DE GRUYTER OPEN
RIGA TECHNICAL UNIVERSITY
Construction Science
ISSN 2255-8551 (online)
ISSN 1407-7329 (print)
2017, vol. 20, 4–9
doi: 10.2478/cons-2017-0001
https://www.degruyter.com/view/j/cons

Ensuring a Sustainable Structure and Efficiency of Thermal Insulation Straw-Boon Slabs in Full-Scale Conditions

Aleksandr Bakatovich[1], Nadezhda Davydenko[2]
[1, 2] *Polotsk State University, Novopolotsk, Belarus*

***Abstract* – The paper addresses the criteria ensuring a sustainable structure and efficiency of thermal insulation straw-boon slabs in full-scale conditions. Sorption humidity of heat insulator and conditions for fungus build-up on the surface of plant-based filler have been studied. Additives providing high water resistance of silicate glass used as the binder for thermal insulation material have been determined. Tests considering an array of technological parameters and fire behavior of straw-boon slabs confirmed a sustainable structure in the process of installation of thermal insulation material and in case of fire.**

***Keywords* – Fire resistance, sodium silicate glass, sorption humidity, straw-boon slab, water resistance.**

I. Introduction

At the moment, along with the tightening of thermal performance requirements, also with regard to heat rehabilitation of building envelope structures, the use of plant residues as a raw material for production of thermal insulation materials is of particular relevance. Modern thermal insulation materials should display a number of performance characteristics that provide favorable indoor climate and heat energy efficiency of the buildings. Multiple raw materials originate in the agricultural sector (straw, boon, husk, cotton and hemp stems). Organic and inorganic binding matters can be used as binding agents.

Along with the use of acryl, rubber latex, PVAC, etc., the use of silicate glass as the binder is most promising in manufacturing of agricultural crop residue-based thermal insulation materials, such as hemp and flax shive, grain crop straw, cotton stems [1], [2]. Silicate glass allows to provide low density of the insulating material, substantially increasing its fire resistance properties and rodent resistance. Absence of adverse impact of sodium silicate glass on the human organism enables production of environmentally friendly thermal insulation material that does not emit detrimental compounds while in operation.

II. Materials and Methods

Milled rye straw with tubes from 20 mm to 40 mm long was used in the tests. The straw was milled with a cylinder strawmill *RSB-0.1*.

Flax shive was used after processing with vibroscreen separator *BA 400N* with grid cell size 5 mm.

Sodium silicate is produced according to GOST 13078 [3]. Silica module of silicate glass is 2.9. Hydrogen value is from 11 to 12.

In the Republic of Belarus, mainly sodium liquid glass is produced, which is due to greater availability of raw materials and rather low cost while providing the required level of technical properties.

Addition of sodium hexafluorsilicate meets the requirements of TU RB (*ТУ РБ*) 289601.002-98 [4]. The assay is at least 98.5 %, density is 2.670 kg/m^3.

Hydrated lime II grade meets standard STB EN (*СТБ ЕН*) 459-1 [5]. Lime activity (CaO + MgO content) is 66 %.

The used gypsum cement with strength G-4 is manufactured according to GOST 125-79 [6].

The research tests used fine-grain chalk stone with mass fraction of lime carbonate ($CaCO_3$) at least 90 %, which meet the requirements of GOST 17498-72 [7].

Basic physical and mechanical parameters of thermal insulation slabs – density, humidity, compressive strength at 10 % linear strain, and bending strength were determined according to procedures set in GOST 17177 [8].

Thermal conductivity of straw-boon slabs under research was measured according to standard STB (*СТБ*) 1618 [9].

Analysis of sorption humidity was done according to standard STB (*СТБ*) EN 12088 [10] and according to the methodology [11].

Solubility of silicate glass was determined by drying of flannel cloths. Samples of flannel cloths 100 mm × 100 mm were silica wash impregnated, dried in a chamber dryer at 80–110 °C. Upon reaching the constant mass, the samples were cooled and immersed into the tank filled with water (20 ± 5) °C. After 2 hours, the flannel samples with the binding agent were taken out of the tank. To remove excess water, the cloth was strung up hanging free for 30 minutes. Upon that the flannel samples were placed into the chamber dryer and the cloth was weighed upon reaching its constant mass. Further the samples were immersed into the tank with water, dried and weighed again. The number of tests was conditioned by constancy of mass for three successively dried flannel samples. Change in a sample mass was expressed in percent. The relative binder solubility value and insoluble residue (water resistance) was determined considering the mass change value of the wetted flannel samples before and after immersion and drying.

III. Experimental Results

Polotsk State University developed and patented thermal insulation slabs based on milled straw and flax shives with sodium silicate as the binder. Main parameters of straw-boon slabs are: average density from 220 kg/m^3 to 250 kg/m^3, compressive strength at 10 % deformation from 0.65 MPa to 0.80 MPa, extreme bending strength from 1.0 MPa to 1.2 MPa, thermal conductivity coefficient from 0.046 W/(m°C) to 0.055 W/(m°C) [12].

A. Sorption Humidity Test

In addition to studying the basic physical and mechanical characteristics, studies have been carried out ***to determine the sorption humidity*** as an indicator that largely determines the sustainability of the structure of the material in conditions of operating the insulation and necessary for calculation of humidity mode of envelope structures.

The amount of moisture absorbed by the material depends on temperatures, air humidity, and on the composition, structure and porosity of the material [13]. The value of sorption humidity of the thermal insulation material was determined according to the requirements hereunder [11], [14]. For straw slabs milled straw (Composition 1) was used as the filler, but for straw-boon slabs – the mixture of milled straw and flax boon with the portion of straw for general filler consumption of 0.6 mass fraction (Composition 2). Binding agent consumption was taken equal to 1.4 mass fraction of the filler mass, molding pressure – 0.03 MPa. Average density of thermal insulation materials in Composition 1 and Composition 2 equals 230 kg/m^3. The studies according to [11] were carried out based on the samples of prefabricated thermal insulation slab materials. Relation curves of sorption humidity of materials to relative air humidity were built as sorption isotherms according to experimental data (Fig. 1).

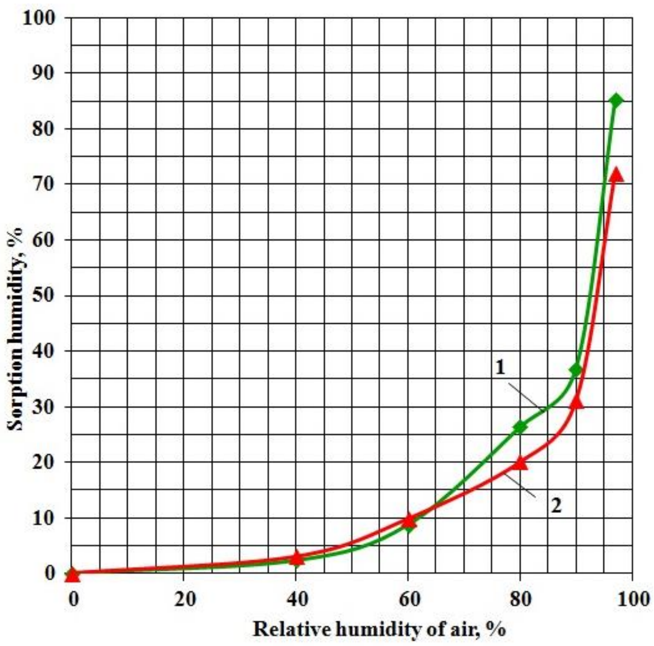

Fig. 1. Water vapor sorption isotherms: 1 – material based on milled straw, 2 – material based on the mix of milled straw and flax boon.

Analysis of the obtained curves shows that sorption humidity of material based on milled straw with relative air humidity up to 60 % is by 11.2 % lower than sorption humidity of the material based on the mixture of milled straw and flax boon. However, at 80 % air humidity sorption humidity of material with Composition 1 is 26.3 % and by 32 % greater compared to sorption humidity of material with Composition 2, being equal to 20 %. Sorption humidity of material with Composition 1 at 90 % air humidity is 36.8 %, which is by 19 % greater than sorption humidity of the material with Composition 2, being equal to 31 %. At 97 % relative air humidity, sorption humidity of the material with Composition 1 reaches 85.2 %, which is by 18 % greater than of that with Composition 2, being equal to 72 %. Relative air humidity range from 65 % to 90 % is a working range for the Republic of Belarus. Within the specified limits of air humidity the process of water vapor sorption by the material with Composition 1 occurs more intensively than for the material with Composition 2, which is confirmed by large values of sorption humidity. Consequently, it can be assumed that during operation thermal conductivity of the material with Composition 2 will be lower than that of the material with Composition 1 and by their heat performance parameters straw-boon slabs will be more effective than straw-filled thermal insulation materials.

In parallel with straw-boon mix and straw sorption humidity survey ***boundary humidity and time conditions were determined for growth of mould and fungus bodies***. After 140 days of tests for sorption humidity at 97 % relative air humidity on the surface of a straw-based composition, mould and spot fungus appeared. On the surface of the composition from straw-boon mixture, mould and spot fungus were detected on the 160th day at 97 % relative air humidity.

At 90 % relative air humidity after 175-day test mould and spot fungus were detected on the straw surface. After 210-day test at 90 % relative air humidity mould and spot fungus were not found on the surface of straw-boon mixture.

On the 210th day at 80 % relative air humidity, mould and spot fungus were not found on the surface of either straw or straw-boon mixture.

B. Alkali Silicate Glass Water Resistance Test

Thermal insulation slabs during their lifetime can be periodically exposed to conditions of high air humidity and wetting as a result of damaged uniformity and leakage in roof covering or vented facades. To provide durability of straw-boon slabs in such operational conditions, it is necessary to provide primarily water resistance of alkali silicate glass as the binder. According to the test data [15], [16], improved water resistance of alkali silicate glass is reached not only with help of additives, the modulus of silicate glass as well as temperature and hardening conditions also have a significant impact on this parameter.

Water resistance of silicate compositions, as a rule, declines along with the increase of silicate glass concentration. It is explained by the fact that during the reaction of interaction between alkali and hardening compound major part of alkali remains free. As the result of heterogeneous reaction behavior in certain conditions high-endurance conglomerates appear, which ensure high mechanical strength to the system as a whole. When wetted these conglomerates are separated and the material appears hydrolabile. At high viscosity of alkali glass the diffusion of the hardening compound into silicate masses is hampered.

Thus, to ensure the water resistance of silicate compositions, the presence of a hardener and the use of a low-density liquid glass are necessary [17].

To enhance water resistance in the research works [18]–[21] it is suggested to add cane sugar, starch, technical lignosulphonates, alcohol-yeast broth, sodium-hexafluorsilicate containing waste from chemical industries to alkali silicate glass.

Firstly, the samples of alkali silicate glass with additives were kept in a closed tank for 6 hours, and then dried at temperature of 50–60 °C to maintain similar conditions as for drying straw-boon slabs based on alkali silicate glass. The table presents water resistance values for alkali silicate glass, containing additives of sodium hexafluorsilicate, lime, gypsum and chalk.

The obtained samples were tested for one day after their manufacturing upon complete drying out (Table I). Alkali silicate glass without additives after the first cycle was disolved to a significant extent, but insoluble residue was 24 % by mass. After the second cycle of tests hard phase of alkali silicate glass was not detected.

When 2 % sodium hexafluorosilicate is introduced into the liquid glass, the solubility is reduced and after four test cycles is 29 %.

Concentration of 6 % sodium hexafluorsilicate in the alkali silicate glass causes formation of water-resistant residue being greater than that after adding 2 % additive by 15 %. In that case, solubility of alkali silicate glass decreases by 38 %. Addition of Na_2SiF_6 in amount of 10 % causes increase of insoluble residue content by 25 % compared to minimum dosage of sodium hexafluorsilicate in alkali silicate glass.

Addition of sodium hexafluorsilicate, especially at 8–10 % dosage, causes increase of viscosity after 30–35 minutes with the following rather quick hardening of alkali silicate glass. Low solubility of sodium hexafluorsilicate both in water and in alkali silicate glass should also be highlighted. As a result, even distribution of Na_2SiF_6 particles in the body of alkali silicate glass can be observed. It may be assumed that during interaction between alkali silicate glass and sodium hexaflursilicate the reaction occurs according to the equation (1) [22]:

$$2(Na_2O \cdot 2SiO_2) + Na_2SiF_6 + nH_2O = 6NaF + 5SiO_2 \cdot nH_2O. \quad (1)$$

According to the reaction and as a result of interaction between sodium hexafluorsilicate and alkali silicate glass, end products of the reaction NaF and SiO_2 are formed.

Addition of lime in the amount of 2 % causes formation of some water-resistant residue at the solubility equal to 42 % by mass. Presence of lime in the amount of 6 % causes increase of water-resistant residue of alkali silicate glass by 19 % compared to the residue containing 2 % $Ca(OH)_2$. Solubility of alkali silicate glass at 10 % lime concentration is lower than when adding 2 % $Ca(OH)_2$ by 2.1, but insoluble residue increases by 38 %.

At $Ca(OH)_2$ dosage from 6 % to 10 % after 40–60 minutes increase in viscosity of alkali silicate glass with further acceleration of hardening is observed, which is, probably, the result of chemical reaction occurring according to the equation (2) [23]:

$$Na_2O \cdot nSiO_2 + Ca(OH)_2 + 6H_2O = \\ = 2NaOH + (n-1)SiO_2 + CaSiO_3 \cdot 6H_2O. \quad (2)$$

TABLE I

WATER RESISTANCE OF ALKALI SILICATE GLASS CONTAINING ADDITIVES

Additive	Portion, %	Insoluble residue by mass, %, after a number of test cycles			
		1	2	3	4
Sodium hexafluorosilicate	2	83	76	72	71
	4	87	80	76	76
	6	91	86	83	82
	8	94	90	87	86
	10	96	92	90	89
Lime	2	77	66	61	58
	4	83	73	67	64
	6	86	77	72	69
	8	90	83	78	76
	10	92	86	83	80
Gypsum	2	86	76	70	67
	4	89	81	76	74
	6	91	85	81	78
	8	95	90	87	86
	10	96	94	91	90
Chalk	2	67	51	43	41
	4	76	60	52	49
	6	81	67	59	56
	8	86	73	65	62
	10	88	77	71	69
Chalk + gypsum	2	89	83	79	77
	4	91	85	82	80
	6	93	88	86	84
	8	95	92	89	88
	10	97	94	91	90
Lime + gypsum	2	91	86	82	81
	4	93	89	86	85
	6	95	92	89	88
	8	97	95	93	92
	10	98	97	96	95

According to the given equation, calcium hydrosilicate is formed due to the interaction between alkali silicate glass and calcium hydroxide.

Adding 6 % $CaSO_4$ to alkali silicate glass, insoluble residue increases by 16 % relative to the residue, with addition of 2 % gypsum. Mass increase of water-resistant residue by 34 % compared to the samples containing minimum amount of the additive is reached at 10 % gypsum dosage.

Gypsum concentration of from 2 % to 4 % practically does not have any impact on the increase of viscosity of alkali silicate glass during fabrication of the samples. At gypsum dosage increase up to from 8 % to 10 % already after 10–15 minutes upon addition of gypsum, fast increase of viscosity occurs with further transition into gelled mass. With addition of gypsum the process of setting and hardening of alkali silicate glass occurs much faster, which is explained by $CaSO_4$ hydration, and, consequently, by alkali silicate dewatering [20]. These chemical processes can be expressed by two equations:

$$CaSO_4 \cdot 0.5H_2O + 1.5H_2O = CaSO_4 \cdot 2H_2O; \quad (3)$$

$$Na_2O \cdot nSiO_2 + CaSO_4 \cdot 2H_2O = \\ = Na_2SO_4 + CaSiO_3 \cdot H_2O + (n-1)SiO_2 \cdot H_2O. \quad (4)$$

Maximum chalk dosage equaling 10 % allows reduction of solubility of alkali silicate glass by 47 % compared to minimum percent of the added material and increase of insoluble residue by 68 %. At 6 % chalk content water-resistant residue is by 37 % greater than the residue formed with 2 % additive.

At chalk dosage from 2 % to 10 % of alkali silicate glass fast changes in viscosity are not observed, as in cases with the additives considered above. During compounding of alkali silicate glass with finely grind chalk powder pasty mass is formed, which gradually turns into hard cast-in-place stone [15] according to the following chemical equation (5):

$$Na_2O \cdot nSiO_2 + CaCO_3 = Na_2CO_3 + (n-1)SiO_2 + CaSiO_3. \quad (5)$$

Thus, hardening of the mixture of alkali silicate glass with chemical chalk is explained by formation of calcium silicate and release of colloidal silica.

With addition of 2 % two-component additive of chalk and gypsum at the ratio 1:1 solubility of alkali silicate glass decreases to 23 %. Presence of a two-component additive from chalk and gypsum in amount of 6 % causes slight mass increase of insoluble residue by 9 % compared to the residue obtained with addition of 2 % additive to alkali silicate glass. The maximum portion of $CaCO_3 + CaSO_4$ additive in alkali silicate glass increases water-resistant residue by 17 % relatively to the residue formed at the minimum dosage of chalk and gypsum, but solubility of alkali silicate glass decreases 2.3 times.

During mixing of alkali silicate glass with two-component additives, first chalk or lime were added, and gypsum afterwards. It should be noted that when a two-component additive from lime and gypsum is used at the ratio 1:1, already at 2 % portion formation of significant amount of water-resistant residue occurs along with the decrease of solubility down to 19 %. At 6 % portion of a two-component additive from lime and gypsum solubility of alkali silicate glass decreases by 37 % compared to minimum amount of the additive. Addition of 10 % $Ca(OH)_2 + CaSO_4$ causes formation of insoluble residue 17 % greater by mass than alkali silicate glass residue formed in presence of 2 % lime and gypsum.

Based on the obtained results, the most effective additives in production of water-resistant alkali silicate glass with the modulus 2.9 are sodium hexafluorsilicate, gypsum, two-component additives from lime and gypsum, and from chalk and gypsum. Optimal portion of additives is from 8 % to 10 %. At such dosages solubility of alkali silicate glass with addition of Na_2SiF_6 makes maximum 14 % with formation of water-resistant residue in amount of 86–89 %. Addition of gypsum allows obtaining water-resistant residue equaling from 86 to 90 % by mass. A two-component additive from gypsum and chalk increases water resistance of alkali silicate glass up to 88–90 %, but addition of lime and gypsum – up to 92–95 %.

C. Determination Operational Characteristics of Straw-Boon Slabs

After assessment of the main physical and mechanical properties of thermal insulation slabs ***experiments to determine operational characteristics*** of straw-boon slabs were conducted. Straw-boon slab sawing experiments were carried out with use of different types of saws. The slabs were sawn both in the transverse and in the longitudinal direction. The results of the experimental sawing demonstrated that the slabs are equally well sawn with a hand saw, chain saw and buzz saw (Fig. 2). After sawing the slab surfaces do not show any chipped angles and ribs along the sawing line (Fig. 3). The sawing line has integral plane surface without cavities and voids. As the experiments showed, the sawn parts of the slab can have any thickness. In Fig. 3 the thickness of two parts of the slab sawn in the transverse direction is 50 mm each. Straw-boon slabs can be drilled with hand and power drills. The inlet holes do not have any chips or voids. The structure of straw-boon frame in the area around the hole is not disturbed.

Fig. 2. Sawing of a straw-boon slab with a chain saw in transverse direction.

Fig. 3. Absence of angle and rib chips, smooth surface along the transverse sawing line.

D. Iinvestigations Fire Resistance of Slab

During the experiment the slabs were exposed to direct fire. Fig. 4 shows the slab fragment during the experiment.

During the experiment, a straw-boon slab did not catch fire during exposure to fire. The slab edge, being exposed to fire, did not undergo any deformation. After 40 minutes of continuous exposure to open fire, the slab surface was inspected.

After 40 minutes of continuous exposure to open flame, the surface of the slab was inspected.

When the fire was extinguished, the slab burning, i.e. the burning of flame on the slab, was not detected. The area exposed to fire got black, in the centre of the slab on the area of 55 mm in diameter the straw-boon slab became charred and collapsed to the depth of 15 mm (Fig. 5). The slab edge opposite to the tested surface did not get any damage. Upon skin contact with the surface it was cold, i.e. heat warmth was not felt.

Absence of burn-up, i.e. non-flammability of straw-boon mixture, is explained by presence of alkali silicate glass as the binder. At the stage of slab fabrication during mixing, alkali silicate glass surrounds particles of straw and boon forming an integral jacket, which hampers their burn-up.

Inspection demonstrated charring alkali silicate glass on the surface, which also hampers burn-up and collapse of a straw-boon slab frame.

Fig. 4. Impact of fire on the slab during the test.

Fig. 5. Outer look of the slab after exposure to open fire.

When examined, it is established that when the straw is charred on the surface, liquid glass is caked in the splice, which also prevents the burning of the slab and the destruction of the straw-bonfire skeleton of the slab.

Presence of alkali silicate glass is also favorable for preservation of the slabs – their surface is not damaged by small rodents, as it happens with straw slabs used as a thermal insulation material [24], which is particularly important in the rural areas.

IV. Conclusion

Tests conducted at maximum relative air humidity from 90 % to 97 % are comparable with wetting of the material in full-scale operation. As the research has demonstrated, mould and spot fungus build-up on straw-boon mixture is possible only at relative humidity 97 % in case of long-term retention. Herewith the samples of straw-boon slabs demonstrated high resistance to mould and spot fungus build-up compared to straw slabs.

It has been found that the maximum resistance of alkali silicate glass is ensured by addition of sodium hexafluorsilicate, gypsum, two-component additives from lime and gypsum, as well as from chalk and gypsum. Still, when selecting an additive, it should be taken into account that based on sanitary norms and environmental safety considerations, the amount of added sodium hexafluorsilicate is limited and should not exceed 10 % of alkali silicate glass mass by dry solids content. Application of gypsum as the only additive considering fast onset of the chemical reaction and, as the result of transition from alkali silicate glass to gel state, makes even distribution of binder throughout the entire volume of a straw-boon mixture technologically unachievable at the stage of mixing. Thus, based on the water resistance value, for alkali silicate glass with modulus 2.9 the used two-component $CaCO_3 + CaSO_4$ and $Ca(OH)_2 + CaSO_4$ additives are the most feasible.

The performed tests demonstrated that straw-boon slabs are equally well sawn by different types of saws, are drilled easily without damaging the structure of the material. Exposure to fire causes only charring of a straw-boon slab without burn-up, and thermal deformations and changes in the structure of the material are not observed. According to the test results at MES laboratory of the Republic of Belarus, straw-boon slabs are given the category G1 – low-flammable thermal insulation material.

The research confirmed a sustainable structure and efficiency of straw-boon slabs, which allows maintaining high physical and mechanical properties of the thermal insulation material in full-scale operation of buildings.

References

[1] V. M. Kurdjumova, "Issledovanie i razrabotka tehnologii izgotovlenija plit iz steblej hlopchatnika," avtoref. dissertacija kand. tehn. nauk. Leningrad, Lesotehnicheskij universitet, 1981, s. 21.

[2] O. E. Smirnova, "Teploizoljacionnye materialy na osnove kostry lna," avtoref. dissertacija kand. tehn. nauk. Novosibirskij gosudarstvennyj arhitekturno- stroitelnyj universitet, Novosibirsk, 2007, s. 18.

[3] *Steklo natrievoe zhidkoe. Tehnicheskie uslovija*, GOST 13078-81, 1982. Moskva: Standartinform, 2005, s. 14.

[4] *Natrij geksaftorsilikat*, TU RB 28960196.002-98, 1998. Minsk: Bel standart, 1998, s. 18.

[5] *Izvest stroitelnaja. Chast 1. Opredelenija, trebovanija i kriterii sootvetstvija*, STB EN 459-1-2007, 2007. Minsk: Minstrojarhitektury Respubliki Belarus, 2007, s. 26.

[6] *Vjazhushhie gipsovye i smesi suhie gipsovye. Chast 1. Opredelenija i trebovanija*, STB EN 13279-1-2010, vzamen STB EN 13279-1-2007. Minsk: Minstrojarhitektury Respubliki Belarus, 2010, s. 28.

[7] *Mel. Vidy, marki i osnovnye tehnicheskie trebovanija*, GOST 17498-72, 1973. Moskva: Izdatelstvo standartov, 1972, s. 3.

[8] *Materialy i izdelija stroitelnye teploizoljacionnye. Metody ispytanij*, GOST 17177-94, 1995. Minsk: Minstrojarhitektur, 1996, s. 56.

[9] *Materialy i izdelija stroitelnye. Metody opredelenija teploprovodnosti pri stacionarnom teplovom rezhime*, STB 1618-2006, 2006. Minsk: Minstrojarhitektury, 2006, s. 9.

[10] *Materialy stroitelnye teploizoljacionnye. Opredelenie sorbcionnoj vlazhnosti*, STB EN 12088-2008, 2008. Minsk: Gosstandart, 2009, s. 8.

[11] U. A. Franchuk, *Metodika po opredeleniju sorbcionnoj vlazhnosti*. Kiev: NIISP Gosstroja USSR, 1970, s. 48.

[12] N. Davydenko and A. Bakatovich, "Operational Characteristics and Technological Features of Straw-Boon Plates Manufacturing," *Herald of Polotsk State University. Series F. Civil engineering. Applied sciences*, no. 16, pp. 61–65, 2015.

[13] K. F. Fokin, *Stroitelnaja teplotehnika ograzhdajushhih chastej zdanija*, pod red. Ju. A. Tabunshhikova i V. G. Gagarina, 5-e izd. peresmotr. Moskva: AVOK-PRESS, 2006, s. 256.

[14] *Materialy stroitelnye teploizoljacionnye. Opredelenie sorbcionnoj vlazhnosti*, STB EN 12088-2008, 2008. Minsk: Gosstandart, 2009, s. 8.

[15] M. I. Babushkina, *Zhidkoe steklo v stroitelstve*. Kishinev: Kartja Moldovenjaskje, 1971, s. 215.

[16] A. I. Zhilin, *Rastvorimoe steklo, ego svojstva, poluchenie, primenenie*. Moskva: Gosudarstvennoe obedinennoe nauchno-tehnicheskoe izdatelstvo, 1939, s. 96.

[17] P. I. Vlasenko, V. M. Kulik, "Mineralnoe svjazujushhee dlja otdelochnyh materialov po drevesine," *Derevoobrabotka*, no. 12. s. 6–23, 1989.

[18] V. V. Lisovskij, et al., "O vlijanii nekotoryh tehnologicheskih parametrov prigotovlenija zhidkostekolnyh celljulozosoderzhashhih kompozicij na vodostojkost," *Plasticheskie massy*, no. 4, s. 23–25, 1997.

[19] A. S. Shherbakov, L. V. Golcova, *Sposob korrektirovanija sostava drevesno-mineralnoj smesi*, A. S. 1571023 SSSR, MKI S04 V18/24, no. 22, 1990.

[20] V. V. Arbuzov, *Kompozicionnye materialy iz ligninnyh veshhestv*. Moskva: Jekologija, 1991, s. 208.

[21] L. Ju. Dubovskaja, "Razrabotka kompozicionnogo materiala celevogo naznachenija na osnove mjagkih othodov derevoobrabotki i modificirovannogo zhidkogo stekla," avtoref. dissertacija kand. tehn. nauk. Belorusskij gosudarstvennyj tehnologičeskij universitet, Minsk, 2008, s. 19.

[22] V. Gluhovskij, *Gruntosilikaty*. Kiev: Gosudarstvennogo izdatelstva literatury po stroitelstvu i arhitekture USSR, 1959, s. 127.

[23] Ruk. A. A. Kozlov, ispoln. N. I. Puchkov, A. I. Balabanov, *Razrabotat i vnedrit uskoritel tverdenija iz kubovyh ostatkov proizvodstva maleinovogo angidrida dlja zhidkostekolnyh kompozicij: otchet o NIR* (*zakljuch*.). Vsesojuznyj mezhotraslevoj nauchno-issledovatelskij institut po zashhite metallov ot korrozii, Vserossijskij nauchno-tehnicheskij informacionnyj centr, no. GR 01850059573, inv. no. 02870039881, 1985, s. 52.

[24] I. E. Shirokov, *Jekotehnologija biopozitivnyh ograzhdajushhih konstrukcij iz solomennyh blokov v Belarusi. Chast 1. Jekodoma iz solomy: tehnologija stroitelstva*. Minsk: Adukacyja i vyhavanne, 2007, s. 40.

Aleksandr Bakatovich, PhD, associate professor, Dean of the Faculty of Civil Engineering, Polotsk State University.
Fields of research: modified mortars and concretes, thermal insulation materials, "green" construction.
Address: Blokhin Street 29, Novopolotsk, Belarus
E-mail: a.bakatovich@psu.by

Nadezhda Davydenko, PhD, assistant professor of the Department of Heat, Gas and Water Supply and Ventilation, Polotsk State University.
Fields of research: heat-mass exchange processes, insulation materials, "green" construction, alternative energy sources.
Address: Blokhin Street 29, Novopolotsk, Belarus
E-mail: a.davydenko@psu.by