WEP Warwick Evans Publishing

International Journal of Materials Science and Technology Studies

ISSN: 3006-7693 (Print), ISSN: 3006-3744 (Online) | Volume 2, Number 1, Year 2024
DOI: https://doi.org/10.62051/ijmsts.v2n1.07
Journal homepage: https://wepub.org/index.php/IJMSTS/index

Research on Tensile Properties and Damage Mechanism of Larix Wood Along Grain

Wenxian Yan

College of civil engineer, Central South University of Forestry and Technology, Changsha 410004, China

350494698@qq.com

ABSTRACT

In order to explore the tensile properties and damage mechanism of larch wood along grain, Northeast Larch was taken as the research object. The deformation characteristics, failure mode and stress-strain curve properties of larch wood under tension along grain direction were analyzed by monotonic tensile test on 12 specimens. By means of scanning electron microscopy, the damage and fracture characteristics of wood fiber were analyzed from the microscopic point of view, and the mono-stress failure mechanism of wood was further revealed. The results show that the body of larch wood can be divided into three stages: rapid growth, slow growth and brittle fracture. Due to the difference between early and late wood tracheids, longitudinal splitting and transverse tearing of tracheid walls usually occur. On this basis, a constitutive model was established to describe the longitudinal tension of larch wood.

KEYWORDS

Material properties; Fracture morphology; Intrinsic modeling; SEM

1. INTRODUCTION

In recent years, a series of research has been carried out on the application of wood structural engineering materials, and it is found that Larix is a good building structure material with the advantages of hard material, high density, high strength grade and good natural corrosion resistance [1] among nearly 200 tree species in China. Wood is hollow cells composed of honeycomb structure, the main body of the cell wall is the thickness of the largest secondary wall middle, its microfibers close to the longitudinal axis of about 10°~30° intersection Angle, which is the basic reason for the anisotropy of wood. The longitudinal C-C and C-O bonds of wood microfibers are very firm, and the deformation when destroyed is very small, but the strength is very high, so the tensile strength along the grain is very large. In order to effectively control the mechanical behavior of wood during tension, domestic and foreign wood structure researchers, such as Zhang Lipeng, Yang Jiyu, Gong Cuizhi, Khennane, etc. [2-5] have carried out relevant research on wood longitudinal tensile deformation. But so far, the domestic research on wood has not been in-depth. With the increasing awareness of low carbon, in order to explore the tensile properties and failure mechanism of this composite material, this study took Northeast larch as the research object, focusing on the tensile stress-strain relationship, tensile strength and failure mechanism of its grain.

2. MATERIALS AND METHODS

2.1. Test Materials

The Larix selected in this test grew from northeast China. A total of 12 specimens were designed for tensile strength test, which were in strict accordance with the national standard "General Rules for physical and Mechanical Test Methods of Wood" (GB/T1928 2009) and "Test methods for physical and mechanical properties of undamaged small specimens of Wood Part 14: Determination of tensile strength along grain (GB/T1927-2022) was made. The sample size of the specimen was a long wooden column with a length of 370mm, and the specific size was shown in the figure. The mechanical properties of the specimens were measured on the CMT 5105 universal test machine, and the loading rate was 2mm/min. After the test, the dry density of larch gas was between 0.60g/ cm3~0.69g /cm3. The moisture content of the damaged specimen was determined, and the moisture content was 10.44%.

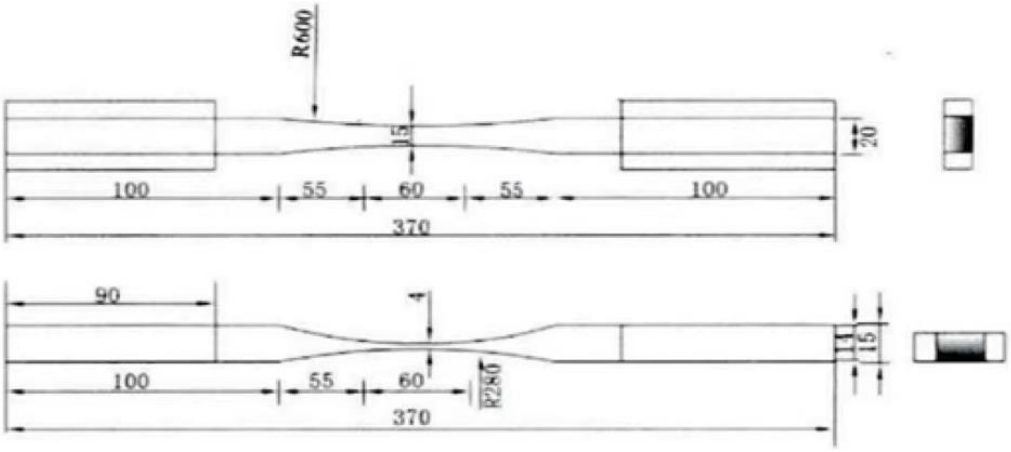


Figure 1. Schematic diagram of the size of larch wood tensile specimen

2.2. SEM Test

The larch wood tensile failure specimen along the grain was taken, and the observation specimen was intercepted on the cross section. The specimen size was not more than 10 mm(longitudinal)×10 mm(chord)×10 mm(radial), and the surface of the specimen was smooth and smooth. Before the test, the sample was treated with absolute drying, the double-sided conductive adhesive was pasted on the sample table, and then the sample to be observed was pasted on the conductive adhesive surface in sequence with tweezers; The Quorum SC7620 metal coater was then used for vacuum gold spraying, and the sample surface microstructure was observed under a scanning electron microscope (TESCAN MIRA LMS).

3. ANALYSIS OF TEST RESULTS

3.1. Tensile Strength Under Static Load

Static load tensile test results are shown in Table 1. It can be seen from Table 1 that the average tensile strength of larch wood along grain is 140.28Mpa and the coefficient of variation is 0.12, which is within the acceptable range of the project.

Table 1. Static load Tensile Test Results along the Grain

Specimen number	b/mm	t/mm	P/kN	σ/MPa
1	15.10	4.20	7.88	120.45
2	15.04	4.10	8.77	137.88
3	15.10	4.16	9.48	146.37
4	15.10	4.04	8.06	128.08
5	15.00	4.00	11.37	183.77
6	15.03	4.05	8.25	131.43
7	15.05	4.14	10.17	158.31
8	15.21	4.08	7.99	124.95
9	15.13	4.05	8.38	132.62
10	15.07	4.01	9.34	149.86
11	15.03	4.11	9.15	143.62
12	15.14	4.07	8.00	125.97
mean value	15.08	4.07	8.99	140.28
standard deviation	0.06	0.05	1.06	17.47
variation coefficient	0.00	0.01	0.12	0.12

3.2. Destructive Form

The tensile damage of larch wood along grain is the result of the wood fiber inside the wood being pulled off, and the damage under tensile stress belongs to the brittle damage. It can be seen from the failure pattern of the sample that the failure position basically appears in the effective area in the middle of the sample. With the increase of the load, the internal wood fiber is gradually pulled off, and the sound of fiber fracture can be heard. Then the sample appears to be damaged without any warning, and the ultimate bearing capacity is reached at this time, accompanied by a violent sound. It is shown in Figure 2. Breaking the port is simple and irregular.

Figure 2. Failure morphology of tensile specimen along grain

3.3. Mechanism of Destruction

At the stretch perpendicular to the fiber, the structural change begins with an increase in the stress level, the instability of the fiber is observed by the appearance of some fiber fracture sounds, and the yield of the material indicates the gradual transition of the unit from the initial state of the elastic material to the irreversible state. The initial crack occurred in the early wood area. Because the early-wood cell wall was thin, the shape was larger and the material was softer, and the late-wood cell cavity was small and the wall was thicker and the organization was tighter, the early-wood area cells

first experienced longitudinal intramural splitting under the action of tensile load. With the increase of the load, the transverse fracture of the tracheid wall occurred in the early-wood region and gradually developed to the late wood region.

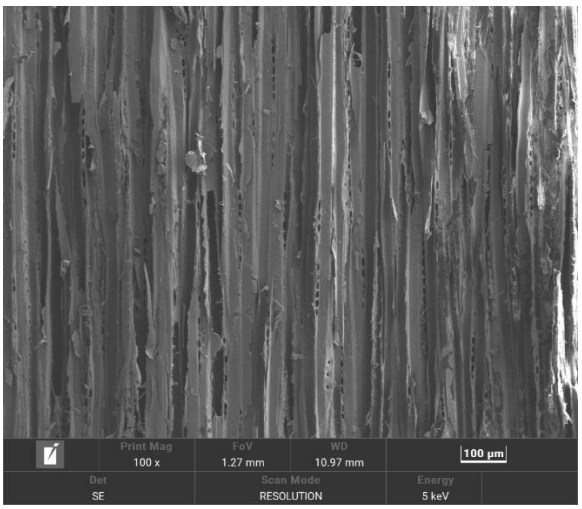


Figure 3. Longitudinal rupture of tracheid wall in early wood area

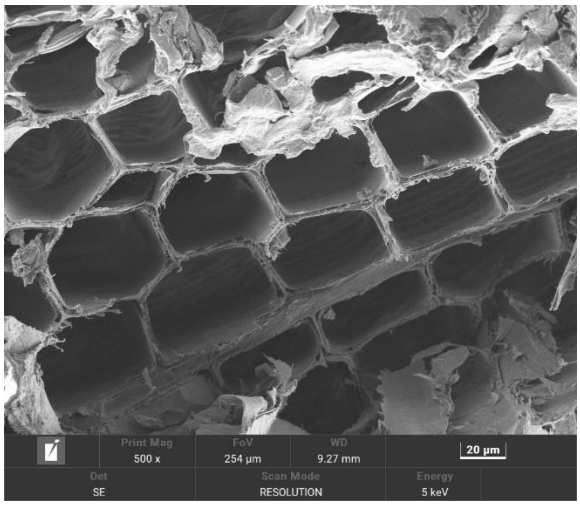
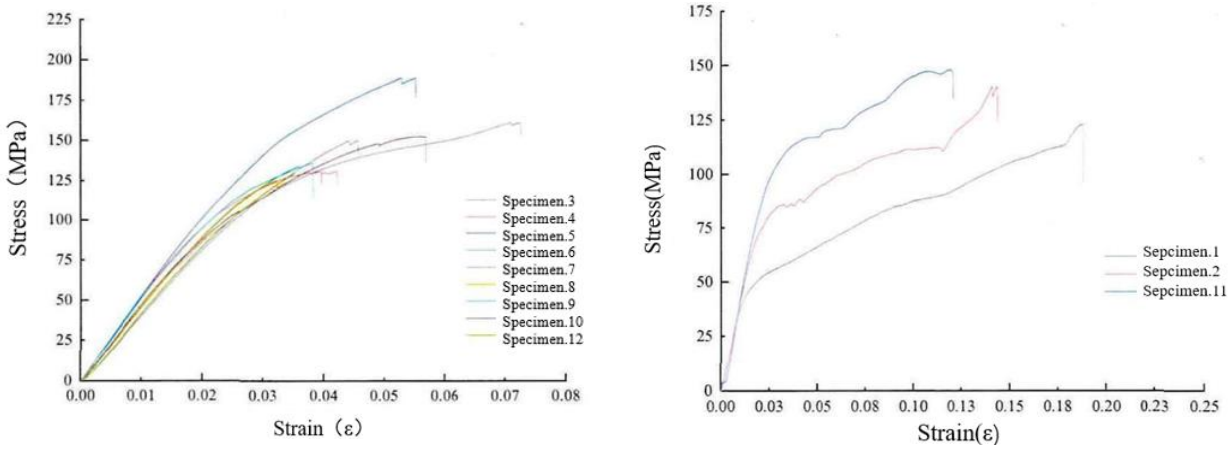


Figure 4. Transverse rupture of the tracheid wall in the late wood area

SEM image can observe the internal structure of the wood, with the edge of the grain hole is the main channel for the exchange of wood moisture and nutrients, the number of the grain hole, the size, the type of arrangement has a greater impact on the penetration of water and liquid, and has a certain impact on the tensile strength of wood along the grain. Under the action of the longitudinal grain tensile load, the cracks begin and develop first in the early wood area with small rigidity, thin wall and large cavity. The main damage is the longitudinal splitting of tracheid wall caused by stress concentration and the transverse tearing of tube wall caused the vertical grain transverse fracture of tracheid. However, in the late wood region with high rigidity, thick wall and small cavity, cracks occur later, and the damage mode is dominated by the transverse tearing of the cell wall. The early wood tracheid cracks further lead to the tearing of the cell interface in the morning and evening wood, and continue to extend to the plane perpendicular to the free plane, and the specimen will eventually form brittle damage.

3.4. Stress-strain Curve

Wood is a kind of heterogeneous, anisotropic natural polymer material, many properties are different from other materials [6-8], its tensile performance is more and other homogeneous materials there are obvious differences. At the time of tension, the sensitivity to defects is different, and once the stress concentration in the defect area exceeds its ultimate bearing capacity, the wood will be caused by plastic deformation and stress redistribution, thereby reducing the impact of stress concentration. On the other hand, some voids and cracks in the wood will become dense due to tension. The stress-strain relationship of larch wood under grain tension is shown in Figure 4. It can be seen from the figure that the stress-strain relationship of most samples is basically linear (FIG. 4a), and only a few samples have nonlinear segments, as shown in FIG. 4b. Among them, the curves of sample 1, sample 2 and sample 11 have obvious nonlinearity, which can be divided into three stages: rapid growth, slow growth and brittle fracture.



(a) (b)

Figure 5. Relationship between tensile stress and strain along the grain

4. TENSILE CONSTITUTIVE MODEL OF LARCH WOOD UNDER TENSILE STRESS ALONG THE GRAIN

Both elastic constitutive model and nonlinear constitutive model are needed for the fine analysis of wood mechanical properties. Reasonable characterization of the whole process of wood mechanical behavior is the premise of the whole process of wood mechanical analysis. According to time and simplicity, the whole process stress behavior of wood can be divided into empirical and theoretical characterization methods. Almost all classical mechanics theories have been applied to the study of constitutive theoretical models of wood. Therefore, the description of wood constitutive behavior can be developed from the aspects of empirical constitutive model, elastic constitutive model and plastic constitutive model.

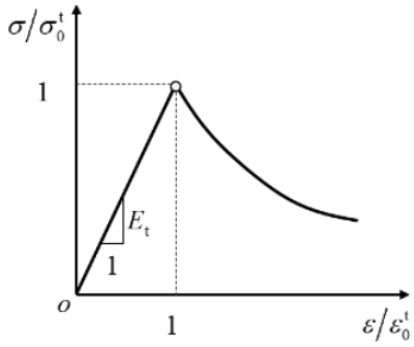


Figure 6. Zhang Lipeng's wood tensile constitutive model under tensile stress along the grain

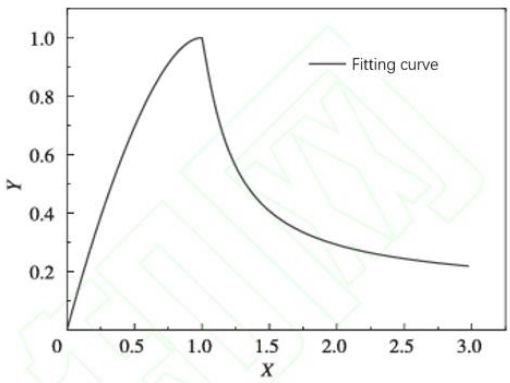


Figure 7. Wang Anxuan's selected imitation wood material tensile constitutive model under tensile stress along the grain

The bilinear model of wood tensile proposed by Zhang Lipeng [2] is shown in Figure 5. The expression is

$$\sigma = E_t \varepsilon \qquad 0 \le \varepsilon < \varepsilon_0^t \tag{1}$$

$$\sigma = \alpha_t \sigma_0^t \left[1 + \beta_t \exp^{\gamma_t \left(\varepsilon / \varepsilon_0^t \right)} \right] \qquad \varepsilon \ge \varepsilon_0^t \tag{2}$$

Where the σ is the tensile stress of the wood in one direction; ε is the strain that corresponds to it; E_t, σ_0^t, ε_0^t represent the tensile elastic modulus, peak tensile stress and peak tensile strain of wood in the grain direction, respectively. and $\sigma_0^t = E_t \varepsilon_0^t$; a_t, β_t, γ_t are dimensionless model coefficients, which control the variation trend of the tensile stress-strain curve of wood along the grain after the peak point.

Wang Anxuan [9] uses a sixth-order polynomial (the curve interval is $0 \le x \le 1$), The descending curve was fitted by rational fraction (the curve interval is $x \ge 1$), The data fitting proposes a tensile constitutive model of wood-like materials as shown in Figure 6, and its expression is as follows

$$y = 1.71088x - 0.6386x^2 - 0.07228x^6 \qquad 0 \le x \le 1 \tag{3}$$

$$y = \frac{x}{4.85439\left(x-1\right)^{1.1524} + x} \qquad x \ge 1 \tag{4}$$

In the formula, $x = \varepsilon / \varepsilon_t$, $y = \sigma / f_t$

It can be seen that the above constitutive models assume that the initial linear segment of the timber continues until the yield point, and fails to consider the partial nonlinearity before the peak point. Based on the results of the tensile stress-strain curve above (see Fig. 7). In this paper, a relational model is proposed to reflect the partial nonlinear behavior of larch wood before yielding The model can be simplified into three stages, namely linear elasticity stage OP, yield stage PC, and strengthening stage CK.

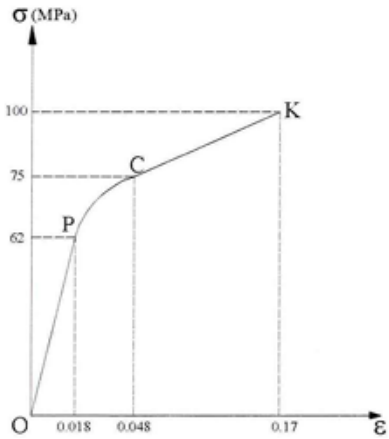


Figure 8. Constitutive model of larch wood along the grain tension

Linear elasticity stage: When the tensile strain is $0 \leq \varepsilon \leq 0.018$, the stress-strain curve is linear, Compliance with the generalized Hooke's law belongs to the elastic stage. As the tensile stress increases, the strain increases steadily. At this time, the ultimate stress of tensile elasticity is 62Mpa, It reaches about 44% of the peak stress; The ultimate tensile elastic strain is 1.8%. Reach about 10% of the peak strain.

$$\sigma = E_{op} \cdot \varepsilon \qquad 0 \leq \varepsilon \leq 0.018 \tag{5}$$

Where: E_{op} is the tensile elastic modulus of elasticity in linear phase

Yield phase: When the tensile strain is $0.018 \leq \varepsilon \leq 0.048$, the tensile deformation of larch wood gradually becomes slow and invisible. At this time, the slope of the stress-strain curve, the modulus of elasticity, gradually decreases. The stress-strain curve gradually changes from a linear relationship to a nonlinear relationship. When the load-bearing strength reaches the yield strength, the slope of the stress-strain curve changes to a minimum, and the model can describe the nonlinear behavior. At this time, the peak tensile stress is 75Mpa, and the peak strain is 4.8%.

$$\sigma = 13.246 \ln \varepsilon + 115.13 \qquad 0.018 \leq \varepsilon \leq 0.048 \tag{6}$$

Intensive phase: When the tensile strain is $0.048 \leq \varepsilon \leq 0.17$, The tensile stress of larch wood maintains the slope of the minimum stress-strain curve after reaching the yield strength. At this time, with the increasing strain, the stress shows a relatively stable trend. At this point, the strain ε_u continues to 17%.

$$\sigma = E_{ck} \cdot \varepsilon \qquad 0.048 \leq \varepsilon \leq 0.17 \tag{7}$$

Where: E_{ck} is the tensile elastic modulus in the strengthening stage

5. CONCLUSION

Through the physical and mechanical properties test of 12 small samples of larch wood with flawless grain, the tensile failure mode of static load was analyzed, and the tensile strength of the specimen with a moisture content of 10% was 140.28Mpa. The tensile process of the grain shows obvious elastoplasticity, which can be regarded as an elastoplastic body. On the basis of the stress-strain curve, a three-stage model of larch wood can reasonably describe the nonlinear behavior before yield; Scanning electron microscopy was used to explore the damage mechanism of the grain microstructure of larch wood through microscopic observation. The experimental results show that the morphology of earlywood cells and latewood cells are obviously different, and their mechanical properties are

also different. Under the continuous action of load, the failure of the specimen originates from the weakest area, and the weak position occurs in the early wood area and the axial tracheid junction of early and late wood, respectively, resulting in longitudinal splitting of the tracheid wall and transverse tearing of the pipe wall, which gradually spreads to the latewood cell part, and finally leads to the occurrence of macroscopic fracture and the final brittle failure.

REFERENCES

[1] SHAO Yali, AN Zhen, XING Xinting et al. Progress of research on mechanical properties and application of larch wood [J]. Wood processing machinery, 2011, 22(03):46-49+37. DOI:10.13594/j.cnki.mcjgjx.2011.03.011.

[2] Zhang Lipeng, Xie Qifang, Liu Yijin, Wu Yajie. Research on the mechanical properties and constitutive model of wood under parallel-to-grain cyclic loading. China Civil Engineering Journal, 2024, 57(3): 42-58.

[3] YANG Jiyu; BI Yujin; WANG Xinzhou; PAN Biao; College of Materials Science and Engineering, Nanjing Forestry University; Physical and tensile properties of compression wood of Taxodium hybrid 'Zhongshanshan' [J]. Journal of Forestry Engineering, 2023, 8(02): 59-67. DOI:10.13360/j.issn.2096-1359.202208004.

[4] Gong Cuizhi, Liu Yixing, Wang Qiang, Liu Wei. Meso-Scale Experimental Investigation and Strain Fields Analysis of Tensile Tests on Microtomed Slices of Picea jezoensis var. microsperma Sample [J]. Scientia Silvae Sinicae, 2008, (03):166-169.

[5] Khennane A, Khelifa M, Bleron L, et al. Numerical modelling of ductile damage evolution in tensile and bending tests of timber structures [J]. Mechanics of Materials, 2014, 68: 228-236.

[6] WU Yiqiang; Central South University of Forestry & Technology; Newly advances in wood science and technology [J]. Journal of Central South University of Forestry & Technology, 2021, 41(01):1-28. DOI:10.14067/j.cnki.1673-923x.2021.01.001.

[7] LIU Weiqing; YANG Huifeng. Research progress on modern timber structures [J]. Journal of Building Structures, 2019, 40(02):16-43. DOI:10.14006/j.jzjgxb.2019.02.002.

[8] ZHAO Hongtie, ZHANG Fengliang, XUE Jianyang, XIE Qifang, ZHANG Xicheng, MA Hui. Research review on structural performance of ancient timber structure [J]. Journal of Building Structures, 2012, 33(08):1-10. DOI:10.14006/j.jzjgxb.2012.08.002.

[9] WANG Anxuan, ZHANG Huagang, YANG Jiaojiao, WU Xiaoqiang, WU Shaoyuan. Experimental Study on the Tensile Strength and Stress-Strain Curve of Imitation Wood Material [J]. Journal of Guizhou University (Natural Sciences), 2024, 41(02):110-115. DOI:10.15958/j.cnki.gdxbzrb.2024.02.15.