on the plane, 8%~40% on the side, and 5%~66% on the end face. Also, the horizontal shear strength decreased by 3.1%~16.7%, the MOR decreased by 15%~27.2%, and the MOE decreased by 2.6%~12.8%.

The results of the mechanical properties of bamboo scrimber treated by the boiling-testing method were similar to those of the six-cycle accelerated ageing method; however, the whole testing time of 20.5 h used in the boiling test method was far below the 288 h used in the six-cycle accelerated ageing method. Furthermore, although different methods had different effects on the mechanical properties, they had relatively large impacts on the nail-holding power. For the four accelerated ageing testing methods, the degree

TABLE 4: Results of bamboo scrimber's mechanical properties after the boiling-testing treatment (mean ± standard deviation).

Specimens	Nail-holding power (N)			Horizontal shear strength (MPa)	MOR (MPa)	MOE (MPa)
	Plane	Side	End face			
Untreated	3339 ± 168	2756 ± 130	1945 ± 100	16.2 ± 0.2	120 ± 2	11032 ± 150
Treated	3008 ± 145	2399 ± 125	1402 ± 70	14.4 ± 0.2	87 ± 1.6	9617 ± 110

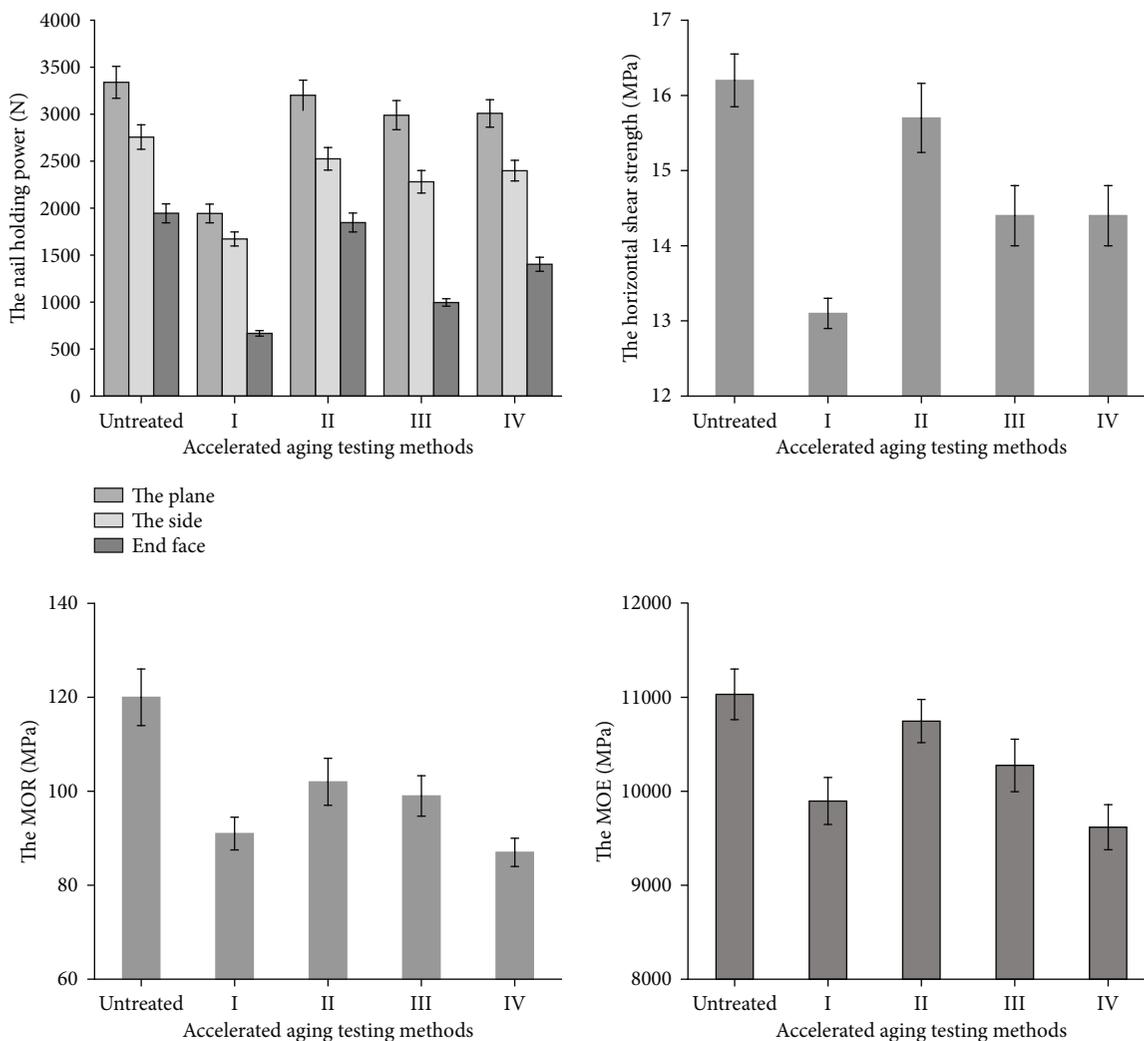


FIGURE 6: Results of the mechanical properties of bamboo scrimber after the four accelerated ageing testing treatment methods.

TABLE 5: The decrease of bamboo scrimber mechanical properties after the four accelerated ageing testing treatment methods.

Degradation of mechanical properties	I (%)	II (%)	III (%)	IV (%)
Nail-holding power				
Plane	41.8	4.1	10.5	9.9
Side	39.3	8.4	17.3	13.0
End face	65.7	5.0	48.8	27.9
MOR	24.2	15.0	17.5	27.2
MOE	8.4	2.6	6.9	12.8
Horizontal shear strength	16.7	3.1	11.1	11.1

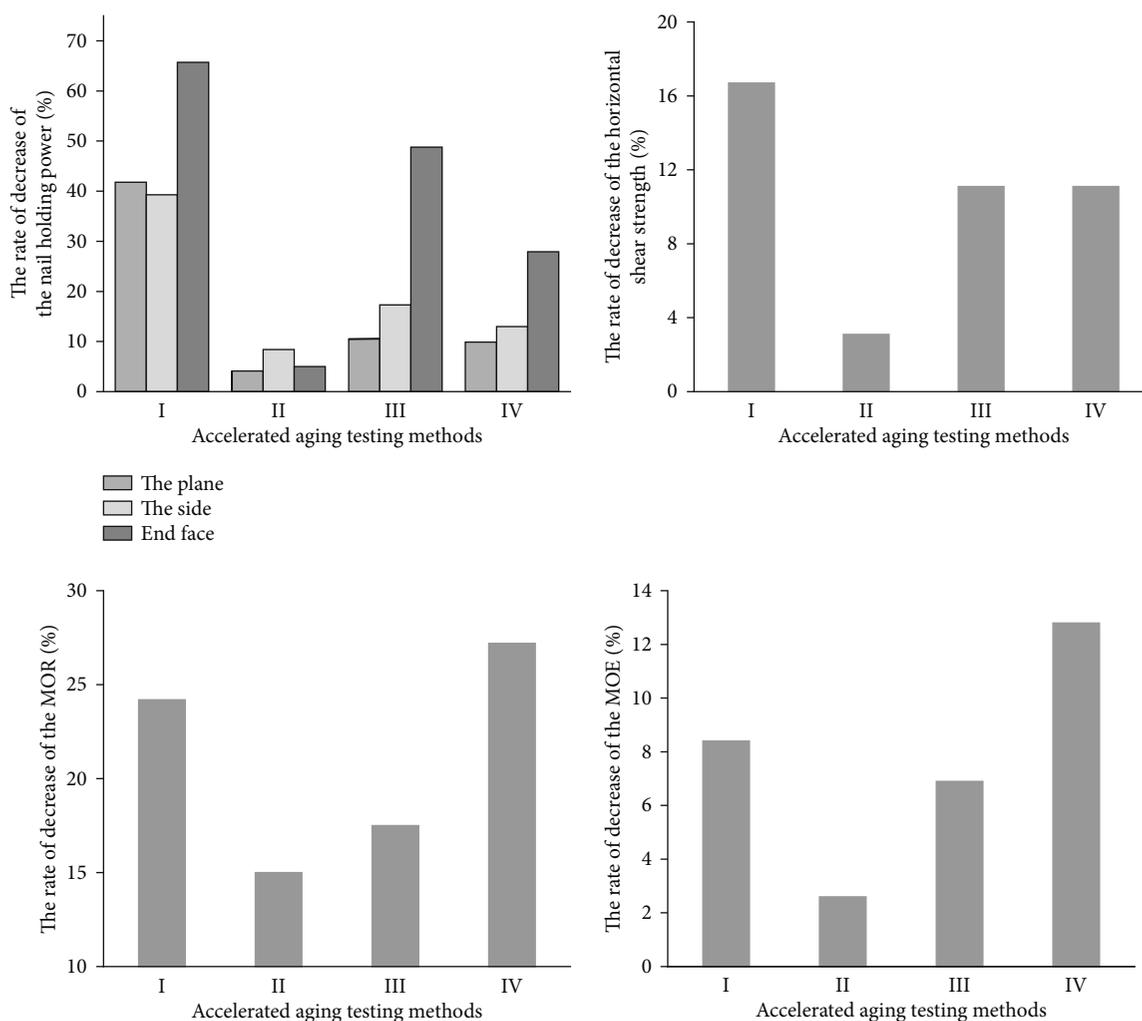


FIGURE 7: The decrease of mechanical properties of bamboo scrimber after the four accelerated ageing testing treatment methods.

of influence on the nail-holding power was in this sequence: method I > method III > method IV > method II. However, after comprehensive consideration, the degree of influence on the mechanical properties was in this sequence: method I > method IV > method III > method II.

5. Conclusions

The nail-holding power of the plane, side, and end face and the horizontal shear strength, MOR, and MOE of bamboo scrimber were tested using four accelerated ageing testing methods (method I: the six-cycle accelerated ageing method; method II: the 6 h boiling-freezing-drying; method III: the wet circulation; method IV: the boiling-testing method). The results show that all mechanical properties decreased after treatment with these four accelerated ageing testing methods: the nail-holding power levels decreased by 4%~42% on the plane, 8%~40% on the side, and 5%~66% on the end face. The horizontal shear strength decreased by 3.1%~16.7%, the MOR decreased by 15%~27.2%, and the MOE decreased by 2.6%~12.8%. The nail-holding power of the three sides and the MOR were the most affected properties after treatment. So, the nail-holding power and the MOR

can be chosen as important indices to evaluate the bamboo scrimber's weather resistance. For the four accelerated ageing testing methods, the degree of influence on the nail-holding power was in this sequence: method I > method III > method IV > method II. However, after comprehensive consideration, the degree of influence on the mechanical properties was in this sequence: method I > method IV > method III > method II.

Data Availability

Data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors gratefully thank the financial support from the Forestry Science and Technology Extension Demonstration Project of Central Finance (Grant No. (2020) TS 09) and

the Special Project of the Scientific Research Institutes of the Zhejiang Province (Grant No. 2015F50051).

References

- [1] Y. X. Huang, Y. H. Ji, and W. J. Yu, "Development of bamboo scrimber: a literature review," *Journal Wood Science*, vol. 65, no. 1, p. 25, 2019.
- [2] W. J. Yu, "Current status and future development of bamboo scrimber industry in China," *China Wood Industry*, vol. 26, no. 1, pp. 11–14, 2012.
- [3] X. Y. Huang, J. L. Xie, J. Q. Qi et al., "Differences in physical-mechanical properties of bamboo scrimbers with response to bamboo maturing process," *European Journal of Wood and Wood Products*, vol. 76, no. 4, pp. 1137–1143, 2018.
- [4] J. H. Zhang, "Design of outdoor recombined bamboo module chemical plant," *China Forest Products Industry*, vol. 42, no. 3, pp. 9–51, 2015, 55.
- [5] G. Wang, Z. Jiang, F. M. Chen, H. A. Cheng, and F. B. Sun, "Manufacture situation and problem analysis on large size bamboo engineering material in China," *China Forest Products Industry*, vol. 41, no. 1, pp. 48–52, 2014.
- [6] H. Zhang, D. Hu, X. C. Zhang, W. B. Zhang, W. J. Yu, and S. X. Jiang, "Experiment on anti-mold performance of different treated bamboo scrimber," *Journal of Zhejiang Forestry Science and Technology*, vol. 5, no. 3, pp. 1–5, 2015.
- [7] J. P. Chen, M. Guagliano, M. H. Shi, X. S. Jiang, and H. P. Zhou, "A comprehensive overview of bamboo scrimber and its new development in China," *European Journal of Wood and Wood Products*, vol. 79, no. 2, pp. 363–379, 2021.
- [8] F. Rao, Y. H. Ji, Y. X. Huang et al., "Influence of resin molecular weight on bonding interface, water resistance, and mechanical properties of bamboo scrimber composite," *Construction and Building Materials*, vol. 292, p. 123458, 2021.
- [9] M. Haglund, "Moisture content penetration in wood elements under varying boundary conditions," *Wood Science and Technology*, vol. 41, no. 6, pp. 477–490, 2007.
- [10] M. Altunok, I. Kureli, and M. Pulat, "Determination of some physical and mechanical properties of the wood-based panels modified by acrylic textile fiber," *Materials Sciences and Applications*, vol. 6, no. 6, pp. 519–526, 2015.
- [11] X. Z. Huang, *The Study on Accelerated Aging Method and Aging Resistant Performance of Parallel Bamboo Strand Lumber*, Nanjing Forestry University, 2009.
- [12] X. Z. Huang, S. X. Jiang, and Q. S. Zhang, "Comparative study on accelerated aging methods of bamboo scrimber," *China Wood-Based Panels*, vol. 6, pp. 25–27, 2010.
- [13] ASTM D1037-12, *Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials*, 2006.
- [14] JG/T 156-2004, *The Construction Industry Standard of the People's Republic of China of Plybamboo Form*, 2004.
- [15] BS EN 321, *Wood-Based Panels—Determination of Moisture Resistance under Cyclic Test Conditions*, 2002.
- [16] ISO 16998-2003, *Wood-Based Panels—Determination of Moisture Resistance-Boil Test*, 2003.
- [17] GB/T 17657-2013, *Test Method of Evaluating the Properties of Wood-Based Panels and Surface Decorated Wood-Based Panels*, 2013.
- [18] GB/T 21128-2007, *Structural Bamboo & Wood Composite Board*, 2007.