Features of production and application of glued wooden beams in cottage construction

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Abstract. This paper discusses the technological features of the production and use of laminated veneer lumber in cottage construction. The main properties of aluminosilicate glue for gluing pine lamellas have been determined. Changes in both the dynamic and plastic viscosity of aluminosilicate glue are given depending on the spindle rotation speed and shear rate. Equations describing these dependencies are given. These dependencies influence the choice of the method for applying the aluminosilicate glue to the substrate surface. It has been shown that a change in dynamic viscosity from 1662 to 1268 cP in the operating speed range from 20 to 30 RPM and shear rate from 4.2 to 6.3 1/s provides a small shear force from 69.9 to 79.88 dynes/cm², which makes it easy to apply the glue with a brush or a special roller.

It is noted that aluminosilicate glue with a density of 1.54 g/cm³ has a low surface tension of 54 mN/m, which affects the contact angle and the tendency to spread on a pine base. It has been found that an increase in the spreading coefficient results in more complete wetting. It is shown that with an increase in the curing time of the glue joints, the shear strength along the fibers and the elastic modulus on the 28th day increase by 1.63/1.1 times as compared with the seven-day age. An increase in strength and elastic modulus is associated with the passage of crystallization processes in an aluminosilicate gel with the subsequent formation of zeolite-like formations. It is noted that the increase in the value of the breaking load of the samples at the age of 28 days is 1.63 times higher than after 7 days of curing, for determining the values of the shear modulus and elasticity does not have such a decisive importance and this decrease is 5.1%.

Key words: aluminosilicate glue, glued laminated timber, pine, physical, mechanical and deformation properties, colloidal-chemical properties, rheokinetic properties.

1. Introduction

The growing global demand for wood products used in construction is primarily due to the fact that wood is a renewable and environmentally friendly material. No other area of building technology has offered so many innovative solutions in the last 20 years as in the processing and use of wood. Industrial construction from wood confidently strides across the planet: buildings and structures using modern materials and structures made of wood have come to cities, where multi-story residential areas, public, social, sports and administrative buildings are being erected. The wooden residential complex 79&Park in Stockholm, Sweden entered the top 20 best buildings in the world in 2018. The world record for the height of wood-based objects is updated almost every year. After the official opening on March 1, 2019, the 84.5 m high wooden skyscraper in Norway, Mjes Tower, which includes residential apartments, a hotel, offices and a swimming pool, will become the world's tallest timber building, surpassing the university dormitory by more than 30 m. Vancouver, Canada (built in 2017). Based on large-scale scientific research and testing in the United States, at the end of 2018, at the state level, it was allowed to build wooden buildings up to 18 floors. With the use of modern glued structures, airports, sports arenas, shopping and office centers, cultural objects, hundreds of grandiose projects are being built all over the world now at the design or construction stage [1]. The same trend is typical for Ukraine because wooden houses are still the most popular in private construction. The main reasons prompting many to move to a cottage from a "concrete box" - the desire for maximum comfort and care for their own health. In our case, the study of the main characteristics of mineral adhesives for gluing beams, as
well as the characteristics of glued beams themselves for the purpose of their use in the designs of ergonomic modular low-rise houses and cottages is an urgent scientific and practical task.

2. Literary review and problem statement.
In modern projects of wooden houses, in addition to solid wood, glued beams are widely used [2, 3]. For gluing of similar products and designs on their basis of designs use, mainly wood of a pine of a radial saw and organic glues (Akzo Nobel, the Netherlands; Klebchemie, Kiilto, Finland and others). To date, there are four types of glue for the production of glued beams:

1. Polyurethane adhesive. It has excellent manufacturability, hardens quickly.
2. Melamine glue. It is widely used in Europe, recently it has become widespread in Ukraine due to its good adhesion characteristics. After polymerization it becomes transparent. It has a wide operating range of weather conditions - relative humidity up to 80%.
3. EPI glue (EPI system - polymer isocyanate emulsion). Meets both domestic and some foreign standards for the production of wall beams. EPI glue does not contain formaldehyde and belongs to the safest group of adhesive compositions. Is universal and transparent.
4. Resorcinol adhesives. They differ in that after polymerization they acquire a dark shade. Became widespread in the United States and Japan in the gluing of floor beams. Used only outdoors.

Sawing of slats is carried out by a special technology that takes into account the angle of the annual rings to reduce humidity and stress in the wood. After drying, the pre-treated slats are glued and pressed under high load and at a temperature of about 200 degrees. In the process of making glued beams, the glue under pressure is pushed deep into the pores of the wood, which provides a strong grip. Then, after the polymerization of the glue, the beam is processed and cut to the desired size.

In addition to high physical and mechanical properties [4, 5], the above adhesives are characterized by high flammability. The basic requirement for fire safety in construction is to limit the spread of fire, smoke and maintain the load-bearing capacity of the structure for a certain period of time, and an important way to ensure these principles is to manufacture fire-resistant building structures and study their fire resistance, including fire resistance. structures. Of the 7106 buildings completely destroyed in 2020, 2263 (31.9% of the total number of destroyed buildings and structures) had a V degree of fire resistance, 1531 (21.6%) had a III degree of fire resistance, 841 (11.8%) - IIIa degree of fire resistance, 431 (6.1% - IV degree of fire resistance, 246 (3.5%) - IIIb degree of fire resistance, 108 (1.5%) - IVa degree of fire resistance, 86 (1.2%) - II degree of fire resistance and 12 (0.2%) - I degree of fire resistance. That is, the largest losses occur in buildings of III degree of fire resistance, to which there are quite high requirements for building structures [6].

An alternative to organic-based adhesives are aluminosilicate adhesives, which, in comparison with the above, are characterized by non-flammability [7, 8].

The main purpose of the study is to study the rheological, colloidal-chemical, physical-mechanical and deformation properties of aluminosilicate for obtaining products in the form of glued beams for their use in ergonomic modular low-rise cottages.

3. Materials and methods of research
For gluing pine lamellas and determining the strength, deformation, rheological and colloidal-chemical properties, we used aluminosilicate glue type KB3 manufactured by Geofip LLC (Kropyvnytskyi, Ukraine).

Given this original feature of aluminosilicate adhesives, they were used for gluing beams from prepared pine slats measuring 270x50x3000 mm, taking into account the requirements for gluing, namely:
1. Humidity of wood - 10-16%.
2. After grouting - clear geometry. Take into account the uneven shrinkage of wood depending on the structure of the rings.
3. After grouting and before applying the glue it is necessary to measure the humidity of the slats for sorting. Humidity between the slats should not exceed 2%.
4. No more than two hours should elapse after grouting before gluing the slats. After two hours gluing is forbidden.

5. To type for gluing of a lamella by fibers in opposite directions. To compensate for torsion, relieve internal stress and deformation of the rafter layers.

6. Conditions in the shop - humidifiers for humidity and the temperature corresponding to the TU of the technological cycle of gluing. In accordance with these conditions, the ratio of glue to hardener is selected.

7. Parameters on gluing: - assembly time - pressing time.

8. A pressure of 10 kg/cm² must be maintained throughout the pressing time. The quality of gluing should be stronger than the body of wood.

To eliminate internal stresses arising in the glued joints, "cold" gluing was carried out. On pre-prepared wood samples (surface roughness Rz 60, wood moisture 12%) aluminosilicate adhesive was applied with a brush. The glued samples were compressed with clamps at a load of 0.6 MPa for 4 hours. After the release of the crimping pressure, further curing of the glue line occurred at ambient temperature of 20 ± 2°C and a relative humidity of 65 ± 5% (Fig. 1). The determination of the strength of the samples after 7 and 28 days of hardening was carried out on a universal testing machine with a servo drive UMT-10 (China) in the range of breaking forces from 0 to 8 kN at a loading rate of 0.5 mm/s with fixing of stresses in the diagram like $F$-$\Delta l$ (Fig. 2) [9].

![Image](image1.png)

Figure 1. Brush application of KB3 aluminosilicate glue on pine lamellas (a) and fixation of glued laminated timber in Waima (b)

![Image](image2.png)

Figure 2. Diagrams fracture after 7 (a) and 28 (b) days of hardening adhesive pine compounds

To analyze the effect of aluminosilicate glue on colloidal-chemical, rheokinetic properties, the following parameters were chosen [7]: work of adhesion, cohesion and wetting forces, spreading and wetting coefficients, dynamic and plastic viscosity, surface tension and angular wetting of pine wood substrates.
The numerical values of the parameters were obtained on devices and according to the methods used in the study of varnishes and paints and varnishes (LKM). Dynamic viscosity was determined with a Brookfield LVDV2T viscometer using an LV-3C spindle. Surface tension, contact angle, work of the forces of adhesion, cohesion and wetting, as well as the values of the spreading and wetting coefficients were calculated using the formulas given in the literature [10]. The error in measuring the values of surface tension and contact angle did not exceed 10%. The physical-mechanical and deformation properties of the glue joints were determined on the 7th and 28th days of the glue hardening according to [11, 12].

4. Results of researches
In fig. 3 shows the architectural solutions of ergonomic modular low-rise buildings, which use curved and rectangular glued beams in the form of beams and posts. In this paper, a variant of using glued laminated timber on aluminosilicate glue in the form of racks in a security house is considered (Fig. 1, g, h).
The amount of adhesive applied per unit surface area depends, first of all, on its viscosity, and secondly, on the required thickness of the glue line, the temperature of the base and the environment, as well as the quality of the base surface preparation. Aluminosilicate adhesive is characterized by a density of 1.54 g/cm$^3$, has a small surface tension of 54 mN/m, pH = 11.77 and EMF = -250 mV.

Changing the dynamic viscosity from 1662 to 1268 cP in the operating speed range from 20 to 30 RPM (Fig. 4) and shear rates from 4.2 to 6.3 1 / s (Fig. 5) provides a slight shear force from 69.9 to 79.88 dyne/cm$^2$, which allows you to easily, using a brush or a special roller to apply glue to the pine slats.

The Figure 6 shows the wetting angles of aluminosilicate glue on a pine substrate.
As seen in Fig. 6, the aluminosilicate glue has a fairly low wetting angle and is prone to slight spreading on a pine base. In Fig. 7 gives data on the change of the adhesive strength along fibers of pine compound.

![Figure 6. Angles of wetting of an aluminosilicate glue on a pine substrate](image)

As seen from Fig. 7, on the 7th day of curing, the shearing strength along the fibers is 5.31 MPa, and on the 28th day after curing, it is 8.66 MPa. The increase in strength is due to the passage of crystallization processes in an aluminosilicate gel with the subsequent formation of zeolite-like formations.

5. **The discussion of the results.**

It is known that more completely the substrate is wetted by an adhesive, the greater loss of energy occurs (from the wetting condition): \( S = s_s - s_a - s_{a-c} \geq 0 \), where \( s_s \) – an adhesive; \( s_a \) – substrate; \( s_{a-c} \) – section adhesive-substrate.

The higher the spreading coefficient “s”, the more complete the wetting is. And for this it is necessary that the free surface energy at the adhesive-substrate \( (s_{a-c}) \) interface be minimal, which is possible only if the molecular nature of the adhesive and the substrate is close. Considering that the molecular nature of the mineral adhesive and the substrate is far from close, many factors must be taken into account for complete wetting and spreading of the substrate, namely: surface tension, contact angle, work of forces of adhesion, cohesion, wetting, etc. According to the criteria, this assumption can be displayed as follows: \( \theta_{av} < 75^\circ \), \( s \to \text{max} \) and \( f \to \text{min} \).

The chemical and colloidal properties of the protective composition are shown in table 1.
Table 1

Chemical and colloidal properties of the protective composition

| Wood | $\Theta_{av}$ | $\cos\Theta_{av}$ | $W_a$, mN/m | $W_k$, mN/m | $W_w$, mN/m | s, mN/m | f, mN/m |
|------|---------------|-------------------|--------------|--------------|--------------|---------|---------|
| pine | 48°32'        | 0.66497           | 89.91        | 108          | 35.91        | 0.8325  | -18.09  |

Note: $\Theta_{av}$ – the average value of the wetting angle of the substrate with the adhesive; $W_a$, $W_k$, $W_w$ – work of adhesion forces, cohesion and wetting, mN/m; s, f – coefficients of wetting and spreading of the adhesive over a substrate surface, mN/m.

The significance of the obtained results of the work is quite obvious and, first of all, is aimed at practical originality, which will help us to solve the problem of stabilizing the rheokinetic properties aluminosilicate glue, namely: the values of dynamic and plastic viscosity in the range of operating speeds when applying a protective composition to substrates surface; ensure the formation of colloidal-chemical structures with minimum wetting angles and maximum values of the spreading coefficient.

The deformation characteristics of adhesive joints are shown in Table 2.

Table 2

The values of the shear modulus $G$ and the modulus of elasticity $E$ of the aluminosilicate glue, determined from experimental data

| Substrate material | Sample age, day | Aluminosilicate glue | Geometric parameters of samples |
|--------------------|-----------------|----------------------|-------------------------------|
|                    |                 | Experimental and calculated values |                        |
|                    |                 | $F$, [kgf] | $\Delta x$, [cm] | $G$, [MPa] | $E$, [MPa] | $A$, [cm²] | $l$, [cm] |
| pine              | 7               | 220        | 0.16      | 76       | 228       | 5.48     | 3.03     |
|                   | 28              | 400        | 0.28      | 79.9     | 239.7     | 5.42     | 3.03     |

From the data of Figure 1 and table 2, it follows that with an increase in the curing age of the aluminosilicate glue, there is a more tendency to an increase in the absolute values of the deformation value from 0.16 to 0.28 mm, starting from which the section of the $F$-$\Delta l$ diagram has an almost linear section. The value of the load, upon reaching which the diagram becomes linear, is $F = 10$ kgf. Obviously, this is the load, under the action of which the samples compensate for all the initial errors and imperfections. At the same time, the upper limit of deformation of the samples decreases (respectively 8.1 mm; 7.0 mm (Fig. 1)), which may indicate an increase in the stiffness of the adhesive joint. A significant increase in the value of the breaking load of the samples at the age of 28 days by 1.63 times higher than after 7 days of curing for determining the values of the shear modulus and elasticity does not have such a decisive importance and this decrease is 5.1%.

6. Conclusions

- The carried-out studies make it possible to determine the conditions and methods of using aluminosilicate glue for the manufacture of glued beams in the construction of ergonomic modular low-rise houses and cottages.
- Methods for applying aluminosilicate glue to pine lamellae from changes in dynamic and plastic viscosity depending on shear rates and shear rates have been determined.
- The angles of wetting of aluminosilicate glue applied to a base made of wood were determined, which made it possible to assess the possibilities of resistance of the material on surfaces depending on the magnitude of surface tension.
- All the main chemical-colloidal properties of aluminosilicate glue have been obtained, which will ensure the durability of the glue seam in real operating conditions.
The strength and deformation properties of glued joints of pine lamellas have been determined, which make it possible to predict the operation of glued beams in the designs of ergonomic modular low-rise houses and cottages.

Further work will be aimed at obtaining the characteristics of the cured glue: modulus of elasticity along the X, Y and Z axes; Pausson's coefficients in XY, YZ and XZ; tensile and compressive strength in the X and Y axes; yield point. These data will make it possible to assess the stress-strain state of laminated veneer lumber under the influence of both static and dynamic loads.

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