Research of strength of gluing of wood

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Abstract. Wood is widely used in industrial and civil engineering. It has many valuable physical, mechanical and other operational properties that make it widely possible to use it not only in construction, but also in other sectors of the economy. Many scientists studied the problems of studying the processes of mechanical processing of wood and the development of rational technological conditions and modes of gluing wood, allowing to obtain products with the required physical and mechanical properties. One of the ways to increase the efficiency of production of glued building materials from wood is gluing lumber along the length of the toothed spike. The strength of glued beams during operation depends on many factors, including the quality of the formation of adhesive joints. The main ones are the properties of wood, mainly density and humidity, and the type of glue. The surface relief, the type of surfaces to be glued, the dimensions and the shape of the tenon also have an effect. The results of a study of the bonding strength of wood in glued beams and the strength of finger jointing are presented in this article.

1. Introduction

Wood is widely used in industrial and civil engineering. It has many valuable physical, mechanical and other operational properties that make it widely possible to use it not only in construction, but also in other sectors of the economy.

Despite the significant advantages, it has a number of disadvantages, among which the most significant is the presence of defects that reduce the quality of raw materials; high variability of its properties even in the same range, for example, in lamellas for the manufacture of glued beams. In the process of using wood, both manufacturers and consumers encounter problems such as a predisposition to cracking and deformation, the presence of knots, which are stress concentrators when loading assortments. Improving the production of glued technology’s bar can solve these problems. In addition, the production of glued’s bar using several types of wood, lamellas glued to the toothed spike, allows rational use of natural resources, including the involvement of soft hardwood in industrial production.

At different times, many scientists, at different times, were involved in the problems of studying the processes of mechanical processing of wood and the development of rational technological conditions and modes of gluing wood, allowing to obtain products with the required physical and mechanical properties, such as A M Borovikov, L M Kovalchuk, V A Kulikov, A S Freidin, V M Khrulev and others [1-18].

The manufacturing process of glued beams to a (timber) is mainly being improved in the following areas:
– selection of lumber with the required structure and properties,
– removal of wood defects from lumber, followed by splicing of short lengths by finger jointing,
– modification of the glue, which allows to increase the strength of the adhesive bond,
– use of new high-strength adhesive.
In order to improve the operational properties of laminated veneer lumber, research is being carried out in the field of:
– forming glued assortments taking into account the structure and stress state of wood,
– increasing the efficiency of serrated adhesive joints, substantiating their shape, size and pitch in bars and beams for various purposes, made from lumber of various types of wood.

One of the ways to increase the efficiency of production of glued building materials from wood is gluing lumber along the length by finger jointing. The strength of glued beams during operation depends on many factors (figure 1), including the quality of the formation of adhesive joints. The main ones are the properties of wood, mainly density and humidity, and the type of glue [1-18]. The surface relief, the type of surfaces to be glued (figure 2), the dimensions and the shape of finger also influence.

Figure 1. Factors influencing the strength of the glued bars during operation.
Figure 2. Types of glued surfaces: radial (a), semi-radial (b), tangential (c).

The results of a study of the bonding strength of wood in glued bars and the strength of finger joints are presented in this article.

2. Methods and Materials
Strength testing of specimens when shearing along wood fibers (figure 3, a) and during static bending (figure 3, b) was carried out in accordance with the Russian Federation standards using testing machine P-5 in accordance with GOST 33120-2014 “Wooden glued structures. Methods for determining the strength of adhesive joints” using a special device. Lamellas with an average moisture of 12% were glued with polyvinyl acetate glue. The pitch between the spiked toothed joints ranged from 180 to 5 00 mm. Parameters of the tested finger joint: finger length - 10 mm, pitch - 3.8 mm, fingertip - 0.6 mm.

Figure 3. Scheme and testing of samples (shape, size, load distribution) on the strength when shearing along the wood fibers (a) and during static bending (b).

3. Results and Discussion
The results of one-factor experiments conducted in laboratory conditions for gluing of pine lamellas with polyvinyl acetate glues showed that the strength of the adhesive joint (τ_chip) depends on the type of glued surfaces:

1) Radial surfaces: \( \tau_{chip} = 3.51 \div 9.35 \) MPa, \( \tau_{chip} = 5.58 \) MPa, after rejection of uncharacteristic values: \( \tau_{chip} = 8.02 \) MPa.

2) Semi-radial surfaces: \( \tau_{chip} = 4.27 \div 9.67 \) MPa, \( \tau_{chip} = 7.15 \) MPa, after rejection of uncharacteristic values: \( \tau_{chip} = 8.34 \) MPa.
3) Tangential surfaces: \( \tau_{\text{chip}} = 3.65 \div 7.88 \text{ MPa} \), \( \tau_{\text{chip}} = 6.39 \text{ MPa} \), after rejection of uncharacteristic values: \( \tau_{\text{chip}} = 7.47 \text{ MPa} \).

The mean value of the coefficient of variation: \( v = 14.9\% \), maximum variability is characteristic of the test results of samples glued with radial surfaces.

Based on preliminary experiments, influencing factors were substantiated and a full factorial experiment was carried out according to the methodology [19]. Factors included in the planning matrix, and their variation levels are presented in table 1.

The results of the experiment are presented in table 2. The relationship between shear bond strength and influencing factors can be represented in the form of regression equations with natural variables (1-3) and graphically (figure 4, 5).

### Table 1. Factors and levels of their variation.

| No. | \( p / p \) | Name of factor | Unit of measurement | Levels of variation | Range of variation |
|-----|-------------|----------------|---------------------|---------------------|-------------------|
| 1   |             | Adhesive consumption, \( x_1 \) | g / m² | lower 120 main 160 upper 200 | 40 |
| 2   |             | Open exposure time, \( x_2 \) | min | 5 10 15 | 5 |
| 3   |             | Pressing pressure, \( x_3 \) | MPa | 0.4 0.8 1.2 | 0.4 |
| 4   |             | The duration of adhesion, \( x_4 \) | hour | 2 3 4 | 1 |

### Table 2. Results of the full second factorial experiment.

| Experience number | Normalized planning matrix | Bonding modes | Shear strength, MPa, when bonding surfaces of the form \( \tau_{\text{chip}} \) |
|-------------------|---------------------------|---------------|------------------------------------------------|
|                   | \( x_1 \) | \( x_2 \) | \( x_3 \) | \( x_4 \) | Glue consumption, \( q \) | Time \( T \) | Open extracts, \( T \) | Pressing pressure, \( P \) | The duration of adhesion, \( t \) | Radial | Semi-radial | Tangential |
| 1                 | - | - | - | - | 120 | 5 | 0.4 | 2 | 4.15 | 6.35 | 4.35 |
| 2                 | - | - | - | + | 120 | 5 | 0.4 | 4 | 7.30 | 7.60 | 7.65 |
| 3                 | - | - | + | - | 120 | 5 | 1.2 | 2 | 3.60 | 4.55 | 5.55 |
| 4                 | - | - | + | + | 120 | 5 | 1.2 | 4 | 7.35 | 4.90 | 5.80 |
| 5                 | - | + | - | - | 120 | 15 | 0.4 | 2 | 3.50 | 4.20 | 3.95 |
| 6                 | - | + | - | + | 120 | 15 | 0.4 | 4 | 4.55 | 4.35 | 5.05 |
| 7                 | - | + | + | - | 120 | 15 | 1.2 | 2 | 5.05 | 4.95 | 3.65 |
| 8                 | - | + | + | + | 120 | 15 | 1.2 | 4 | 5.90 | 7.00 | 6.30 |
| 9                 | + | - | - | - | 200 | 5 | 0.4 | 2 | 6.55 | 7.10 | 6.45 |
| 10                | + | - | - | + | 200 | 5 | 0.4 | 4 | 5.10 | 5.65 | 4.15 |
| 11                | + | - | + | - | 200 | 5 | 1.2 | 2 | 5.33 | 6.70 | 6.05 |
| 12                | + | - | + | + | 200 | 5 | 1.2 | 4 | 7.03 | 8.70 | 7.88 |
| 13                | + | + | - | - | 200 | 15 | 0.4 | 2 | 6.35 | 6.85 | 5.95 |
| 14                | + | + | - | + | 200 | 15 | 0.4 | 4 | 6.25 | 5.75 | 5.30 |
| 15                | + | + | + | - | 200 | 15 | 1.2 | 2 | 4.80 | 6.55 | 6.35 |
| 16                | + | + | + | + | 200 | 15 | 1.2 | 4 | 6.55 | 7.25 | 7.50 |
τ_{chip \ rad} = 2.8961 + 0.0055q - 0.0358T + 0.3837P + 0.6315t \hspace{1cm} (1)
τ_{chip \ semi \ rad} = 3.7278 + 0.012q - 0.0419T + 0.6324P + 0.1658t \hspace{1cm} (2)
τ_{chip \ tangen} = 2.2614 + 0.0113q - 0.0326T + 1.1643P + 0.3818t \hspace{1cm} (3)

Figure 4. Dependence of strength when chipping samples glued by radial surfaces on the adhesive layer on the consumption of glue and the duration of gluing.

Analysis figures 4 and 5 show that the greatest influence on the bonding strength is exerted by the consumption of glue and the duration of the process.

The results of experiments on the study of the strength of finger adhesive joints are presented in table 3.

For practice, the results of the first 4 experiments are of the greatest interest, since gluing along the length of short-length lumber more than 300 mm long has been studied quite fully.

The dependence of tensile strength (τ_{bend}), MPa on a distance, a, in the range of 180-240 mm is described by the equation:

τ_{bend} = 0.72 + 0.133a \hspace{1cm} (4)

The response functions are given in table 3. The graphical dependence of the tensile strength - τ_{bend}, MPa on the distance - a (mm) is shown in figure 6.
Figure 5. The dependence of the strength when chipping along the adhesive layer of samples glued with tangential surfaces on the duration of bonding and pressing pressure.

Table 3. Experiment results.

| Experience number | Step (distance between stud connections - \(a\), mm) | Average output parameter (modulus of rupture - \(\tau_{bend}\), MPa) | Estimates of the variance of experimental results | The model value of the output parameter |
|-------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------------------|-------------------------------------|
| 1                 | 180                                           | 24.1                                            | 35.07                                         | 24.66                               |
| 2                 | 200                                           | 28.3                                            | 12.62                                         | 27.32                               |
| 3                 | 220                                           | 30.2                                            | 16.68                                         | 29.98                               |
| 4                 | 240                                           | 32.0                                            | 17.13                                         | 32.64                               |
| 5                 | 300                                           | 38.3                                            | 6.2                                           | -                                   |
| 6                 | 400                                           | 46.1                                            | 3.9                                           | -                                   |
| 7                 | 500                                           | 48.1                                            | 2.7                                           | -                                   |
4. Conclusion
1. The maximum bonding strength when chipping along the adhesive layer is characteristic of radial surfaces. 2. The strength of specimens with a spiked toothed joint during static bending increases with increasing length of the spliced lamellas. Lamellas longer than 200 mm ensure the strength of the workpieces that meets the requirements of Russian standards.

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