Determined the effect of the composition of an aluminosilicate binder on the rheotechnological properties of adhesives for wood

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1. Introduction

Glued wooden structures are widely used in construction, primarily due to their high strength characteristics, moisture resistance, and a relatively low cost of installment [1, 2]. Another advantage of glued structures is the utilization of substandard wood [3]. Wood glueing mainly involve organic adhesives based on polyvinyl acetate emulsions that has water resistance indicators of D2...D4 [4], as well as phenol-formaldehyde [5], acrylic [6], epoxy [7], polyurethane [8], and others.

The share of mineral adhesives is insignificant and they serve as a base for mineral adhesives from a technological point of view.

Mineral adhesives represent heterogeneous physical-chemical systems (suspensions). They consist of three or more phases, separated by an interface. The liquid phase is a dispersed medium with the suspended solids (dispersed phases) distributed in it, whose sizes vary from 0.5 to 100 μm. Phases may differ from each other in composition and properties, component content, thermodynamic character and in the degrees freedom. Typically, solid components in a dispersed environment are bound by a phase rule [10].

For the case where a dispersed medium is an alkaline aluminosilicate binder, highly-filled with functional additives, it manifests its heterogeneity and predisposition to sedimentation with a change in the dynamic viscosity over time.

Therefore, it is a relevant task in terms of colloidal chemistry to regulate aggregate stability and processes of structure formation in alkaline aluminosilicate suspensions that serve as a base for mineral adhesives from a technological point of view.
To control the processes of structure formation and the rheological properties of aluminosilicate adhesives, thinning and stabilizing chemical additives are used. These additives make it possible to purposefully change both their electro-surface and rheological characteristics aimed at modifying the phase interface «solid body – solution».

2. Literature review and problem statement

We did not find any papers reporting studies into the rheotechnological properties of adhesives for wood arrays. Given the fact that an aluminosilicate adhesive contains in its composition metakaolin, micro silica, and liquid glass, it is advisable to analyze scientific works on the rheology of the components specified above.

Paper [11] reports results of the gelation of a composite colloidal-silica system. It is shown that it occurs due to the hydroxylation of silica particles with the formation of primary aggregates that are chemically bonded by a gel-like siliceous phase. The influence of Cl\(^-\), NH\(_4^+\), OH\(^-\) ions from a liquid phase on the formation of a silica skeleton has remained unclarified from the rheokinetic point of view.

In [12], a rotary viscometry method was applied to study the dynamics of the destruction of dispersed structures in aerosil A-175 in water and aqueous solutions of non-ionic polyethylene oxide. It was found that the presence of gas (air) inclusions causes the structural and hydrodynamic instability of dispersions. The aerosil dispersions, modified by polyethylene oxide, belong to the thixotropically structured systems. Increasing the concentration of polyethylene oxide leads to a substantial increase in the structure arrangement of the system and changes the rheological behavior of the dispersion. At the concentrations of polyethylene oxide SPEO<1.25⋅10\(^{-4}\) mol/l dispersions demonstrate the quasi-Newtonian current character. At SPEO>2.5⋅10\(^{-3}\) mol/l, the dispersion current demonstrates attributes typical of highly structured solid-state (Rebinder) systems.

Paper [13] investigated the electrokinetic and rheological properties of kaolin dispersions with a volumetric share of solid phase particles at φ=0.20 and φ=0.47 in the presence of a sodium silicate dispersant (Xs=0.075 mg dispersant/m\(^2\) and Xs=0.225 mg dispersant/m\(^2\). Dispersions with Xs≤0.075 mg dispersant/m\(^2\) demonstrated plastic behavior (when tested for shear) and the characteristics of a gel (at vibrational tests) due to the large aggregation of kaolinite particles. Dispersions with a dispersant in the amount Xs≥0.105 mg/m\(^2\) demonstrated rarefaction characteristics at shear and behaved as viscoelastic fluids at vibrational tests. Such a behavior is typical of dense dispersions with lamellar colloidal particles, which are well stabilized by electrostatic repulsion, which is characteristic of the stabilized highly concentrated dispersions.

Works [14, 15] report results from regulating the rheological properties of kaolin and kaolin-hydroxyaceous clay suspensions and ceramic slurries. It is shown that control becomes possible due to effective organo-mineral diluents. The effect of diluents is associated with a change in the electrokinetic potential of the system due to the parallel progress of two processes – cation exchange and physical adsorption of anions. The authors did not study the influence of diluents on the rheokinetics of dispersions over time. It was noted in [16] that the nonaqueous layered silicate dispersions exhibit a complex rheology behavior due to the sensitivity of the structure to the flow. The nature of nonequilibrium and metastable structures, caused by the flow in the investigated layered silicate suspensions with their linear and non-linear viscous elastic properties, is based on a fractal scaling theory, whereby the space of percolation networks, consisting of clusters with a mass fractal dimensionality of Df=2, makes it possible to identify the formation of aggregates in the flow of a dispersed environment. It was noted that the suspension shear speed is associated with a reversible aggregation process. After stopping the flow, the authors observed the thixotropic properties in the suspension, associated with local restructuring at the nanolevel.

Since the main phases in the process of polycondensation of aluminosilicate structures are zeolite-like new formations [17, 18], work [19] carried out a research of the rheological characteristics of natural zeolite aqueous suspensions. It is shown that at pH=7 at the concentration of particulate matter to 20 % the suspensions demonstrated a Newtonian behavior and withstood higher loads at shear. With a solid phase content exceeding 35 %, the suspensions showed hysteresis and had a limit of fluidity, which increased exponentially at an increase in solid substance. The emergence of the yield strength and its rapid growth at a relatively low concentration of solids, compared with other concentrations of particulate matter in suspensions, were explained by intra-particle interaction.

From a technological point of view, the dilution and increased fluidity of aluminosilicate suspensions is possible under conditions of cavitation treatment [20–23], following which the dynamic viscosity of the compositions was characterized by pseudoplasticity and homogeneity.

3. The aim and objectives of the study

The aim of this study is to determine the effect of the composition of an alkaline aluminosilicate binding agent on the rheotechnological properties of aluminosilicate adhesives for wood, which would make it possible, under industrial conditions, to control the time it takes for both causing and gluing the arrays of wood.

To achieve the set aim, the following tasks have been solved:

- to define the rheotechnological characteristics of sodium soluble glass as the dispersed phase of an aluminosilicate adhesive;
- to determine the rheotechnological characteristics of an aluminosilicate adhesive based on the alkaline aluminosilicate binding agent with a composition of Na\(_2\)O Al\(_2\)O\(_3\)-4.5SiO\(_2\)-17.5H\(_2\)O;
- to determine the rheotechnological characteristics of an aluminosilicate adhesive based on the alkaline aluminosilicate binding agent with a composition of Na\(_2\)O Al\(_2\)O\(_3\)-6SiO\(_2\)-20H\(_2\)O.

4. Materials for obtaining rheotechnological aluminosilicate adhesives and methods to study them

In order to obtain the alkaline aluminosilicate binding agent with a composition of Na\(_2\)O Al\(_2\)O\(_3\) (4.5–6)SiO\(_2\) (17.5–20)H\(_2\)O to serve as a model system, we used metakaolin, micro silica, and sodium liquid glass. Calculation of the optimum ratio of oxides was carried out taking into consideration recommendations from [24–26]. We adjusted the composition of the binding agent for alkaline oxides by using their aqueous solutions.
According to work [9], it is expedient to use adhesives with a ratio of basic structure forming oxides $\text{SiO}_2/\text{Al}_2\text{O}_3 = 4.5$ and $\text{SiO}_2/\text{H}_2\text{O} = 17.5$ for gluing wood arrays. The adhesives at ratio $\text{SiO}_2/\text{Al}_2\text{O}_3 = 6$ and $\text{SiO}_2/\text{H}_2\text{O} = 20$, representing a more elastic system [27–31], should be use to glue plywood and structural elements with an enhanced flame resistant of the adhesive joint.

To obtain an aluminosilicate adhesive for gluing wood arrays, a series of functional organo-mineral additives were expediently introduced into the composition [32]. The additives would contribute to the regulation of rheological characteristics – viscosity, spreadability, wetting angle, etc. The set of the organo-mineral additives is the «know-how» and is not disclosed in this work.

We prepared the alkaline aluminosilicate binder and the adhesive based on it at a laboratory dissolver. Conditional viscosity of suspensions was determined using the viscometer VZ 246 with a hole diameter of 4–6 mm at a temperature of $20\pm 2$ °C.

The rheological characteristics were acquired using the Brookfield viscometer LV D2T in the speed range from 0 to 200 RPM applying the spindles LV-2C(66) and LV-3C(67).

We determined a surface tension coefficient for the aluminosilicate adhesives by a drop separation method [5, 33]:

$$\gamma = \frac{mg}{nD}, \text{ mN/m},$$

where: $m$ is the mass of a suspension, $g$ is the acceleration of gravity force, $m/\text{cm}^2$; $n$ is the number of drops, $n=23$; $D$ is the capillary diameter, mm ($D=5$ mm).

We determined the work of adhesion ($W_\text{a}$), cohesion ($W_k$), wetting ($W_\text{w}$) forces, as well as wetting ($S$) and spreadability ($f$) coefficients, according to data from paper [34].

Wetting angle was determined by digital photography followed by image processing using the software paint.net and COMPASS.

The wood backings used were alder, birch, pine, ash, oak, and beech wood. The samples of wood were characterized by an equilibrium humidity of 12 % and a surface roughness of 80 µm. The criteria that were chosen for estimating the rheotechnological characteristics of aluminosilicate adhesive suspensions included: dynamic viscosity, plastic viscosity, the cosine of the wetting angle, surface tension, and shear force.

The object selected for comparing the rheotechnological characteristics was sodium liquid glass with silicate module $M_s=2.84$ and density $1.383 \text{ g/cm}^3$.

5. Results from studying the rheotechnological properties of aluminosilicate adhesives

The main dispersive environment both for the alkaline aluminosilicate binder and the adhesive on its base is sodium liquid glass. Determining its rheotechnological characteristics is important to understand changes in the rheotechnological characteristics of aluminosilicate adhesives when they are used to wet the surface of wooden backings made from different types of wood in the process of coating and gluing.

Fig. 1–3 show results of change in the dynamic and plastic viscosity of sodium liquid glass, as well as adhesives obtained based on the binding agents with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4.5\text{SiO}_2 \cdot 17.5\text{H}_2\text{O}$ and $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot x\text{SiO}_2 \cdot 20\text{H}_2\text{O}$, depending on spindle rotation velocity and the momentum; Fig. 4 – shear efforts on shear rate.
Fig. 5–7 show results from wetting the surface of back-
ings made from wood of different breeds with sodium liquid
glass and the adhesives that were obtained based on binders
with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4.5\text{SiO}_2 \cdot 17.5\text{H}_2\text{O}$ and
$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 20\text{H}_2\text{O}$. 

The colloidal-chemical characteristics of sodium liquid
glass and the suspension of adhesives based on the alka-
line aluminosilicate binder with compositions $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \times 
4.3\text{SiO}_2 \cdot 17.5\text{H}_2\text{O}$ and $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 20\text{H}_2\text{O}$ are given
in Tables 1–3.
Fig. 5. Wetting angle of liquid glass on wooden backings: 

- Alder, $\theta_{av} = 65^\circ 92'$; 
- Birch, $\theta_{av} = 68^\circ 82'$; 
- Pine, $\theta_{av} = 31^\circ 08'$; 
- Ash, $\theta_{av} = 67^\circ 28'$; 
- Oak, $\theta_{av} = 63^\circ 59'$; 
- Beech, $\theta_{av} = 59^\circ 64'$

Fig. 6. Wetting angle of the adhesive suspension based on the alkaline aluminosilicate binder with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4.5\text{SiO}_2 \cdot 17.5\text{H}_2\text{O}$ on wooden backings: 

- Alder, $\theta_{av} = 44^\circ 17'$; 
- Birch, $\theta_{av} = 50^\circ 74'$; 
- Pine, $\theta_{av} = 48^\circ 09'$; 
- Ash, $\theta_{av} = 47^\circ 3$; 
- Oak, $\theta_{av} = 64^\circ 31'$; 
- Beech, $\theta_{av} = 37^\circ 13'$

Fig. 7. Wetting angle of the adhesive suspension based on the alkaline aluminosilicate binder with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 20\text{H}_2\text{O}$ on wooden backings: 

- Alder, $\theta_{av} = 54^\circ 01'$; 
- Birch, $\theta_{av} = 66^\circ 72'$; 
- Pine, $\theta_{av} = 58^\circ 78'$; 
- Ash, $\theta_{av} = 71^\circ 78'$; 
- Oak, $\theta_{av} = 58^\circ 09'$; 
- Beech, $\theta_{av} = 64^\circ 52'$
Colloidal-chemical properties of liquid glass

| Indicators | UM          | Backing from wood breeds |
|------------|-------------|--------------------------|
|            | alder       | birch                    | pine | ash | oak | beech |
| density    | 1.427 g/cm³ | 1.628 g/cm³              | 1.676 g/cm³ | 1.678 g/cm³ | 1.4335 g/cm³ | 0.7973 g/cm³ |
| cosθ       | 0.7173      | 0.7326                   | 0.66796 g/cm³ | 0.6782 g/cm³ | 0.4335 g/cm³ | 0.7973 g/cm³ |
| Wy         | mN/m        | 55.64                    | 52.99 | 54.04 | 54.37 | 46.45 | 58.23 |
| Wk         | mN/m        | 64.89                    | 64.89 | 64.89 | 64.89 | 64.89 | 64.89 |
| Ww         | mN/m        | 23.24                    | 20.59 | 21.64 | 21.97 | 14.05 | 25.83 |
| s          |             | – 0.8586                 | 0.8164 | 0.834 | 0.839 | 0.717 | 0.8986 |
| f          | mN/m        | – 9.16                   | – 11.9 | – 10.76 | – 10.43 | – 19.35 | – 6.5 |

6. Discussing the experimental results from studying the rheotechnological properties of aluminosilicate adhesives

Fig. 1, a shows that in the speed range from 70 to 200 RPM the dynamic viscosity of sodium liquid glass varies nonlinearly at a magnitude of 45±0.4 Pa·s.

The plastic viscosity of the liquid glass, which is determined from the cotangent of the inclination angle of the straight line in the dependence \( v = f(M) \), amounts to the magnitude of 84.43 sP in the velocity range from 70 to 200 RPM. Difference in the values for dynamic and plastic viscosity can be explained by the structure arrangement of the structural components of glass, namely colloidal particles of ortho-, di-, and trisilicates of sodium in the dispersed environment [35].

One can see from Fig. 2, a that in the speed range from 0 to 200 RPM the dynamic viscosity of the adhesive suspension based on the alkaline aluminosilicate binder with a composition of Na₂O·Al₂O₃·4.5SiO₂·17.5H₂O changes in line with an exponential dependence characterizing the pseudoplastic type of a liquid. The same dependence is observed for a change in the values of dynamic viscosity \( (v=200 \text{ RPM}=\text{const}) \) d depending on the time of spindle rotation (Fig. 2, b).

Plastic viscosity of the adhesive with a composition of Na₂O·Al₂O₃·4.5SiO₂·17.5H₂O was determined based on the cotangent of the inclination angle of the straight line in the dependence \( v = f(M) \), in the speed range from 0 to 200 RPM, its magnitude is 86.27 sP (Fig. 2, c). The increase in the values for plastic viscosity, in comparison with the same indicator for the liquid glass, is explained by the larger filling of the dispersed environment with the dispersive phase, as evidenced by the increase in spindle torque.

One can see from Fig. 3, a that in the speed range from 0 to 200 RPM, the dynamic viscosity of the adhesive suspension based on the alkaline aluminosilicate binder with a composition of Na₂O·Al₂O₃·6SiO₂·20H₂O varies in line with an exponential dependence, which characterizes the pseudoplastic type of a liquid. The same dependence is observed for a change in the dynamic viscosity \( (v=200 \text{ RPM}=\text{const}) \) d depending on the time of spindle rotation (Fig. 3, b).

Plastic viscosity of the adhesive suspension based on the alkaline aluminosilicate binder with a composition of Na₂O·Al₂O₃·4.5SiO₂·17.5H₂O, which was determined based on the cotangent of the inclination angle of the straight line in the dependence \( v = f(M) \), amounts to a magnitude of 85.72 sP. Alder in the speed range from 0 to 200 RPM. The increase in the values of plastic viscosity, in comparison with the same indicator for the liquid glass, is explained by the larger filling of the dispersed environment with the dispersive phase, as evidenced by the increase in spindle torque.

Changes in the deformation characteristics of liquid glass and adhesion suspensions are shown in Fig. 4. It follows from the obtained experimental data that for liquid glass the shear effort is proportional to the shear rate and is linear in character (Fig. 4, a). For the adhesive of composition Na₂O·Al₂O₃·4.5SiO₂·17.5H₂O (Fig. 4, b) the character of change in dependence is similar to the liquid glass. There is an abnormal effect at small values of shear rate from 0.0378 to 1.05 1/s. The shear effort increases from 26.21 dyne/cm² to 48.64 dyne/cm², exceeding the same indicators for liquid glass at larger shear speeds from 14 to 39 1/s. For the adhesive of composition Na₂O·Al₂O₃·6SiO₂·20H₂O (Fig. 4, c), one observes at low shear speeds a sharp surge in shear effort from 40 to 110 dyne/cm². With an increase in the shear rate values from 5 to 42 1/s the shear effort increases from 110 to 158 dyne/cm².

The derived rheotechnological characteristics of the examined compositions contribute to understanding the changes in their colloidal-chemical characteristics when wetting a wood surface.

When applying liquid glass drops on wooden backings from different breeds, one can see that at the same parameters for surface roughness the wetting angle does differ; most likely it depends on the viscosity, surface charge, and density of the wood breed (Fig. 5).

The smallest value of wetting angle \( \Theta_m = 31°08' \) is characteristic of pine, which is explained by the lower value of its density, porosity characteristics, etc.

For birch, the wetting angle value is the largest \( \Theta_m = 68°82' \) and it is dense enough compared to other backings. The lowest value for wetting angle \( \Theta_m = 37°13' \)
characteristic of beech wood, the largest, $\theta_{av}=64^\circ31'$, of oak wood, which is explained by the lower value of its density, porosity characteristics, etc.

As seen from data in Table 1, at the same value of superficial tension and cohesive work, the smallest wetting angle ($\cos \Theta = 0.8564$) and the largest coefficients of wetting ($s = 0.9283$) and spreading ($f = -7.79$ mN/m), as well as the work of adhesion forces ($W_a = 100.81$ mN/m), wetting forces ($W = 46.5$ mN/m), for liquid glass are demonstrated by a pine backing.

When applying droplets of the adhesive based on the alkaline aluminosilicate binder with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4.5\text{SiO}_2 \cdot 17.5\text{H}_2\text{O}$ onto backings made from different types of wood, one can see that at the same parameters for surface roughness, the wetting angle does differ and, most likely, it depends on the surface charge and density of the wood breed (Fig. 6). The smallest wetting angle value $\theta_{av} = 54^\circ01'$ is characteristic for alder wood, the largest $\theta_{av} = 71^\circ78'$ for ash wood, due to the greater value of its density, the characteristics of porosity, etc.

It was noted that at the same value of surface tension and cohesive work (Table 2), the smallest wetting angle ($\cos \Theta = 0.7973$) and the largest coefficients of wetting ($s = 0.8986$) and spreading ($f = -6.5$ mN/m), as well as the work of adhesion forces ($W_a = 58.23$ mN/m), wetting forces ($W = 25.83$ mN/m), are demonstrated by backings made of beech, followed by alder, ash, pine, birch, and oak.

When applying droplets of the adhesive based on the alkaline aluminosilicate binder with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4.5\text{SiO}_2 \cdot 17.5\text{H}_2\text{O}$ onto backings made from different types of wood, one can see that at the same parameters for surface roughness the wetting angle does differ, most likely, it depends on the surface charge and density of the wood breed (Fig. 7). The smallest wetting angle value $\theta_{av} = 54^\circ01'$ is characteristic of alder wood, the largest $\theta_{av} = 71^\circ78'$ – of ash wood, due to the greater value of its density, the characteristics of porosity, etc.

It was shown that at the same value of surface tension and cohesive work (Table 3) the smallest wetting angle ($\cos \Theta = 0.5876$) characterizes the alder backing, followed by pine, oak, birch, beech, and ash.

Such a behavior of suspensions clearly manifests thixo-tropy, it is consistent with data from papers [36, 37] and makes it possible to control the gluing of arrays of different types of wood with a certain time of survivability, which makes it possible to develop the mechanisms to feed aluminosilicate adhesives to gluing sites, to predict the conditions for thermal treatment of glued arrays, etc. Special features of this study relate, first, to that an aluminosilicate adhesive has a mineral nature and exhibits resistance to fire, and other factors; second, to that, by controlling its rheotechnological properties, it is possible to use it at automated lines for the production of wooden pallets.

Our studies in the future will be aimed at studying the yield strength of aluminosilicate adhesives by reducing the size of dispersed particles, providing for uniformity with the increased adhesive capacity under conditions of cavitation treatment of aluminosilicate suspensions.

6. Conclusions

1. It has been established that in the speed range from 70 to 200 RPM the dynamic and plastic viscosity of sodium liquid glass changes linearly and amounts to a magnitude of 45±0.4 sP and 84.43 sP, respectively. It was noted that at the same value of surface tension and cohesive work, the smallest wetting angle ($\cos \Theta = 0.8564$) characterizes the pine backing.

2. For the adhesive based on the alkaline aluminosilicate binder with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4.5\text{SiO}_2 \cdot 17.5\text{H}_2\text{O}$, the dynamic viscosity in the range of speeds from 0 to 200 RPM varies from 6.933 sP to 368.4 sP, and the mean plastic one amounts to a magnitude of 86.27 sP. At small values of shear rate from 0.0378 to 1.03 1/s, the shear effort increases from 26.21 dyne/cm$^2$ to 48.64 dyne/cm$^2$, exceeding the same indicators for liquid glass at large shear speeds from 14 to 39 1/s. It was noted that at the same value for surface tension and cohesive work, the smallest wetting angle ($\cos \Theta = 0.7973$) is demonstrated by the beech backing, followed by alder, ash, pine, birch, and oak.

3. For the adhesive based on the alkaline aluminosilicate binder with a composition of $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4.5\text{SiO}_2 \cdot 20\text{H}_2\text{O}$ the dynamic viscosity in the range from 0 to 200 RPM varies from 5.340 sP to 374.4 sP, and the mean plastic one amounts to a magnitude of 85.72 sP. It was discovered that at low shear rates there is a sharp surge in shear effort from 40 to 110 dyne/cm$^2$, which is associated with the dispersing processes of silica component; and with an increase in the shear rate values from 5 to 42 1/s the shear effort increases from 110 to 158 dyne/cm$^2$, which is due to the stabilization of values for viscosity and the homogeneity of the adhesive structure. It was noted that at the same value for surface tension and cohesive work, the smallest angle of wetting ($\cos \Theta = 0.5876$) characterizes the alder backing, followed by pine, oak, birch, beech, and ash.

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Concrete as a composite building material is widely used in construction due to its relatively low cost, variety of applications, high durability and environmental friendliness [1, 2]. It is the second most used material on the planet after water.

Current trends lean towards increasing the cement content in concrete. Between 2004 and 2019 cement consumption in construction due to its relatively low cost, variety of applications, high durability and environmental friendliness [1, 2]. It is the second most used material on the planet after water. The development of new nanocomposite materials is one of the main directions of research in the field of building materials. The main goal is to improve the properties of cement-based composites, reduce the consumption of Portland cement and the level of environmental emissions.

In recent years, research has focused on the use of nanomodifiers to improve the properties of Portland cement-based composites [3, 4]. The use of nanomodifiers allows for the creation of materials with improved properties, such as increased strength, improved durability, and reduced environmental impact. 

The use of nanomodifiers is also a way to achieve sustainable development in building materials, as it allows for the reduction of the amount of Portland cement used in construction [5, 6]. This is particularly important in the context of the increasing demand for building materials and the need to reduce the environmental impact of construction activities.

1. Introduction

Concrete as a composite building material is widely used in construction due to its relatively low cost, variety of applications, high durability and environmental friendliness [1, 2]. It is the second most used material on the planet after water.