Key Engineering Materials
ISSN: 1662-9795, Vol. 808, pp 172-176
doi:10.4028/www.scientific.net/KEM.808.172
© 2019 Trans Tech Publications Ltd, Switzerland

Submitted: 2018-10-25
Revised: 2019-02-07
Accepted: 2019-02-07
Online: 2019-06-21

Alkaline Aluminosilicate Binder-Based Adhesives with Increased Fire Resistance for Structural Timber Elements

Krivenko P.V.[1,a*], Guzii S.G.[2,b], Bondarenko O.P.[3,c]

[1-3]Kyiv National University of Construction and Architecture,
Scientific Research Institute for Binders and Materials,
Povitroflotskyi Prospect 31, Kyiv, Ukraine

[a]pavlo.krinenko@gmail.com, [b]sguziy2@gmail.com, [c]bondolya3@gmail.com

Keywords: adhesion, alkaline aluminosilicate binders, adhesives, hardly burnable, hardly flammable, strength in splitting, heat conductivity, timber, zeolite-like phases

Abstract. The paper presents data on the use of the alkaline aluminosilicate binder-based adhesive of the system Na_2O•Al_2O_3•(4-6)SiO_2•(17-20)H_2O for gluing and fire protection of structural timber elements. The results of the study of thermoresistant phases in the reaction products of the alkaline aluminosilicates are reported and discussed. The results allowed to show that at SiO_2/Al_2O_3 between 5 and 6 the zeolite-like phases of heulandite types, which, under action of temperatures, are able to form a porous aluminosilicate artificial stone with low thermal conductivity (λ=0.09 Wt/m·K, DSTU B V.2.7-105-2000 (GOST 7076-99)) are formed in the reaction products.

The use of the developed aluminosilicate adhesives allow for to classify the structural timber elements as hardly burnable and hardly flammable materials (GOST 12.1.044-1989, EN 13823 + A1: 2014-12, ASTM E119-07). They have the following characteristics: water resistance D3 (EN 204:2001), resistance in splitting up 7.8 MPa (GOST 16483.5-1973), adhesion in normal pull-off test up to 2.6 MPa (GOST 32299- 2013 (ISO 4624:2002)).

Introduction

When restoring or strengthening damaged wood structures, glue is used on various bases. The process of gluing wood occurs as a result of drying and curing of the adhesive film applied on the bonding surface. By the nature of the process, wood glue can be divided into three groups: – dispersion; – formulations containing organic solvents; – reactive. Dispersion adhesives are becoming more and more common lately, since dispersion formulations emit only water vapors during drying, which indicates their environmental cleanliness. However, with this undeniable dignity, there are also disadvantages. When using water-dispersion formulations, it is important to withstand the temperature and humidity characteristics in the room in order for the moisture to evaporate and the glue to polymerize normally. Solvent adhesives have no restrictions on use and are distinguished by a faster connection than members of the above group, but work with them is usually accompanied by very sharp odors and unhealthy fumes. Reactive (two-component, three-component, etc.) adhesives do not contain either water or solvents. Polymerization occurs because of a chemical reaction between the components after they are mixed, and the lifetime of such an adhesive is only 30-40 minutes. Reactive adhesives are quickly gaining strength and are characterized by excellent adhesion to almost all materials. The adhesives of this group do not contain organic solvents, however, other harmful substances may be included in the composition of the mixed components, therefore, in some cases, special protective equipment is appropriate.

The group of synthetic adhesives includes: carbamide, polyurethane, rubber, epoxy, polyvinyl acetate (PVA), phenolic, polyacrylic, etc. They provide high bonding strength, have good resistance to external influences and are widely used for gluing wood and other materials, but they are fire hazardous.

Inorganic compounds based on liquid glass (aqueous solutions of sodium and potassium silicates) are used to glue cellulosic materials that are more resistant to the effects of fire, however, they have a rather low durability.

An alternative to the latter are alkali hydroaluminosilicate based adhesives, the theoretical bases of which have been developed at the V.D. Glukhovsky Scientific Research Institute for Binders and Materials [1-5].

The purpose of this work is to study the fire resistance of aluminosilicate adhesive compositions intended for bonding and fire protection when restoring massive wood products.

Materials and Research Methods

To study the physico-mechanical and fire properties of glued wood, an alkaline aluminosilicate adhesive composition of the composition $Na_2O{\bullet}Al_2O_3{\bullet}(4\text{-}6)SiO_2{\bullet}(17\text{-}20){\bullet}H_2O$ modified with organic and mineral additives was used: Vinnapas® RI 551Z, Mullite and $CaCO_3$.

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

The water resistance of the adhesive compound was determined according to (EN 204: 2001, the shear strength at spallation along the fibers of GOST 16483.5-1973, the adhesion with normal force separation according to GOST 32299-2013 (ISO 4624: 2002).

Flammability group was determined according to GOST 12.1.044-1989, EN 13823 + A1: 2014-12, ASTM E119-07. The study on determining the combustibility group of wood treated with the proposed coating was carried out in accordance with the current normative base. The essence of the test method for the experimental determination of the group of heavy and combustible solids and materials according to the influence of the sample is located in the ceramic tube of the OTM installation, the flame of the burner with the given parameters (the temperature of the gaseous combustion products at the exit from the ceramic tube is 200 ± 5 ºC). In the course of experimental studies, the maximum increase in the temperature of the gaseous combustion products (Δt) and the sample mass loss (Δm) are recorded. According to test results, materials are classified as:

− heavyweight − Δt < 60ºC and Δm < 60%;
− combustible − Δt ≥ 60ºC or Δm ≥ 60%.

To compare the properties, Kestokol D 4000 glue (KIILTO, Finland) was used as an analogue.

Samples for testing glued wood were made according to the requirements of the standards.

Discussions of Results

The results of the physico-mechanical properties of glued wood are given in Table 1.

Table 1. Physico-mechanical properties of the glued wood

Name of the indicator	The normalized value of the monitored parameter, MPa	Glue Kestokol D 4000, MPa	Aluminosilicate glue, MPa
Adhesion strength with wood	not less 2	2.07	2.6
The strength of adhesive bonding along the fibers	not less 4	5.4	7.8
The strength of adhesive joints in bending with a gear connection	not less 26	33.8	37.0
Water resistance of adhesive joints after:			
exposure of samples in water for 48 hours at a temperature 20±2 °C;	not less 3.2	3.2	3.2
after boiling for 3 hours at a temperature 100±2 °C	not less 3.0	3.0	2.6

As can be seen from the above data (Table 1), the developed aluminosilicate glue, in many respects exceeds the analog, but is slightly inferior in water resistance when boiled. However, we also had this indicator to tighten up to the normalized parameter.

The results of fire tests to determine the group of flammability of laminated wood samples (with a gear connection) were carried out at the OTM installation (Fig. 1 and Fig. 2)).

As can be seen from Fig. 1, clean wood begins to ignite for 50 seconds of dough; a sharp jump in temperature from 260 °C and higher is fixed at 170 seconds of dough.

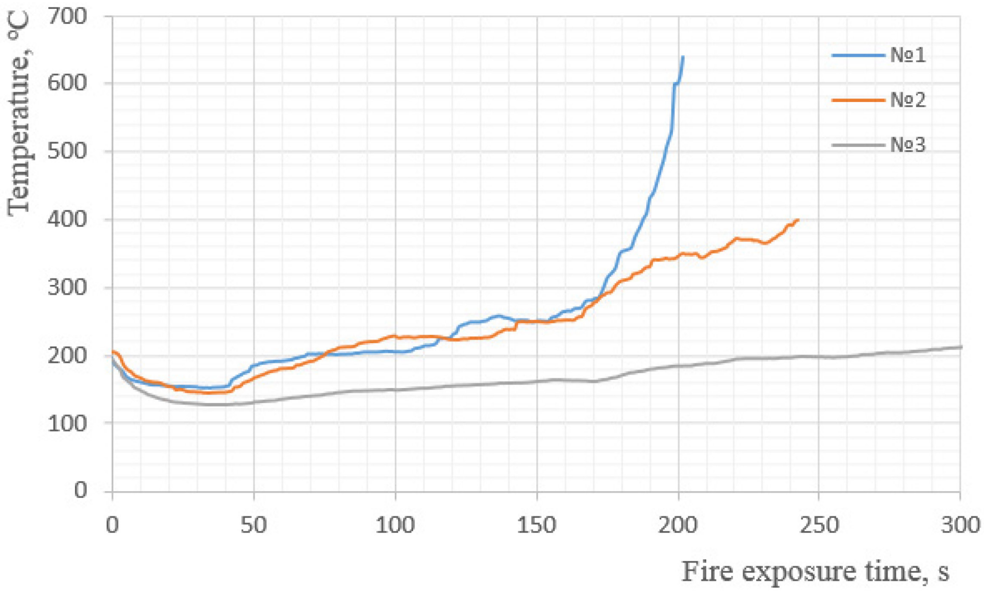

Fig. 1. Changes in the temperature of glued samples depending on the time of fire exposure: 1 – pure wood; 2 – wood gear joint on Kestokol D 4000 glue; 3 – wood gearing on aluminosilicate glue

The ignition of samples of the gear wood compound on Kestokol D 4000 glue starts at 170 seconds of dough, the temperature exceeds the critical value (260 °C) and tends to increase.

a) b)

Fig. 2. The appearance of samples of glue-like wood connections after fire exposure: a - on Kestokol D 4000 glue; b - on aluminosilicate glue

Ignition of samples of gear wood compounds on aluminosilicate glue is not observed throughout the test, the temperature does not exceed the critical - less than 200 °C, the mass loss does not exceed 4%, which, according to the standard, is regulated by both slow-burning and flame-resistant. The use of aluminosilicate glue when gluing wood massifs translates them into the first group on fire resistance. Resistance to fire exposure to aluminosilicate glue is provided by the peculiarities of its phase composition, described in detail in [1, 6 and Fig. 3], and the formation of a porous layer with a low value of thermal conductivity – λ = 0.09 Wt / m·K.

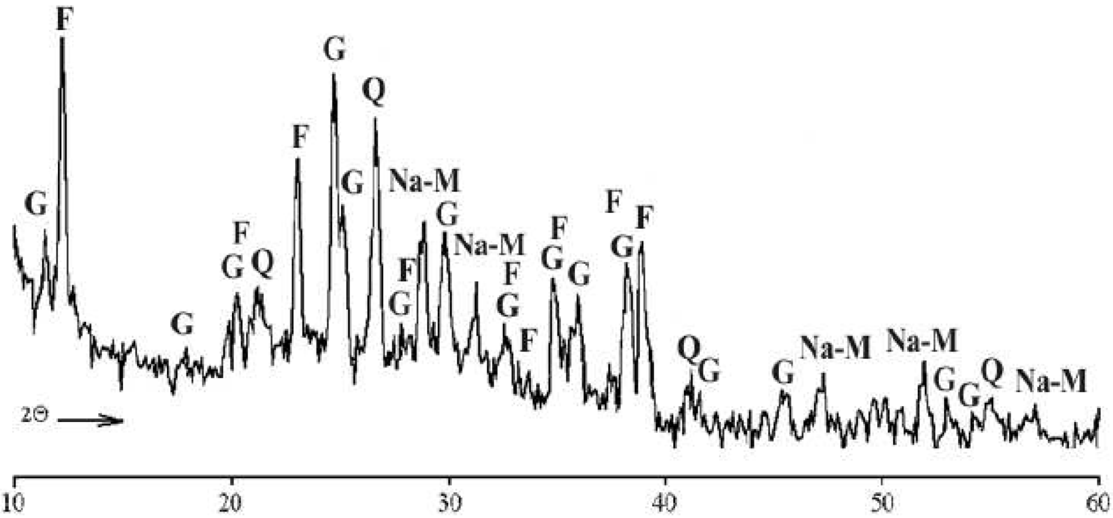

Fig. 3. X-ray patterns of the alkaline aluminosilicate glue of the type $Na_2O{\bullet}Al_2O_3{\bullet}6SiO_2{\bullet}20H_2O$: G – heulandite type (Ca, Na_2){$Al_2Si_6O_{16}$}•$5H_2O$; F – faujasite type $Na_2O{\bullet}Al_2O_3{\bullet}4.7SiO_2{\bullet}xH_2O$; Na-M – mordenite type (Ca, Na_2, K_2){$Al_2Si_{10}O_{24}$}•$7H_2O$

Conclusions

As a result of the conducted experiments, the prospects of using the aluminosilicate glue of the system $Na_2O{\bullet}Al_2O_3{\bullet}(4\text{-}6)SiO_2{\bullet}(17\text{-}20)H_2O$ for gluing wood massifs were established. According to the main physicomechanical properties, the developed glue is 1.1-1.4 times higher than the properties of the Kestokol D 4000 glue, and in terms of resistance to fire, it is much higher than the analog, ensuring the conversion of wood into flame-resistant and flame-resistant. The noted properties of aluminosilicate glue are provided due to the formation in its structure of zeolite-like phases such as heylandite and others, which, when exposed to temperatures, are capable of forming a porous aluminosilicate layer of low thermal conductivity.

Acknowledgements

The authors would like to acknowledge financial support of the Ministry of Education and Science of Ukraine (Fundamental research project “Physico-chamical bases for regulation of structure formation process and properties of the mineral aluminosilicate binder as adhesive for the use in ecologically safety wood products for various use” (Reg. No 0117U004842).

References

[1] P.V. Krivenko, K.K. Pushkareva, M.V. Sukhanevich and S.G. Guziy in: Fireproof coatings on the basis of alkaline aluminum silicate systems, volume 29 (10) of Ceramic Engineering and Science Proceedings (2009)

[2]. S.G. Guzii, P.V. Krivenko, Wood protection from burning using the geopolymer compositions / Building materials, products and sanitary engineering: Collection of scientific publications, Kyiv, No 41, 2011, pp. 56-64 (in Russian).

[3] P. Krivenko, S. Guzii, A. Kravchenko: Adv. Mater. Res. Vol. 688 (2013) p 3-9.

[4] V. Petránek, S. Guzii, P. Kryvenko, K. Sotiriadis and A. Kravchenko: Adv. Mater. Res Vol. 838-841 (2014), p. 183

[5] P. Krivenko, O. Petropavlovsky, G. Vozniuk: KEM, Vol. 761, pp 11-14

[6] K. Sotiriadis, S. Guzii, I. Kumpová, P. Mácová, A. Viani: SSP, Vol. 267, pp. 58-62