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EFFECT OF DIMENSION ON THE MECHANICAL BEHAVIOR OF WOOD SCRIMBER

Guofang Wu[1], Yong Zhong[2], Yahui Zhang[3], Haiqing Ren[4], Yinlan Shen[5]

ABSTRACT: This study investigates the influence of cross-sectional area and stressed length on the mechanical behavior of wood scrimber, a type of reconstituted engineered wood product increasingly used in construction due to its superior mechanical properties and sustainability. Despite its growing popularity, limited research has been conducted on how the dimensional characteristics of wood scrimber affect its mechanical performance, particularly in terms of size effects. This paper presents experimental results on the compressive and tensile strength of wood scrimber specimens of varying sizes and aspect ratios. The results demonstrate significant differences in the impact of size on tensile strength and compressive strength. Specifically, the study shows that size has a much larger effect on tensile strength than on compressive strength. For tensile strength, the stressed length has a more pronounced impact than the cross-sectional area, with longer specimens exhibiting lower tensile strength. Using the weakest link theory, the study quantifies these size effects, providing a theoretical framework for understanding how the size and geometry of wood scrimber components influence their performance. The findings are crucial for optimizing the use of wood scrimber in structural applications, providing insights into its design and ensuring more reliable and efficient engineering solutions in the construction industry.

KEYWORDS: timber, wood scrimber, size effect, weakest link theory

1 – INTRODUCTION

Wood scrimber, a material first introduced by CSIRO in Australia in 1973, is made from small-diameter wood and lower-quality timber, which are processed into bundles through crushing [1]. However, its industrial production has faced challenges due to variations in raw materials, which affect the consistency and quality of the final product. To address this issue, Zhang et al. [2] improved the production process by using oriented wood fiber mats instead of irregular small-diameter logs. This new method involves peeling logs into veneers, creating oriented fiber mats from fluffed veneer strips, resin-treating these mats, hot-pressing them in molds at 50-70 MPa, and curing them at 140°C to form the final product. For more detailed descriptions of the production process, readers may refer to references [3] and [4].

Wood scrimber offers significantly enhanced mechanical properties, including a modulus of rupture exceeding 200 MPa and excellent dimensional stability, making it highly suitable for structural and outdoor applications [5]. Additionally, it increases the value of fast-growing plantation timber, such as poplar and paulownia, allowing their use in structural applications. Its environmentally friendly characteristics have further driven its growing adoption, particularly in China, where it is seen as a sustainable alternative in construction.

As a biomass material, the strength of wood scrimber decreases with increasing size. This phenomenon can be explained by the "weakest link" theory, which posits that the maximum load capacity of a chain is limited by its weakest component [6-8]. Initially, this theory was solely applicable to brittle materials. However, Bohannan [9] applied the theory to wood beams by considering the non-uniform stress distribution in bending members. Later, the size effect pertaining to sawn lumber or dimension lumber has been extensively investigated by scholars worldwide [10-21]. Currently, the design standards for timber

[1] Guofang Wu, Department of Wood Mechanics and Timber Structure, Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing, China, 100091, gfwu@caf.ac.cn

[2] Yong Zhong, Department of Wood Mechanics and Timber Structure, Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing, China, Zhongy@caf.ac.cn

[3] Yahui Zhang, Department of Wood-Based Panels and Adhesives, Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing, China, zhangyh0206@163.com

[4] Haiqing Ren, Department of Wood Mechanics and Timber Structure, Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing, China, renhq@caf.ac.cn

[5] Yinlan Shen, Faculty of Architecture, Civil and Transportation Engineering, Beijing University of Technology, Beijing, China,

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structures in leading nations have incorporated the implications of the size effect related to sawn lumber. The complexity of the size effect is further amplified when it comes to engineering wood products. Many researchers have delved into the size effect of glued laminated timber [22-26], cross-laminated timber [27], and LVL [28], etc. For bamboo-based engineering products, Zhao and Zhang [29] conducted research on the size effect of strength on compressive strength, while their later work [30], they explored the size effect of bending and shear strength of bamboo scrimber based on tests and the weakest link theory. addressed the size effect on bending and shear strength of bamboo scrimber. However, there is a notable lack of research on the size effects in wood scrimber, creating a significant knowledge gap. This study aims to address that gap, with important implications for the structural use of wood scrimber. Quantifying the effect of size on the strength of wood scrimber is essential for its broader application in construction.

A diverse range of wood scrimber specimens, covering various sizes and configurations, were tested. Based on the weakest link theory, insights were gained into how variations in specimen dimensions affect the tensile and compressive strength of wood scrimber. Furthermore, a method for calculating the strength reduction coefficient to account for size effects was proposed, offering practical guidance for engineers and designers aiming to utilize wood scrimber in load-bearing structures.

2 –EXPERIMENTAL PROCEDURE

The wood scrimber used in the test, made from poplar (*P. tomentosa Carr*), was produced by Jiangsu Hengximu New Material and Technology Co., Ltd. The raw material had a density of approximately 0.9 g/cm³ and a moisture content of around 8.4%. The phenolic resin used in the production process, supplied by Shandong Shengquan New Material Co., Ltd., had a solids content of 53.0%, a viscosity of 61.8 CPS, and a pH value of 9.69.

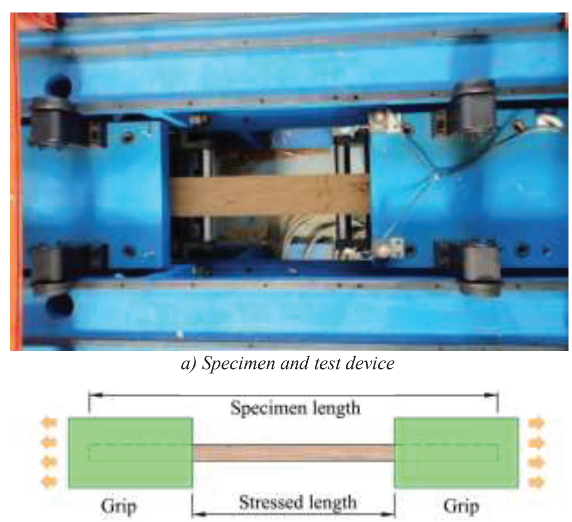
2.1 TENSION TEST

Eight groups of wood scrimber with varying dimensions were prepared for testing. All specimens had a length of 1900 mm and a thickness of 20 mm, with the width varying from 10 mm to 135 mm. For groups A1 to A6, the stressed length was kept constant at 600 mm, while the width ranged from 10 mm to 135 mm, allowing for an evaluation of the effect of width on tensile stress. For groups A3, A6 to A8, the width was fixed at 40 mm, and the stressed length varied from 150 mm to 900 mm, enabling an assessment of the effect of length on tensile stress. The dimensions and details of each group are provided in Table 1.

Tensile tests were conducted in accordance with the Chinese standard GB/T 28993-2012 [31], using a 1000 kN computer-controlled electro-hydraulic servo tension testing machine (Model LAW-1000, Jinan Popwil Co., Ltd., China). Each specimen was securely clamped at both ends using the machine's grips before testing. The specimen was then loaded by the controlled movement of the crosshead at a rate of approximately 5 mm/min, continuing until failure, which typically occurred within 1.5 minutes. Photographs of the testing device and schematic diagrams are shown in Fig. 1.

Table 1: Details of tension specimens.

Groups	Width *(mm)*	Stressed length *(mm)*	Replicates
A1	135	600	20
A2	80	600	20
A3	40	600	24
A4	20	600	20
A5	10	600	20
A6	40	900	20
A7	40	300	20
A8	40	150	20



a) Specimen and test device

b) schematic drawing

Figure 1. Tension tests specimens and loading appautus.

2.2 COMPRESSION TEST

Additionally, six groups of wood scrimber with varying dimensions were prepared for the compression tests. All specimens were prismatic in shape. The B1 group had a height-to-width ratio of 1.5, while specimens in groups B2 to B6 maintained a height-to-width ratio of 2.5. The specimen widths ranged from 20 mm to 100 mm, and the heights started at 30 mm, allowing for the examination of volume effects on the compressive strength of wood scrimber. The dimensions and details of each group are provided in Table 2.

The parallel-to-grain compressive strength tests were conducted in accordance with ISO 13061-17 [32]. For this, the B1 to B3 groups were tested using a 100 kN universal testing machine (Instron 5582, Instron Corporation, USA), while the B4 to B6 groups were tested with a 3000 kN servo-hydraulic testing machine (YAW-3000A, Jinan Shidai Testing Instruments Co., Ltd., China). Pre-loading tests were performed on 2–3 specimens per group to determine the optimal loading speed, aiming for a failure time of approximately 1.5 minutes. Photographs of the test apparatus and schematic diagrams are shown in Fig. 2

Figure 2. Compression tests specimens and loading appautus.

3 – RESULTS

3.1 TENSION TEST

During testing, specimens that exhibited failure within the grips were excluded from the analysis. The tensile strengths of the valid specimens are listed in Table 3.

3.1.1 Effect of area

As shown in Fig. 3, the relationship between tensile strength and cross-sectional area for specimens in groups A1 to A5 is illustrated. From the figure, it can be observed that tensile strength decreases as the cross-sectional size increases, initially declining rapidly before gradually slowing down.

According to the weakest link theory, the strength of a member is determined by the strength of the weakest unit cut from that member. Assuming the strength of these units follows a Weibull distribution, the logarithm of strength is linearly related to the logarithm of the material volume or size, and the absolute value of the reciprocal of the slope represents the size effect factor.

Table 2: Detail of tension specimens.

Groups	Width *(mm)*	Thickness *(mm)*	Height *(mm)*	Replicates
B1	20	20	30	45
B2	20	20	50	25
B3	30	30	75	25
B4	40	40	100	20
B5	80	80	200	20
B6	100	100	250	25

Table 3: Test results of tensile strength.

Group	Tensile strength (MPa)		Valid data point
	Mean	*Cov(%)*	
A1	69.81	11.18	17
A2	69.93	10.20	16
A3	72.71	10.78	19
A4	79.83	14.57	18
A5	81.34	16.31	18
A6	71.33	9.75	15
A7	78.75	11.38	16
A8	81.65	12.62	16

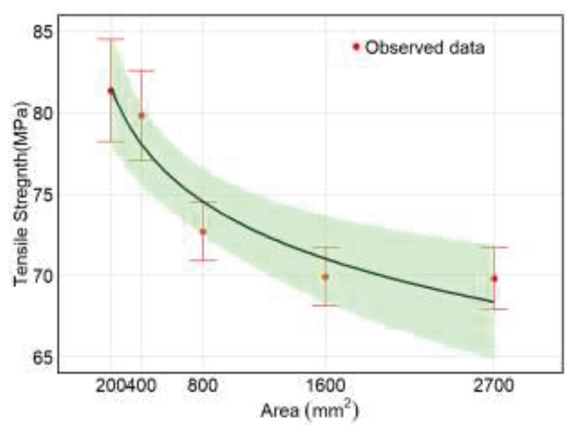


Figure 3. Tensile strength of specimens with different cross-sectional area.

After taking the logarithms of the tensile strength and cross-sectional area of the specimens, a linear correlation between tensile strength and cross-sectional area was observed, as shown in Fig. 4. By fitting a linear model, a coefficient of determination (R^2) of 0.9292 was obtained,

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indicating a strong correlation between the regression model and the observed data. The absolute value of the slope, 0.0671, represents the size effect factor.

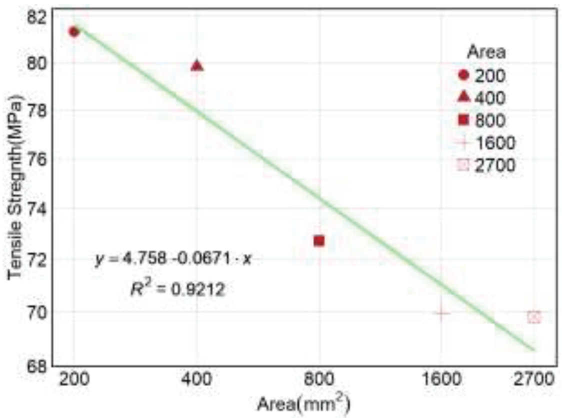

Figure 4. Relationship of tensile strength with cross-sectional area after taking logarithms.

3.1.2 Effect of length

As shown in Fig. 5, the relationship between tensile strength and stressed length for specimens in groups A3, A6 to A8 is presented. The figure reveals that tensile strength decreases as stressed length increases, with an initial rapid decline followed by a gradual slowdown, also.

Similarly, after taking the logarithms of both tensile strength and stressed length, a linear correlation between the two variables is evident, , as shown in Fig. 6. By fitting a linear model, a coefficient of determination (R^2) of 0.9727 was obtained, indicating a strong correlation between the regression model and the observed data. The absolute value of the slope, 0.0804, represents the size effect factor for stressed length.

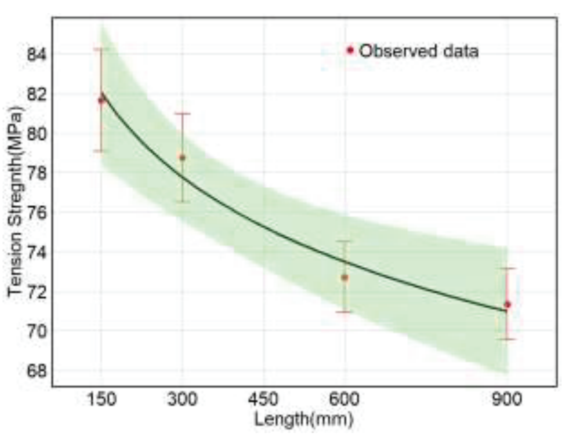

Figure 5. Tensile strength of specimens with different stressed length.

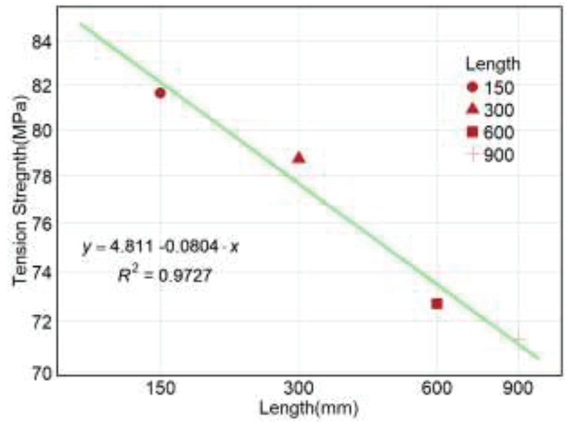

Figure 6. Relationship of tensile strength with stressed length after taking logarithms.

By comparing the size effect factors corresponding to the cross-sectional area and stressed length, it can be observed that the size effect factor for length is larger, indicating that the stressed length has a greater impact on tensile strength. This is likely because, when a unit fails in the width direction, the load can be redistributed to adjacent units, meaning the member may not fail immediately. However, when a unit fails in the length direction, the member will fail more abruptly.

3.2 COMPRESSION TEST

Specimens exhibiting non-typical compressive failure modes were excluded from the test results. The mean values and coefficients of variation for the compressive strength of each group are listed in Table 4.

Table 4: Test results of compressvie strength.

Group	Compressive strength (MPa)		Valid data point
	Mean	Cov(%)	
B1	90.30	6.09	42
B2	89.32	7.14	22
B3	85.42	5.66	21
B4	85.96	7.46	16
B5	82.27	7.25	16
B6	81.11	6.88	21

As shown in Fig. 7, the relationship between compressive strength and the volume of specimens is illustrated. From the figure, it can be observed that compressive strength also decreases as the volume increases, with an initial rapid decline followed by a slower decrease. This trend is consistent with the change in tensile strength as the specimen size increases.

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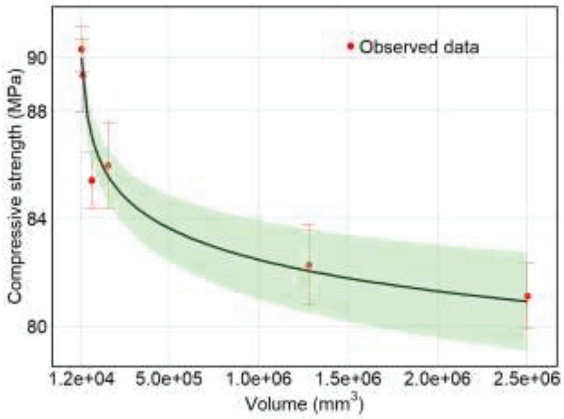

Figure 7. Compressive strength of specimens with different volume.

Similarly, after taking the logarithms of both compressive strength and volume, a linear relationship between the two is observed. By fitting a linear model, a coefficient of determination (R^2) of 0.9590 was obtained, indicating a strong correlation between the regression model and the observed data. The absolute value of the slope, 0.0193, represents the size effect factor for compressive strength.

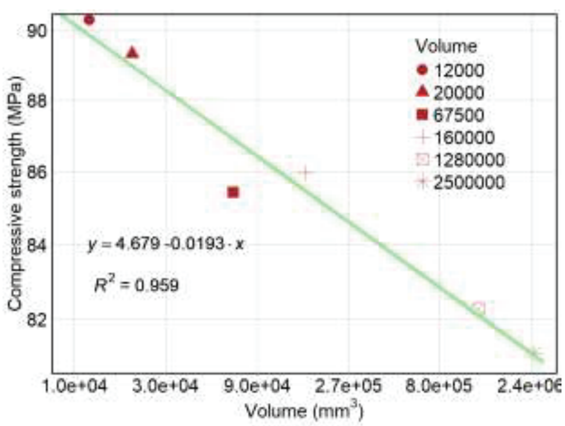

Figure 8. Relationship of compresive strength with volume after taking logarithms.

By comparing the size effect factors corresponding to tensile and compressive strength, it was found that the size effect factor for compressive strength is much smaller than that for tensile strength, indicating that the size has a significantly lower impact on compressive strength compared to tensile strength. This trend is consistent with findings for bamboo scrimber [29,30]. The reason for this is that under compressive loading, the individual units can share the load among themselves. When one unit reaches its maximum load capacity, it does not fail abruptly, but rather retains its original load-bearing capacity, allowing the member to continue carrying the load and even potentially withstand higher loads.

3.3 CALCULATION METHOD

According to the weakest link theory, the strength of a member is inversely related to its size, following the relationship [33]:

$$\frac{f}{f_0} = \left(\frac{D_0}{D}\right)^k \tag{1}$$

where f and f_0 represent the strengths of the target member and the reference member, respectively, and D and D_0 denote the size of the target and reference member, respectively. k is the size effect factor related to size.

For tension members, Eq. (1) can be rewritten as:

$$\frac{f_t}{f_{t0}} = \left(\frac{A_0}{A}\right)^{k_A} \left(\frac{L_0}{L}\right)^{k_L} \tag{2}$$

where f_t and f_{t0} represent the tensile strengths of the larger member and the reference member, respectively. A and A_0 denote the cross-sectional areas of the larger member and the reference member, respectively. L and L_0 denote the stressed lengths of the larger member and the reference member, respectively. k_A and k_L are the size effect factors related to cross-sectional area and stressed length, i.e. 0.0671 and 0.0804, according to the fitting results.

Taking the strength of group A3 as the reference, the strengths of other cross-sectional areas and stressed lengths can be calculated using the following equation:

$$f_t = f_{t0} \left(\frac{800}{A}\right)^{0.0671} \left(\frac{600}{L}\right)^{0.0804} \tag{3}$$

Similarly, For comprension members, Eq. (1) can be rewritten as:

$$\frac{f_c}{f_{c0}} = \left(\frac{V_0}{V}\right)^{k_V} \tag{4}$$

where f_c and f_{c0} represent the compression strengths of the larger member and the reference member, respectively. V and V_0 denote the volume of the larger member and the reference member, respectively. k_v is the size effect factor related to volume, i.e. 0.0193, according to the fitting results.

Taking the strength of group B1 as the reference, the strengths of other volume can be calculated using the following equation:

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$$f_c = f_{c0}\left(\frac{12000}{A}\right)^{0.0193} \tag{5}$$

4 – CONCLUSIONS

This study has examined the impact of dimensional characteristics on the mechanical performance of wood scrimber. The experimental results demonstrate that size has a significantly greater influence on tensile strength than on compressive strength, with stressed length having a more pronounced effect than cross-sectional area.

The tensile strength decreases more sharply as the stressed length increases, likely due to the more abrupt failure of units in the length direction compared to the width direction, where load redistribution can occur. In contrast, compressive strength is less affected by size, as individual units under compression can share the load, allowing the member to continue bearing load even after one unit reaches its failure point.

Based on the weakest link theory, the size effects were quantified, providing a theoretical framework to calculate the influence of size and geometry on the performance of wood scrimber.

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