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**International Journal of Materials Science and Technology Studies**

ISSN: 3006-7693 (Print), ISSN: 3006-3744 (Online) | Volume 1, Number 1, Year 2024
DOI: https://doi.org/10.62051/ijmsts.v1n1.11
Journal homepage: https://wepub.org/index.php/IJMSTS/index

# Research on the Compression Performance and Damage Mechanism of Larix Wood With Smooth Grain

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## ABSTRACT

In order to investigate the compression performance and damage mechanism of fallen wood in the down-grain direction, northeast larix was taken as the research object. Through the monotonic compression test of 12 specimens, the deformation characteristics, damage mode, and stress-strain curve properties of larix wood under compression in the direction of the smooth grain were analyzed; scanning electron microscope technology was used to analyze the damage and fracture characteristics of wood fibers from the microscopic point of view to further reveal the damage mechanism of wood monotonic compression. The results showed that larix wood compressed in the paragons produced three damage modes of end collapse, shear damage and paragons splitting after the peak load, and the shear damage usually occurred at the junction of the early and late wood tubular cells due to the difference between the early and late wood tubular cells. On this basis, an isomorphic model was established to describe the compression of larix wood in the smooth grain.

## KEYWORDS

Material properties; SEM; Fracture morphology; Intrinsic modeling

## 1. INTRODUCTION

In recent years, the application of wood structural engineering materials to carry out a series of research, found in China's nearly two hundred tree species, larix[1] in the material properties of greater density, compressive strength, material compact hardness, good mechanical properties, corrosion resistance, etc., which is widely used in the field of civil engineering and construction. However, wood is a kind of anisotropic porous material, and the stress performance of its smooth grain and transverse grain is very different. In order to effectively control the mechanical behavior of wood in compression, domestic and foreign scholars in wood structure research, such as Zhang Hongwei, Liu Yixing, Tao Junlin, Tabarsa T, etc.[2-5]have carried out research related to compression deformation of wood in the smooth grain and transverse grain, respectively. However, the domestic research on wood has not been deepened so far. With the improvement of people's awareness of environmental protection, in order to explore the compression performance and damage mechanism of this composite material, this study takes northeastern larix as a tree species and focuses on the compression stress-strain relationship, compressive strength and damage mechanism of its smooth grain.

## 2. MATERIALS AND METHODS

### 2.1. Test Materials

The larix selected for this test grows from northeast China, and a total of 12 specimens were designed for the compressive strength test. Specimens in strict accordance with the national standard "General Principles of Physical and Mechanical Test Methods for Wood" (GB/T1928-2009) and "Test Methods for Physical and Mechanical Properties of Wood in Small Specimens without Defects Part 11: Determination of Compressive Strength of the Shunyi Grain" (GB/T1927-2022) for the production of the specimen, the sample size of the specimen is 20mm × 20mm × 30mm, the length direction is the direction of the Shunyi grain, height direction Along the direction of pressure action, the mechanical properties of the specimen were determined on a CMT 5105 universal testing machine with a loading rate of 0.8mm/min. The larix air dry density was tested to be between 0.60 g/ $cm^3$ and 0.69 g/$cm^3$, and the moisture content of the damaged specimens was determined to be 10.45%.

### 2.2. SEM Test

Larix wood compression damage test piece, in the cross-section of the intercepted observation specimens, the specimen size does not exceed 10 mm (longitudinal) × 10 mm (chordal) × 10 mm (radial), the specimen surface is flat and smooth. Before the test, the specimens were adiabatic, double-sided conductive adhesive was pasted on the sample stage, and then the specimens to be observed were pasted on the surface of the conductive adhesive with tweezers in a sequential order; after that, they were vacuum sprayed with gold through the instrument Quorum SC7620 metal coater, and then placed in a scanning electron microscope (TESCAN MIRA LMS) for observation of the microstructure of the sample surfaces.

## 3. ANALYSIS OF TEST RESULTS

### 3.1. Static Compressive Strength

The results of the static load compression test are shown in Table 1. It can be seen that the average compressive strength of larix timber with smooth grain is 55.54Mpa, and the coefficient of variation is 0.10, which is within the acceptable range of the project.

**Table 1.** Results of Compression Test along Grain

| Specimen number | b/mm | t/mm | P/kN | $\sigma$/MPa |
|---|---|---|---|---|
| **1** | 20.40 | 19.82 | 25.51 | 63.09 |
| **2** | 19.68 | 20.58 | 19.96 | 49.27 |
| **3** | 20.02 | 20.40 | 24.33 | 59.58 |
| **4** | 19.74 | 20.46 | 25.64 | 63.49 |
| **5** | 20.06 | 20.30 | 23.42 | 57.52 |
| **6** | 20.28 | 20.02 | 21.88 | 53.89 |
| **7** | 19.96 | 20.30 | 21.65 | 53.44 |
| **8** | 20.08 | 20.48 | 25.12 | 61.07 |
| **9** | 19.92 | 20.56 | 20.22 | 49.38 |
| **10** | 19.70 | 20.50 | 18.17 | 45.00 |
| **11** | 20.62 | 20.20 | 23.05 | 55.35 |
| **12** | 19.98 | 20.42 | 22.59 | 55.37 |
| **mean value** | 20.04 | 20.34 | 22.63 | 55.54 |
| **standard deviation** | 0.27 | 0.22 | 2.27 | 5.53 |
| **variation coefficient** | 0.01 | 0.01 | 0.10 | 0.10 |

## 3.2. Destructive Form

Larix timber compression damage is the result of the loss of stability of the wood cell wall, under the action of compressive stress damage belongs to the ductile damage. Due to the differences in the natural defects of the wood itself, in the moisture content, density of the subtle differences, its compressive load bearing capacity is not the same, which makes the wood compression will produce obvious plastic deformation, the main damage form is divided into three kinds of destruction: the end of the pressure collapse, split the grain, shear damage as shown in Figure 2. Wood compression of the process of its side of the fiber grain with the loading action of the constantly larger, the deformation increases, the wood fibers will be flexed, so the surface of the specimen will appear with obvious plastic deformation characteristics of the folds.

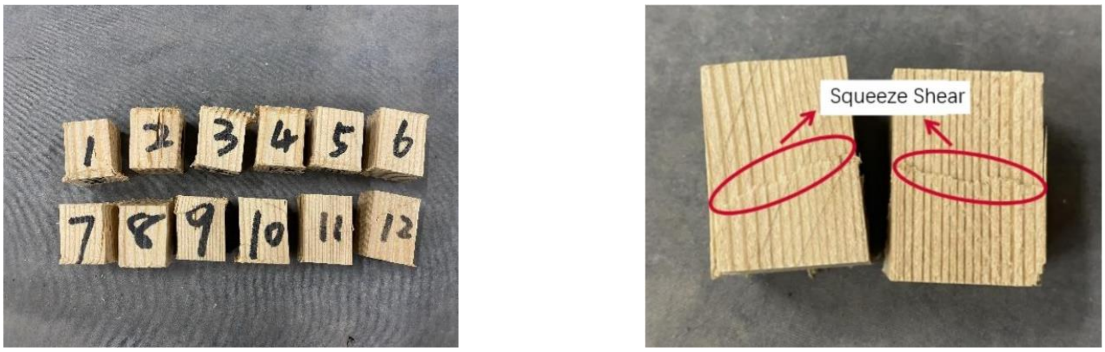

**Figure1.** Failure mode of compression specimen along grain

## 3.3. Mechanism of Destruction

SEM can observe the internal structure of the wood morphology, with the edge of the grain holes is the main channel for the exchange of wood moisture and nutrients, the number of holes, size, arrangement of the type of water and liquid infiltration has a greater impact on the wood compressive strength of the parapetalous grain to produce a certain effect. Fig. 2 shows the earlywood cell pores are large and the distribution of more dense, rounded, mainly distributed in the two ends of the tube cell, Fig. 3 shows the latewood cell pores are small and less distribution.In the early and late wood junction is the first to produce kinking, this phenomenon spreads to the early wood cell part, under the action of compression loading, the early wood tubular cell buckling, which further leads to the early and late wood cell interface tearing (Fig. 4), and continues to extend to the plane perpendicular to the free surface of the expansion, the specimen will ultimately form a shear damage.

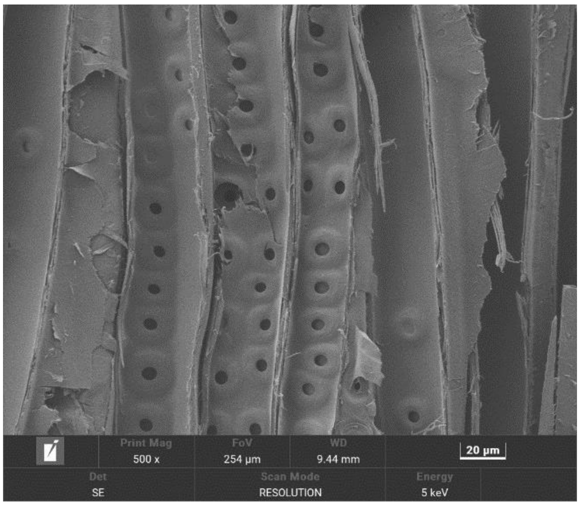

**Figure 2.** Earlywood radius section

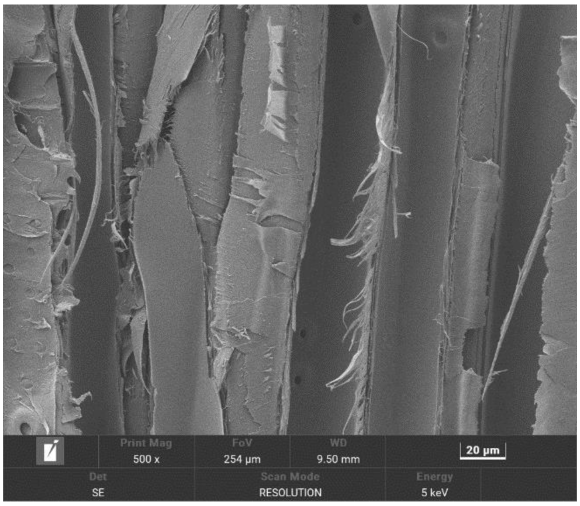

**Figure 3.** Latewood radius section

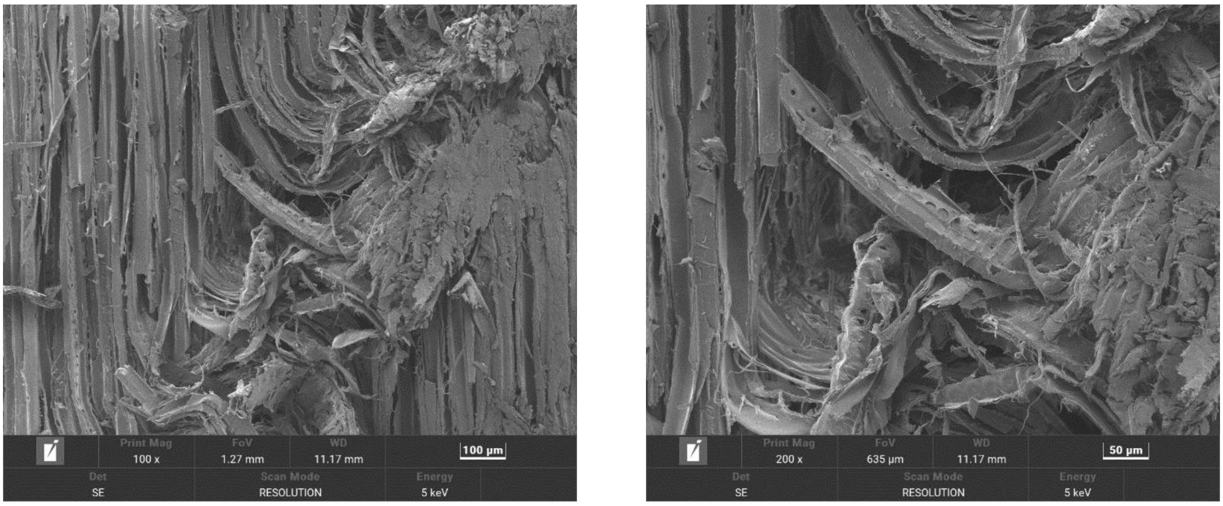

**Figure 4.** Microscopic damage diagram

Since the damage surface is not perpendicular to the direction of the applied load, the compressive strength consists of the total or effective stress, of which the normal and shear stresses are the components, Christoforo[6] et al. conducted fracture analysis of pine specimens subjected to uniaxial compression of the tropical wood with a conforming grain and found that the direction of the positive stresses did not coincide with the main elastic direction, and that there were shear strains in addition to the positive ones, in accordance with the generalized Hooke's law. At compression parallel to the fibers, the structural change begins with an increase in the stress level, and the instability of the fibers is observed by the appearance of a number of macroscopic kinks, where the yielding of the material indicates a gradual transition of the unit cell from the initial state of an elastic material to an irreversible state. The earliest kinking occurs between earlywood and latewood tubular cells at the junction of two growth rings, where earlywood axial tubular cells buckle under compressive loading due to the thin walled, shapely, and flimsy material of earlywood cells, and the small lumen and thicker walled, tighter organization of latewood cells.Gong Smith, Pinho et al. and Gukin at al.[7-9] explained the phenomenon of buckling by the fact that wood tubulars have higher stiffness than early wood tubulars.

## 3.4. Stress-strain Curve

Wood is a non-homogeneous, anisotropic natural polymer material, many properties are different from other materials, and its compression performance is even more than other homogeneous materials there are obvious differences. The degree of sensitivity to defects in compression is different, once the stress concentration in the defective area under compression exceeds its ultimate bearing capacity, the wood will cause stress redistribution to occur due to plastic deformation, thus reducing the effect of stress concentration. On the other hand, some voids and cracks in the wood will become dense due to compression. The stress-strain relationship of larix timber compressed along the grain is shown in Fig. 5.

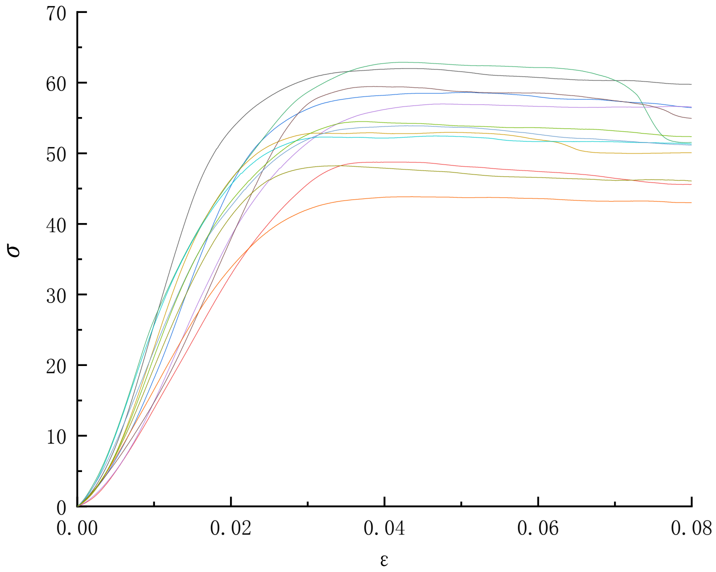

**Figure 5.** Stress-strain relationship of compression specimen along grain

# 4. INTRINSIC MODELING OF LARIX WOOD UNDER COMPRESSION IN THE SMOOTH GRAIN

The refined analysis of wood stress performance requires both its elastic and nonlinear constitutive models, and the reasonable characterization of the whole process stress behavior of wood is the prerequisite for the analysis of the whole process stress of wood. The whole process force behavior of wood is divided into empirical and theoretical characterization methods according to the time and the degree of simplicity, and almost all the classical mechanical theories have been applied to the study of the ontological theoretical model of wood. Therefore, the description of wood's constitutive behavior can be developed from empirical constitutive model, elastic constitutive model, plastic constitutive model and so on.

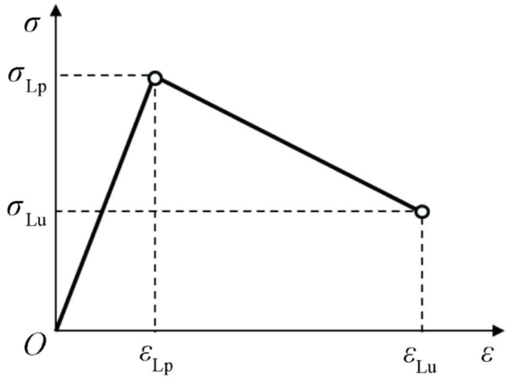

**Figure 6.** Intrinsic modeling of Xie Qifang's wood under compression in the smooth grain

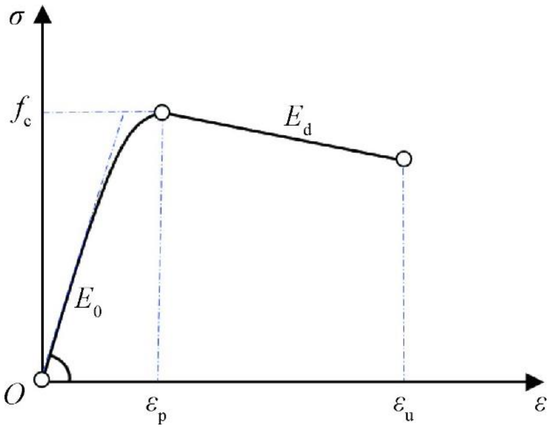

**Figure 7.** Intrinsic modeling of Xiaobin Song's wood under compression in the smooth grain

The bilinear model for compression of wood in the smooth grain proposed by Qifang Xie [49] and others is shown in Fig. 6, with the expression

$$\sigma = E_L^e \cdot \varepsilon \qquad \varepsilon \leq \varepsilon_L^P \qquad (1)$$

$$\sigma = \sigma_L^P + E_L^S \cdot (\varepsilon - \varepsilon_L^P) \qquad \varepsilon > \varepsilon_L^P \qquad (2)$$

where $\sigma_L^P$ is the peak compressive stress of the unidirectional smooth grain of the wood; $\varepsilon_L^P$ is the corresponding peak strain; $E_L^e$ and $E_L^S$ are the elastic modulus of the linear-elastic loading section and the softening modulus of the linear-softening section, respectively. In particular, when $E_L^S = 0$, the model degenerates into an ideal elastic-plastic model; when $E_L^S > 0$, it is an ideal elastic-linear strengthening model.

Xiaobin Song[50]used nonlinear rising and linear falling segments to describe the compression intrinsic model of wood smooth grain, the expression of which is shown in Equation 3-4.

$$\sigma = (r-2)f_c\left(\frac{\varepsilon}{\varepsilon_p}\right)^3 + (3-2r)f_c\left(\frac{\varepsilon}{\varepsilon_p}\right)^2 + E_0\varepsilon \qquad 0 \leq \varepsilon \leq \varepsilon_p \qquad (3)$$

$$\sigma = f_c + E_d \cdot (\varepsilon - \varepsilon_p) \qquad \varepsilon_p \leq \varepsilon \leq \varepsilon_u \qquad (4)$$

In the formula, r is the shape constant of the compression stress-strain curve of the wood grain, usually 2; $f_c$ and $\varepsilon_p$ are the compressive strength of the wood grain and the corresponding strain; $E_0$ and $E_d$ are the initial modulus of elasticity of the compression of the wood grain and the slope of the descending section of the stress-strain curve, respectively; $\varepsilon_u$ is the ultimate compressive strain of the wood cross grain.

It can be seen that all of the above constitutive models assume that the initial linear segment of the wood continues until the peak point, and fail to consider the partial nonlinearity before the peak point. Based on the previous results of the compressive stress-strain curve, this paper proposes a relational model that can reflect the partial nonlinear behavior of larix wood before yielding. The model can be simplified into three stages, which are elastic stage OA, elastic-plastic stage AB, and plastic stage BC.

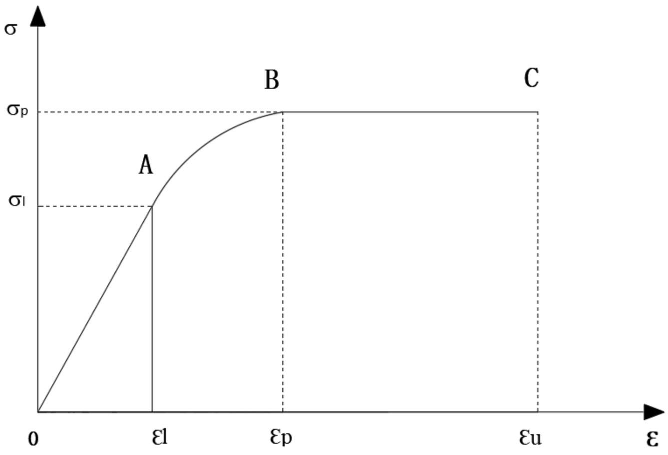

**Figure 8.** Constitutive model of timber under compression

Linear elasticity stage: When the compressive stress $0 \leq \varepsilon \leq \varepsilon_L$, the stress-strain curve is linear, in line with the generalized Hooke's law belongs to the elasticity stage. With the increase of compressive stress, the strain increases steadily. At this time, the compressive elastic limit stress $\sigma_l$ is 34.72Mpa, reaching about 64% of the peak stress; the compressive elastic limit strain $\varepsilon_l$ is 1.6%, reaching about 50% of the peak strain.

$$\sigma = E_L \cdot \varepsilon \qquad 0 \leq \varepsilon \leq \varepsilon_L \tag{5}$$

Where: $E_L$ is the compressive modulus of elasticity in linear phase

Elastic-plastic stage: when the compressive stress $\varepsilon_l \leq \varepsilon \leq \varepsilon_p$, the compressive deformation of larix wood along the grain increases significantly, at this time, the slope of the stress-strain curve, i.e., the modulus of elasticity, becomes gradually smaller, and the stress-strain curve is gradually transformed from a linear relationship to a nonlinear relationship. When the ultimate bearing capacity is reached, the slope of the stress-strain curve tends to zero, and the model can not only describe the nonlinear behavior at the peak point, but also smoothly pass the peak point and continue to reflect the linear behavior after the peak point. At this time, the compressive peak stress $\sigma_p$ is 55.54 MPa and the peak strain $\varepsilon_p$ is 3.5%.

$$\sigma = \sigma_l + A(\varepsilon - \varepsilon_l)^2 + B(\varepsilon - \varepsilon_l) \qquad \varepsilon_l \leq \varepsilon \leq \varepsilon_p \tag{6}$$

Where: A, B are the coefficients, the results obtained in this paper are -6, 21

Plastic phase: when the compressive stress $\varepsilon_p \leq \varepsilon \leq \varepsilon_u$, larix wood compression stress in the peak point after the compressive stress of the smooth grain does not increase with the strain and the trend of a steep decline, but there is an approximate platform stage, the strength of the specimen did not suddenly disappear completely, there is still a high load-bearing capacity. At this time, with the continuous increase of strain, the stress shows a more stable trend. At this time the strain $\varepsilon_u$ lasts until 7%.

$$\sigma = \sigma_p \qquad \varepsilon_p \leq \varepsilon \leq \varepsilon_u \tag{7}$$

## 5. CONCLUSION

Through the physical and mechanical properties test of 12 small specimens of larix wood with smooth grain and no defects, the static load damage pattern was analyzed, and the compressive strength of the specimen with 10% moisture content in smooth grain was obtained to be 55.54 Mpa. The process of compression in smooth grain showed obvious elasticity and plasticity, which can be regarded as an elastic-plastic body. Based on the stress-strain curve, a three-stage model of larix wood compression was established, which can reasonably describe the nonlinear behavior before yielding; Scanning electron microscope technology was used to investigate the damage mechanism of larix wood by the microstructure of the smooth grain through microscopic observation. The test results show that the mechanical properties of the earlywood cells and latewood cells are different due to the obvious difference in their morphology. Under the continuous action of the load, the damage of the specimen originates from the weakest region, and the weak position occurs at the junction of the early and latewood axial tubular cells where buckling occurs, resulting in the phenomenon of kinking, which gradually spreads to the cellular part of the earlywood, and further exacerbates the separation of the tearing of the cell wall sections of the earlywood and the latewood, which ultimately results in the production of macroscopic cracks, presenting the final shear damage mode.

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