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Study on Physico-Mechanical Properties of the Modified Alkaline Aluminosilicate Adhesive-Bonded Timber Elements

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Abstract. The purpose of the work was to study physico-mechanical properties of glued connections of wood rods, toothed lamellae after splicing and corner spike clamping of window frames which were obtained in the production conditions. The alkaline aluminosilicate binder-based adhesive (glue) of the composition $0.8Na_2O \cdot Al_2O_3 \cdot 4.5SiO_2 \cdot 20H_2O$ modified using organo-mineral additives was used in testing. After solidification of the adhesive, the samples were cut to determine the strength of frame corner joints in bending, glued timber connections for splitting along the grains, toothed glued connections in bending and water resistance of the glued connections of timber elements. The results of these tests showed high values of strength characteristics in case of the proposed modified alkaline aluminosilicate binder-based adhesive (glue), which were by 1.5 times higher than those in case of the WoodMax (D2) taken as a reference glue, and in water resistance complied with Class D2/D3 as per PN-EN 204.

Introduction

Currently the products from glued solid wood constitute main volume of products manufactured at the wood processing plants. In gluing products from solid timber, high strength is a basic requirement for adhesive-bonded connections [1]. To improve strength of the glued solid wood the technologies of gluing are being developed further, new types of adhesives (glues) are developed, among them: polyvinyl acetates (with solidifier or without it)(PVA), copolymer-based PVAs, melamine-urea-formaldehyde, urea-formaldehyde, phenol-resorcinol-formaldehyde, one-component polyurethane which possess maximum moisture resistance (Classes D3 or D4 as per DIN/EN 204) and temperature resistance (WATT 91).

General requirements for wood to be glued, for example, in case of PVAs are: moisture = 8-12%; optimal working temperature = 18-20 ˚C; use temperature not lower than +10 ˚C; application from one side or from two sides in gluing hardwood, in particular, tropical hardwood [2-4].

One of perspective directions of how to improve strength of the glued connections is to apply physical fields which lead to re-arrangement of the structure of polymer base of a glue. Also, treatment of glues under permanent magnetic and alternating electric current were found to be effective ones [5-7].

However, these measures do not allow to meet to a full extent such important requirements like health safety and ecological friendliness due to emissions of hazardous substances (formaldehyde, etc.). Above, these organic-based glues are subjected to thermodestruction under action of ultraviolet radiation, have not enough fire resistance and make the technology of application rather complicated.

One of alternative solutions allowing to eliminate or remove all listed above drawbacks is to use for gluing solid wood the mineral glues – alkali-activated aluminosilicate binder – based adhesives (glues), the theoretical bases of which have been developed in the V.D. Glukhovsky Scientific

Research Institute for Binders and Materials. The developed glues are health safety, ecologically friendly (zero emissions), have the higher fire resistance and do not produce dangerous suffocating smoke in case of fire. The idea "behind" creation of these glues is a directed synthesis of reaction products – analogs to natural minerals like zeolites, feldspathoids and hydromicas [8-14].

The purpose of the research work – to study physico-mechanical properties of the glued solid wood produced with the mineral adhesives (glues) based on alkali-activated aluminosilicate binder (in accordance with the Technical Specification TU U 23.5-02070909-002:2016 "Glues, aluminosilicate, mineral, for wood").

Raw Materials and Research Methods

To study physico-mechanical properties of the glued solid wood, the alkaline aluminosilicate binder of the following composition $0.8Na_2O \cdot Al_2O_3 \cdot 4.5SiO_2 \cdot 20 \cdot H_2O$ (in accordance with the Technical Specification TU U 23.5-02070909-001:2016 "Binders, aluminosilicate, alkali-activated") was chosen.

The binder constituents were: metakaolin, soluble sodium silicate (Ms=3.0, ρ=1400±10 kg/m^3). Sodium hydroxides and microsilica were added when required.

In order to modify physico-mechanical properties the following organic and mineral additives, these were: Vinnapas® RI 551Z, mullite and $CaCO_3$ were added.

The WoodMax SW 12.47 D2 (Synthos S.A., Poland), being close in required properties, was taken as a reference to compare properties.

In order to eliminate internal stresses occurring in the glued connections the gluing of the solid wood was performed under normal conditions (so-called "cold" gluing).

The application of the alkali-activated aluminosilicate binder-based glue on preliminary prepared timber elements from off-quality pine wood was performed manually by dipping and with the help of a paint brush and a putty knife at ambient temperature = +22 ˚C and a relative humidity = 65%. Time of curing of the glued lumbers under pressure of 6 atm was 4 hrs, toothed lamellae after lengthening and removal of pressure – 24 hrs, corner dowelled clumps of a window frame and removal of pressure – 24 hrs. Visual observation did not show starved spots on the solid wood. After solidification of the glue the following samples for standard tests, these were: for determination of bending strength of the corner connections – 4 pcs, for shear strength along the grains of the glued connections – 5 pcs, for bending strength of the glued toothed connections – 5 pcs, for water resistance of the glued connections of timber elements – 20 pcs, were cut. The tests were held in accordance with the national standards of the Republic of Belarus (STB), these were: STB 939, STB 2433, STB 1074, GOST 25885, GOST 24404, GOST 15140, GOST 19414, GOST 15613.1, GOST 15613.4, GOST 17005 and PN-EN 204. Consumption of the glue for all products was 400 g per 1 m^2.

Roughness of surfaces of the wood products forming an external (visible) joint, assessed by a parameter Rz, did not exceed 60 μm, and that of the surfaces forming interior (invisible) joint – did not exceed 200 μm; height of the dowel was 10 mm (dowels on pine lamellae were cut with the help of a milling machine of the company Wintersteiger Sägen GmbH, Germany).

Fire testing was performed using a test equipment OTM, the duration of fire exposure was 300 s. A bending strength of the toothed connections was determined using a universal testing equipment of the company CMC (P.R.China) within the range of destructive forces between 0 and 8 kN.

Macrostructure of the glued toothed connections was studied with the help of an optical digital microscope Delta Optical (Italy) with magnification of 4^x.

Discussions of Results

Basic technological processes on gluing solid pine in the industrial conditions are shown in Figures 1-3.

The samples of the toothed lamellae with the WoodMax SW 12.47 D2 (Fig. 4, a, c) and alkali-activated aluminosilicate binder-based glue (Fig. 4, b, d) are shown in the photos below.

Fig. 1. Application of the glue to wood lumbers (a) and following curing under pressure (hydraulic press of the company R. Beck Maschinenbau, Germany) (b)

Fig.2. Application of the glue to the corner dowelled connections of a window frame (a) and following pressing (a hydraulic press of the company Waima, Germany) (b)

As it follows from Fig. 4, c, d, after machine-tool milling of the surfaces of wood teeth, a thickness of the layer of the alkali-activated aluminosilicate binder-based glue is within the range of 0.1-0.5 mm, it is rather homogeneous in thickness, thus providing a uniform distribution of the stresses that occur in it.

Physico-mechanical properties of the glued solid wood are given in Table.

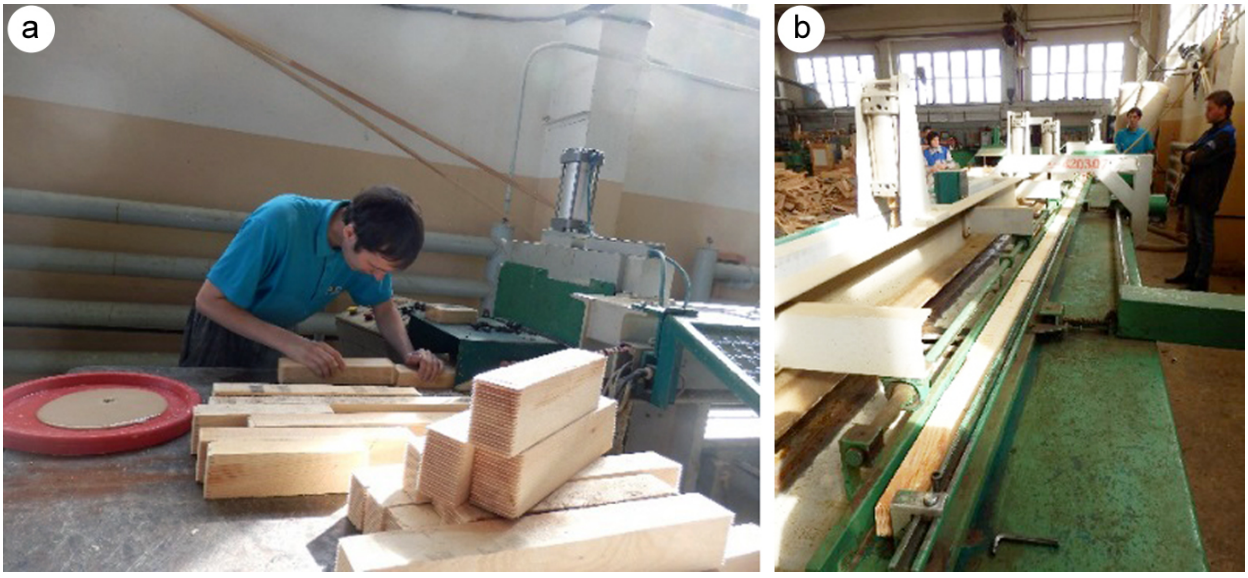

Fig. 3. Splicing (lengthening up to 6 m) of toothed wood lamellae (a) with following curing under pressure (b) (a technological line for lengthening of the company Dumter, Germany)

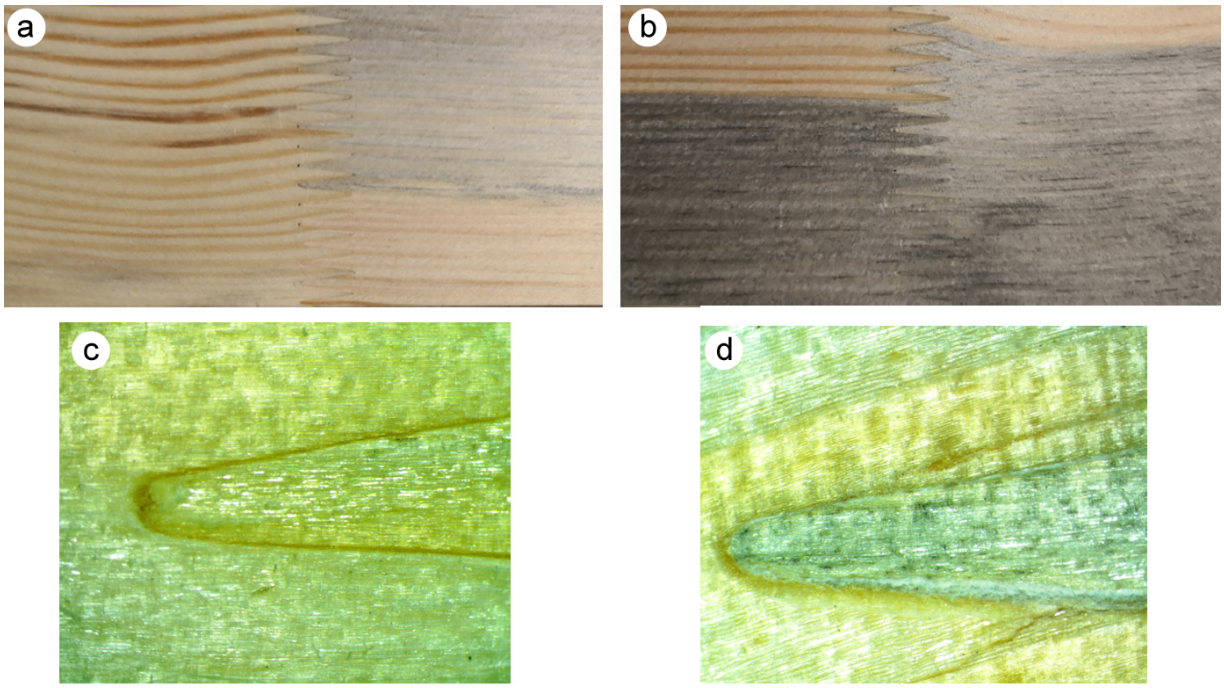

Fig. 4. View (a, b) and macrostructure (c, d) of the spliced pine lamellae with the WoodMax SW 12.47 D2 (a, c) and alkali-activated aluminosilicate binder-based glue (b, d).

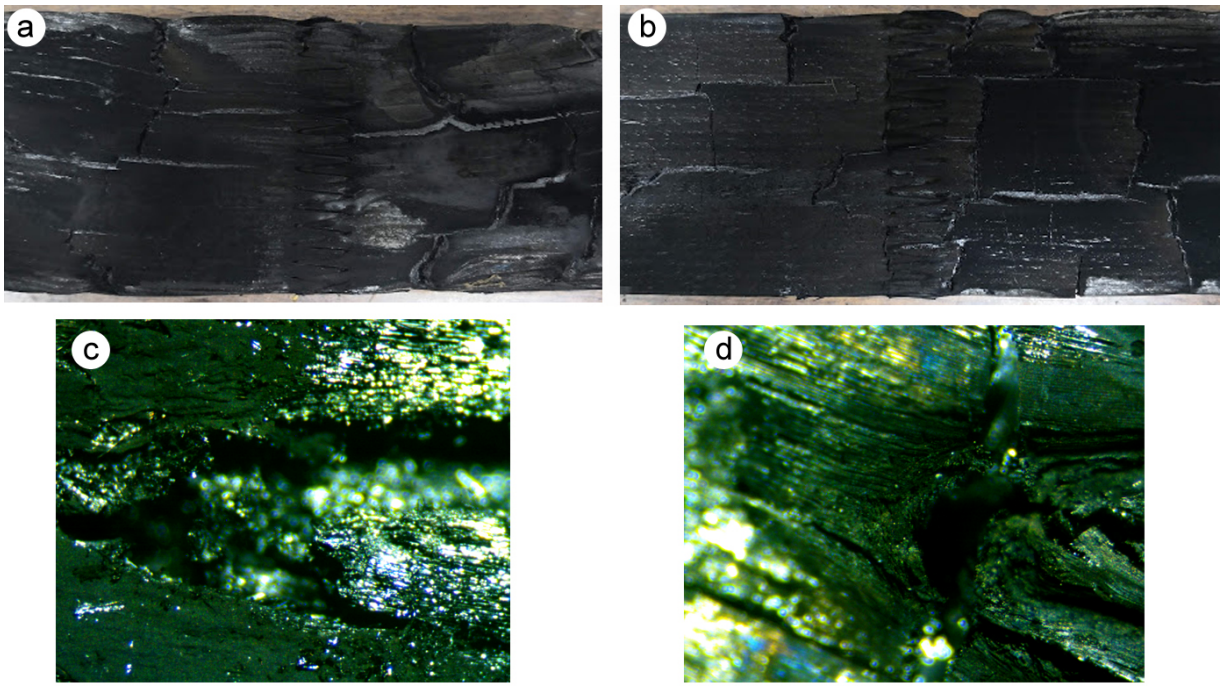

Fig. 5. View (a, b) and macrostructure (c, d) of the spliced pine lamellae after fire testing with the WoodMax SW 12.47 D2 (a, c) and alkali-activated aluminosilicate binder-based glue (b, d).

As it follows from the data of Table 1, the developed alkali-activated aluminosilicate binder-based glue (adhesive) exceeds in strength characteristics the reference glue, however is inferior to it in strength after boiling (by 0.4 MPa) and in water resistance determined under a method of boiling in water. The bringing of these values closer to the normative values seems to be realistic and this is a subject for further research.

Table 1. Basic physico-mechanical properties of the glued solid wood.

Characteristics (parameters under control)	Normative values of parameters under control	Proposed alkali-activated aluminosilicate-binder glue	WoodMax SW 12.47 D2 (reference)
Adhesion strength of paint-and-lacquer coatings to wood	minimum 2 points	1.0	2.0
Shear strength of the glued connections along the grains	minimum 4 MPa	7.8	5.4
Bending strength of the glued toothed connections	minimum 26 MPa	37.0	33.8
Bending strength of the glued toothed connections after fire testing	-	34.33	30.50
Water resistance of the glued connections after curing			
in water for 48 hrs at T= 20±2°C and	minimum 3.2 MPa	3.2	3.2
boiling in water for 3 hrs at T= 100 ±2°C	minimum 3.0 MPa	2.6	3.0

A mean value of the bending strength of the glued toothed connections in case of the aluminosilicate aluminate binder-based glue – 34.33 MPa, that in case of the WoodMax SW 12.47 D2 – 30.5 MPa, that is by 1.13 times higher.

Conclusions

Physico-mechanical properties of the solid wood glued using the alkali-activated aluminosilicate binder-based adhesive (glue) with the following binder composition $0.8Na_2O \cdot Al_2O_3 \cdot 4.5SiO_2 \cdot 20H_2O$ were tested in the industrial conditions. The results showed the higher values of some important strength characteristics in case of the proposed adhesive (glue), compared to the WoodMax SW 12.47 (Class D2) both before and after fire testing. In water resistance the proposed adhesive (glue) meets the requirements for Classes D2/D3 (PN-EN 204).

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