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IMPROVING THE STRENGTH OF COMPOSITE MATERIAL THROUGH THE EFFECTIVE MODIFICATION OF THE SURFACE OF THE CELLULOSE FILLER

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An effective technique has been devised in order to increase the strength of arbolite, based on the method of rice husk thermal treatment. Given the fading of the surface layer of the grains during thermal exposure, the accompanying elements are removed from the outer cellulose fibers of the husk structure, that is, the texture of the surface of the material changes. It is known that the strength of multicomponent materials depends on the strength of bonds between the structural elements and the strength of the elements themselves. In arbolite, the strength of the constituent elements is great but the strength of arbolite almost does not exceed 2.5–3.5 MPa. Therefore, one of the factors determining the strength of arbolite is the adhesion strength of its heterogeneous particles. Therefore, a necessary and mandatory condition for the preparation of rice husks is soaking them in water, as well as the use of chemical additives for their treatment. This study's results established that the surface of the modified rice husk is chemically more active than without treatment. The use of chemical additives made it possible to neutralize the effect of extractive aggregates on cement due to the formation of additional chemical bonds in the contact zone and reduce their toxic effect on cement when removed from this zone. As a result of thermal exposure, a new potential property is revealed in the rice husk, which is expressed in the modification of the husk by changing the texture of its surface, which, when mixed with cement, enhances the adhesive adhesion of the surfaces. The rice husk thermal treatment method was employed to increase the class of arbolite to B 2.0 in terms of compressive strength, that is, arbolite of structural purpose was obtained, used as load-bearing structures in low-rise construction

Keywords: rice husk, arbolite, strength, aggregate, modification, heat treatment, binder, composite material

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1. Introduction

The environmentally friendly "green" trend, which has been gaining increasing popularity in recent years, has not bypassed the construction sector. The depletion of energy resources, and, according to the latest expert estimates, the remaining coal, oil, and gas reserves to last at a maximum of 100 years, requires changes toward a more conscious and rational utilization of natural resources. Since most energy in the modern world is consumed by residential buildings, improving the energy efficiency of buildings are among the most important tasks to preserve the environment and reduce energy consumption.

With further increases in energy prices and stricter requirements for reducing the heat transfer by external enclosing structures, the use of traditional small-piece wall materials, in particular arbolite, has increased.

The experience of production and application of its various types, developed in the world, has proved the effectiveness and expediency of its use. The most established area of application of arbolite articles is low-rise construction of residential, civil buildings, as well as agricultural and industrial facilities.

The large-porous structure of arbolite provides the required air exchange in the premises and high thermomechanical indicators, which reduce energy consumption for heating and ventilation of buildings, as well as additional external thermal insulation.

Under modern conditions, taking into consideration the requirements of rational environmental management, it is necessary to strive for waste-free production of materials from wood raw materials, especially since a significant amount of waste is generated.

The traditional filler for arbolite is crushed wood. Currently, crushed wood chips are not used but there are many other non-recyclable agricultural wastes, namely rice husks. Rice husk is a special type of arbolite aggregate. Its natural reproducibility and homogeneous granulometric composition, which excludes its grinding, makes it industrially interesting.

Of great importance are the preparatory operations in the technological cycle of arbolite production, based mainly on the physical and chemical techniques, regulated by the relevant documents. According to the general theory of artificial conglomerates (ISC) [1], the potential properties of ISC components are revealed during the technological period of preparatory operations. If we proceed from the concepts of this theory, then the techniques of preliminary preparation of aggregates that have a specific glossy surface (rice husk and straw, reeds) require special approaches to their improvement. The reserve potential of the aggregate is not sufficiently used, which can be revealed, for example, by modifying the surface structure, eliminating the glossy film on the surface of the grains, and activating the aggregate itself with chemical additives.

One of the relevant tasks in the technology of arbolite production is to study and improve the processes of adhesion of aggregate with a binder, as well as improve the strength of arbolite by increasing its density by introducing mineral additives.

The composition of the arbolite mixture includes a binder and a filler with different physical and chemical properties. Cellulose aggregates belong to the group of colloidal capillary-porous bodies with elastic-viscous properties [2, 3], so the "cellulose aggregate – water" system has special specific properties different from the "mineral aggregate – water" system.

Water is the most important component in the processes of structure formation and serves as a dispersion medium in the arbolite mixture, actively participating in chemical reactions. The intermolecular interaction of water is characterized by a hydrogen bond, the strength of which occupies an intermediate position between the strengths of van der Waals and ionic bonds. Water is part of the cellulose aggregate, which gives off and absorbs moisture from the environment (Fig. 1) [4, 5].

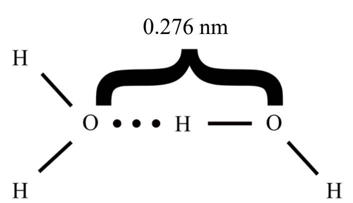

Fig. 1. Scheme of intermolecular interaction of water [5]

In the water, around the negatively charged cement particle, cations accumulate to form adsorption and diffuse layer [6, 7]. First, under the influence of surface forces, the primary hydrogen bonds between water molecules are broken, then a hydrogen bond with oxygen and hydroxyl groups of the particle surface is formed.

The thickness of the solvate shell (adsorption and diffuse layers) depends on the mineralogical composition of the cement particle, temperature, and atmospheric pressure. In the adsorption, strongly bound, layer of water, dipoles are located strictly oriented, and in a diffuse, loosely bound layer, the molecules are arranged disorderly, and under the influence of molecular forces, diffusion water moves from one particle of matter to another.

Cement particles, interacting with water, are covered with hydrate new formations, which is caused by micelle formation due to the electroneutrality of the micelle and the electronegativity of the cement granule [8].

During the research and practical experiments, specific features of the filling part of arbolite were established, which distinguish it from the mineral part of ordinary concrete, necessitating an increase in the adhesion of the surfaces of the matrix and filling parts of arbolite.

The principles of improving the quality of composite materials in the process of their fabrication always remain a relevant problem since the quality of products depends on countless technical and technological factors of manufacturing. A solution to such an urgent task implies the possibility of obtaining the predefined quality of composite material by controlling the properties of the initial raw materials.

2. Literature review and problem statement

Studying the system "cellulose aggregate – mineral substance" revealed that Portland cement is most actively affected by sugars in the composition of water-soluble substances of the aggregate [9]. Specific features of the surface structure of cellulosic aggregates are the presence of a glossy surface (rice straw, husk, reeds) covered with a water-repellent waxy cutin film that reduces their adhesion to cement. The authors of [10] found that the effect of micro additives (0.015–0.125 %) of monosaccharides on the hydration and hardening of aluminates and C4AF depends on the length of the hydrocarbon chain of surfactants. With increasing length, the intensifying effect of additives on the hydration of aluminates and C4AF decreases. Intensification of belite hydration is most active in the presence of polysaccharide additives. At the same time, the hydration of C_3S slows down, which is associated with an adsorption decrease in strength, accelerated dispersion, and dissolution of minerals. In work [11], it was found that mono- and polysaccharides delay the hydration of C3A. According to paper [12], complex compounds make it difficult to diffuse water to the surface of cement grains as they form a shell that impedes water access to cement grains, which inhibits the hydration of cement. The authors of [13] found that the hydrate new formations of C_3A hydration with additives of glucose and its oxide derivatives are C_3AH_6 and C_4AH_{13}. At the same time, acidic glucose derivatives due to increased stability in an alkaline environment slow down hydration by 10 times more efficient than glucose, which is due to the adsorption of organic molecules to C_3A. Paper [14] reports the results of studying the suspension of C_3A and CA in a solution of lignosulfonates and sucrose. It is shown that the acceleration of hardening is explained by the replacement of normally crystallized hydrates with highly dispersed amorphous products – "germinal" phases. The effect of substances of organic origin (glucose, sorbitol, glycerol aldehyde, lactic, and other acids) on the processes of C_3A hydration is due to a change in the phase composition of new formations. The action inhibiting the hardening of cement is explained by the fact that these substances hinder, and sometimes completely prevent the conversion of the hexagonal calcium hydro aluminates C_4AH_{19}, C_4AH_{13}, C_2AH_8 to cubic C_3AH_6 due to the greater thermodynamic stability of C_4AH_{19} under conditions of solutions supersaturated with respect to $Ca(OH)_2$ in the presence of soluble calcium saccharate [13]. However, the low strength of arbolite cannot be explained only by the presence of extractive substances in the cellulose aggregate. The strength of arbolite on the aggregate, from which water-soluble substances are removed as much as possible, increases slightly and does not ensure obtaining its stable properties. Among the technological stages, the most important is the preliminary preparation of raw materials. Since organic aggregate contains water-soluble extractive substances that adversely affect the hardening of the mineral binder, it is necessary to subject the aggregate to preliminary refinement in a way that depends on its nature. In the technology of production of concrete and reinforced concrete articles, a fundamentally new way of preparing mixtures with organic aggregate is their treatment with a constant electric current of alternating pulses, which causes electrokinetic processes (electrolysis, electroosmosis, electrophoresis). The impact of direct electric current with pole switching makes it possible to create the conditions necessary to equalize the composition of the liquid phase and reduce the time of structure formation with a simultaneous increase in the strength of the cement stone.

To prevent the harmful effects of water-soluble wood sugars on cement stone, mineralization of sugary substances into insoluble compounds is resorted to or their effect on cement slurry is localized. In this case, an impermeable film is created on the surface of the wood for sugars. However, these measures do not ensure the high quality of arbolite. The authors of [15] explain that the destruction of arbolite is caused by cellulose aggregate due to its weak adhesion. To improve adhesion, the processes of thermal modification of cellulose aggregate have become increasingly popular in recent years. In work [16], a decrease in the strength of a composite material with a torrefied aggregate is, apparently, associated with a decrease in the influence of the matrix on the composite and the occurrence of aggregate defects.

Under the influence of the electric field of direct current of the sign-variable pulses, the energy of the arbolite mixture is transmitted. As a result of work performed by it, the charge of the particles periodically changes, and electrical energy passes into mechanical energy. At the same time, a number of other physicochemical processes and accompanying primary and secondary reactions take place.

Thus, direct current excites several new processes and reactions in the arbolite mixture, directs, intensifies, and accelerates the various physicochemical interactions occurring in it.

The emerging progress in the production technology and introduction of arbolite was manifested in the expansion of the range of binders from gypsum, phosphorus slag, belite slag, white aluminum binder, phosphogypsum to polymer binder. The application of these binders makes it possible to abandon the use of chemical additives to neutralize water-soluble compounds that negatively affect the hardening of cement and its heat treatment.

The method of treating arbolite with direct current, proposed in work [17], showed that using this technique, arbolite is treated with a sign-alternating direct current. At the same time, the direction of its movement changes every 2–3 minutes for 40–60 minutes, at a temperature of 40 °C. In this case, the time of increase in the strength of arbolite is reduced. Electric current, passing through the arbolite mixture placed between two electrodes, which are simultaneously the walls of the metal mold, contributes to the dispersion, and disaggregation of cement particles, and increases the number of colloidal new formations [18]. When treating cement-water mixtures with direct current, secondary coagulation structures are destroyed, which contributes to more complete hydration of cement and increases the strength of arbolite.

Arbolite is characterized by a large-porous structure, the proportion of cement stone of which is 10–20 %. The strength of arbolite is mainly provided by the adhesion of the aggregate to the binder. The frame of arbolite consists of thin films of cement stone. Study [19] has established that one of the important reserves for increasing the strength of concrete is to improve the adhesion of the aggregate to the binder. The predisposition of the aggregate of plant origin to increased moisture deformations, the glossy surface of such arbolite aggregates as rice straw and husk, reeds affect the strength of the system "cellulose aggregate – cement stone" [20].

Several researchers suggest that the mechanism of adhesion of the "cellulose aggregate–cement" system is due to the interaction of calcium oxide hydrate formed during the hardening of cement with the polar functional groups of substrate components (cellulose aggregate). The bonding of these natural polymeric materials due to the chemical and physical-chemical processes occurring between them determines the adhesion of the cement stone with the aggregate [21].

Adhesion forces are determined by various factors: the nature of the contacted bodies, the number of contact points per unit surface area, the distance between the contact points, external influences, temperature, and pressure [22].

The nature of the adhesion forces is determined by the nature of the molecules in contact. Electric charges, unevenly distributed between atoms in a molecule with a predominance of positive charges in one part and negative charges in the other, represent the main factor in the structure of polar molecules. Dipole moment – the distance between the centers of charges is a measure of the polarity of such molecules. Orientational interaction is characteristic of polar molecules. Acids, alcohols, esters, many polymers, oxidized surfaces of many metals, and glasses belong to polar substances. Nonpolar substances under the action of neighboring polar molecules or ions are easily polarized; induced induction dipoles arise. Under the influence of such dipoles, an induction interaction of molecules occurs with a characteristic weaker cohesion between molecules than with the interaction of constant dipoles. Intermolecular van der Waals interactions with several types are known: electrostatic, induction, dispersed, hydrogen bond. Bonding can be caused by the formation of chemical bonds, for example, electrovalent, hundreds of times stronger than intermolecular forces.

The author of [23] believes that covalent bonds, which provide cohesion between uncharged atoms due to the formation of a common electron pair by unpaired electrons belonging to two interacting atoms, are weaker than electrovalent ones but they always provide high adhesion. One of the first theories of adhesion – mechanical – considers the process of adhesion by penetrating the binder material into the pores of surfaces, on the surface area and shape of which the strength of the adhesion depends. In the case of a smooth surface, the strength of the adhesion is determined by the affinity of the film and the surface of the material, a significant place in the explanation of the bonding mechanism is given to wetting. Only those materials that wet the glued surfaces can stick together, and the best bonding effect is ensured when the edge angle is $\varphi=0$, and if the surface-active additives in the glue are adsorbed at the interface of the "glue-glued body" [24].

In recent years, a chemical theory of adhesion has been developing, explaining the interaction of glue with the surface of a solid body by chemical bonds – covalent. According to [25], the energy, in kcal/mol, is the highest in chemical bond (50–150), and then in hydrogen (5–10), electrostatic (up to 9), dispersion (up to 6.5), and induction (up to 0.5).

Adsorption theory explains adhesion and cohesion by the interaction of intermolecular forces and as a purely surface process [26].

The author of [27] believes that adhesion is reduced to the diffusion of the alkaline bond between the glue and the bonding substance, and the closer the chemical nature of the materials being glued, the easier their interaction.

According to the theory considered in [28], gluing is the result of the influence of forces of electrical origin between molecules, atoms, and ions.

In work [29], a new electro relaxation theory is proposed, based on the chemical nature of the adhesive and substrate molecules, providing adhesive and cohesion interaction at contact points.

However, none of those theories of bonding is universal while each contributes to the theory of bonding.

Modern science believes that bonding is determined by adhesion and cohesion. The adhesion weakens, and the destruction occurs along the contact layer of the glue and the hard surface with a weak cohesion of the glue on the glue itself.

The thickness of the adhesive layer is important in the bonding process [30]. As the thickness of the adhesive seam increases, the internal stress increases, and the strength of the connection decreases. The transition of the binder to the film state and uniform envelopment of the aggregate grains with it provides the necessary conditions for increasing adhesion on the interface of the binder with the aggregate.

According to the cited studies, for the preparation of arbolite, a cut of reeds is used, which is obtained by cutting the stems of reeds in a straw cutter, followed by additional grinding on a hammer crusher. The resulting reed cut has a glossy surface of the original stem. At the same time, as a result of crushing, the structure of reeds is destroyed, and due to the deformation of tissues, the water absorption of the section reached 200–220 % of its mass in comparison with the water absorption of the reed stem (150–160 %) [31].

Rice straw also preserves the glossy surface after cutting and crushing it to a cut, reducing the adhesion to the binder. Rice husk does not require crushing since its grain composition in the form of grains of the fraction of 2–5 mm determines the manufacturability of its use, which excludes the operation of sieving into fractions. However, the glossy surface of rice husk, as already noted, reduces its adhesion to binder and mineral additives [32].

At present, there is no universally recognized theory of adhesion. The adhesion, for example, of wood to cement, depends on the W/C mixture, humidity, surface type, and shape of the aggregate; it amounted to 0.005–1.25 MPa [33].

The results reported in [34] showed the boundary of the separation of wood and cement stone and the characteristic of the adhesive in the form of its loose structure, which determines the cohesive nature of the destruction of arbolite during its testing. It is established that the adhesive strength and cohesive strength of cement stone depend on the degree of exposure to wet deformations and swelling pressure, wood species, particle shape, and surface roughness of the aggregate.

Increasing the solution part of arbolite by introducing a micro filler helps increase the adhesive strength of arbolite. Another, no less effective way, is the surface treatment of the aggregate.

The low strength of arbolite cannot be explained only by the presence of extractive substances in the cellulose aggregate. The strength of arbolite on aggregate, from which all water-soluble substances are removed as much as possible, increases slightly and does not provide for an increase in the stability of its properties due to their weak adhesion of aggregate with cement.

All this allows us to assert the need for a study on the modification of the surface of the aggregate in order to increase its adhesion to cement and improve the strength of arbolite.

3. The aim and objectives of the study

The purpose of this study is to devise technology for modifying the surface of cellulose aggregate to obtain a composite material of improved quality. This will make it possible to increase the class of arbolite in terms of compressive strength to B 2.0.

To this end, we tackled the task to determine the effect of modifying the surface structure of the aggregate on increasing its adhesion to the binder.

4. The study materials and methods

The object of our study is the activation of rice husk by reducing its negative effect on the hardening of the mineral binder.

The hypothesis of the study assumes the possibility of increasing the strength of arbolite on rice husk by finding new ways to improve the adhesive strength of the adhesion of rice husk to cement stone. The surface structure of the rice husk is covered with a water-repellent waxy cutin (glossy) film. The water-repellent property of the glossy film causes instability of the balance of water migrating to or from the aggregate, with the enrichment or depletion of the dispersion medium of the resulting slurry (frame) of the binder. A necessary condition for stimulating the effect of adhesive adhesion of surfaces in the contact zone is the modification (removal) of the glossy layer of the surface of the rice husk.

The composition of rice husks includes silica, so it can be assumed that when using s thermal treatment technique, the surface of the husk is exposed and contributes to the additional effect of increasing its adhesion to cement.

The mixture of composite material was made using the Portland cement M400, cellulose aggregate – rice husk, ash, liquid sodium glass, and calcium chloride.

The general view of the cellulose aggregate is shown in Fig. 2.

Fig. 2. Cellulose aggregate sample

The grain composition of cellulose aggregate is given in Table 1; its properties – are in Table 2.

Table 1

Grain composition of cellulose aggregate

Name of residues	Measurement unit	Sieve hole size, mm	
		2	less 0.16
Partial	%	90	10
Full	%	90	100

Table 2

Characteristics of cellulose aggregate

Properties	Measurement unit	Value
Bulk density	kg/m^3	120
Humidity	%	5
Water absorption for 1 hour	%	130
Maximum particle size	mm	5
Coefficient of thermal conductivity	W/m°C	0.150

The chemical composition of cellulose aggregate is characterized by a high silicon content. Cellulose aggregate has a lower equilibrium humidity, increased hardness, and abrasive properties compared to wood, as well as increased density and high smoldering and burning temperatures (800–1000 °C). The density of cellulose aggregate is 735 kg/m^3, bulk density is in the range of 96 to 160 kg/m^3; when compacted, it reaches 400 kg/m^3. The coefficient of thermal conductivity is about 0.151 W/m°C.

A distinctive feature of cellulose aggregate is the high content of inorganic substances and protein compounds. Of the hemicelluloses in the husk, only pentosans are present. There are about the same number of them in it as in wood (in hardwood 16–24 %).

Cellulose aggregate contains metabolic active acids – acetic, citric, malic, oxalic, phenolic acids are found in its aqueous extract.

The surface of the scales is covered with a thin smooth and lumpy, transparent structureless glossy film, chemically and biologically called cutin. Cutin is a mixture of waxy substances that dissolve only in concentrated acids, very resistant to external influences, does not pass water, providing a protective function.

As chemical additives, calcium chloride, aluminum sulfate, calcium oxide hydrate, and soluble sodium glass were used; their characteristics are given in Table 3.

Table 3

Characteristics of chemical additives

Name	GOST	The content of the main substance	Chemical formula
Calcium chloride, crystalline, "chemically pure"	4141	51	$CaCl_2*6\ H_2O$
Aluminum sulphate	3758	52	$Al_2(SO_4)_3*18\ H_2O$
Soda soluble glass	42	42	$Na_2O*nSiO_2*mH_2O$
Calcium oxide hydrate	–	–	$Ca(OH)_2$

To compare the strength characteristics of arbolite subjected to various types of treatment, a breaking machine was used. The braking machine determines the adhesion strength of a rice husk laid on a metal plate measuring 4*4 cm with pre-applied epoxy resin and fastened in the formwork with a cement slurry of normal density.

At the same time, studies were conducted using a different methodology. To create hardening conditions for cement binders similar to those in arbolite, samples were made from an arbolite mixture and stored under normal hardening conditions for 28 days. Samples were made in the form of a cylinder with a diameter of 100 mm and a height of 50 mm in special molds. This shape and size of the samples were adopted in order to achieve uniformity of the sample, both in area and volume. After the samples reached 28-day age, 10 mm thick steel disks were glued to them with epoxy resin. Samples prepared in this way were subjected to a tensile test under the action of a normal tearing force. To study the strength characteristics of arbolite, cube samples were simultaneously made to test their compressive strength. In these studies, the influence of aggregate surface treatment factors and chemical additives on the adhesive strength of arbolite was established.

To determine the effect of the amount of cement on the adhesive strength, cube samples were made from modified rice husks. As an additive, calcium chloride was used in the amount of 4 % of the mass of cement and liquid soda glass – 1 % of the aggregate weight. The consumption of husks was constant, and the consumption of cement varied from 200 to 600 kg per cubic meter of arbolite.

5. Results of devising the technology for modifying the surface of cellulose aggregate grains

Rice husk has a glossy surface and consists of waxy substances, which reduces its adhesion to cement stone. A necessary and mandatory condition for the preparation of rice husk is its soaking in water, the use of chemical additives for its treatment, or the dissolution of waxy substances in ether, chloroform, or gasoline. Unraveling the surface of the husk in water requires an elevated temperature – up to +50 °C [35].

The proposed technique for treating rice husk is to thermally expose it using the laboratory device depicted in Fig. 3.

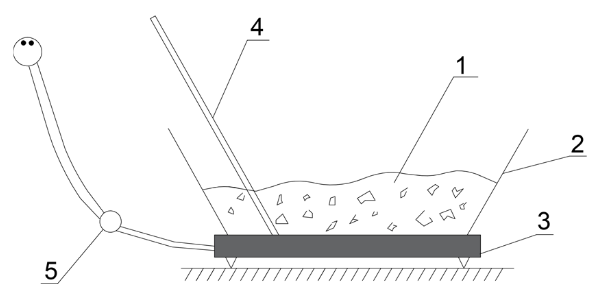

Fig. 3. Laboratory device for the heat treatment of rice husk: 1 — rice husk; 2 — metal container, 3 — heating element, 4 — thermometer with sensor, 5 — electricity consumption meter

The laboratory device for refining rice husks consists of a heating element, a metal container, and a thermometer of the brand TCM 91210M-03P with a sensor TTC07P-600 of the patch type for surface measurements, and a device for measuring electricity consumption.

Before starting the experiment, the rice husk should be soaked in water at room temperature (18–20 °C) at the ratio of Z/V of 1:7.

To make a sample of arbolite with dimensions of 10×10×10 cm, 240–280 g of rice husk are needed. After soaking and draining the water, the aggregate should be placed in a metal container of the laboratory device and subjected to heat treatment.

The thermal process is carried out at a temperature of 175 °C on the working surface of the metal container (2). The husk is constantly agitated during processing. As a result of continuous pouring of mass, there is a separation and reverse free fall of particles on the heated surface of the device.

In the process of heat treatment, the aggregate is dehydrated, then the surface of the particles burns to some depth. Signs of readiness of the treated state of the aggregate are determined visually by the organoleptic method by acquiring the color of the husk to a dark brown shade, after which the material must be cooled.

Next, the prepared aggregate is used to make an arbolite sample by mixing with cement, liquid glass, calcium chloride, and sealing water. After mixing, the mass is placed in a mold with a closed lid with a punch and is in a compressed state until a set of camber strength.

The proposed technique involves electric heating of arbolite articles in a metal mold with direct electric current for 1–2 hours, followed by holding on a pallet for 6–8 hours. To gain transport strength, the articles must be kept at a temperature of 20–25 °C for 1–2 days.

Many different techniques of chemical treatment of rice husks have been investigated in order to neutralize water-soluble substances. Lime and cement milk, liquid glass, calcium chloride, iron sulfate, and magnesium sulfate; many of them are not widely used due to the complexity of treatment processes, as well as the scarcity of expensive chemical reagents.

It is known that the strength of multicomponent materials depends on the strength of the bonds between the structural elements and the strength of the elements themselves. The strength of the elements constituting arbolite is high: the strength of wood is 15 MPa, cement – 40 MPa [36]. However, the strength of the arbolite itself almost does not exceed 2.5÷3.5 MPa since it is largely determined by the strength of the adhesion of its heterogeneous particles [37].

The results of studying the effect of heat treatment of husk on the strength of arbolite are given in Table 4. Arbolite production technology provides for soaking aggregates in water. According to GOST 19222-2019, wood crushing and cotton stems are soaked for 15 minutes, the cut of reeds – 20. Work on the selection of the composition of arbolite was carried out on rice husk, pre-soaked in water with a temperature of 20 °C for 15 minutes. Prototypes with dimensions of 10×10×10 cm and an age of 7, 14, and 28 days were tested.

Table 4

Strength of arbolite on thermally-treated rice husk

Treatment type	Ultimate compressive strength after 28 days, MPa
Soaking in water without heat treatment (GOST 19222-2019)	1.0
Soaking in water with heat treatment	2.0

At a 28-day age, the tensile strength of arbolite during compression after soaking in water without heat treatment was 1.0 MPa, and after soaking in water with heat treatment – 2.0 MPa.

The effect of water on the aggregate is manifested by its swelling and leaching of water-soluble extractive substances from it, such as monosaccharides, tannins, and acids. The macromolecules of cellulose are held, in addition to chemical bonds, also by electrical attractive forces and are in equilibrium due to the action of repulsive forces of a non-electrical nature equal to the attractive forces modulo. In environments with a large dielectric constant, the attractive forces weaken, and the repulsive forces act, which causes swelling.

The dependence of the strength of the adhesion of rice husk with cement on the type of treatment is given in Table 5.

Table 5

Dependence of the strength of the adhesion of rice husk to cement on the type of treatment

Treatment type	Adhesion strength after 28 days, MPa
No treatment	0.20
Soaking in water at a temperature of 50 °C	0.35
Thermal treatment	0.43

Table 4 demonstrates that in samples of arbolite after heat treatment at 28-day age, the adhesion strength increases to 0.43 MPa.

Table 6 gives data on the effect of the state of the aggregate and the type of its treatment on the adhesive strength and arbolite strength at compression.

Table 6

Influence of aggregate state and type of treatment on the adhesion strength and compressive strength of arbolite

Component consumption, kg/m^3			Consumption of chemical additives, kg/m^3		Filler treatment type	Specific separation force, MPa	Ultimate strength in compression, MPa
cement	rice husk	water	liquid glass	calcium chloride			
360	240	430	–	–	no treatment	0.13	1.5
360	240	430	2.4	15.2	thermal treatment	0.21	2.14
360	240	430	2.4	15.2	introduction of additive to cement slurry	0.20	2.2
360	240	430	2.4	15.2	thermal treatment	0.43	2.35
360	240	430	2.4	15.2	thermal treatment	0.42	2.29
360	240	430	2.4	15.2	thermal treatment	0.39	2.18
360	240	430	2.4	15.2	thermal treatment	0.41	2.28

As follows from Table 5, the following composition with the consumption of materials per 1 m^3 of arbolite is effective: cement – 360 kg, rice husk – 240 kg, water – 430 g, liquid glass – 2.4 kg, calcium chloride – 15.2 kg. After heat treatment, the compressive strength is 2.35 MPa, while the strength of other compositions is in the range of 1.5–2.29 MPa.

6. Discussion of results of studying the technology for modifying the surface of cellulose aggregate grains

The use of complex measures in the production of arbolite produces a very tangible effect on increasing its strength both in the early stages of hardening and at the age of 28 days. Heat treatment of rice husk, as well as a complex additive consisting of liquid sodium glass and calcium chloride with subsequent heat treatment, increases strength in comparison with control samples by 4 times at a 1-day age and, approximately, by 2 times at a 28-day age.

Analyzing the data given in Table 5, it may be noted that the surface of the modified rice husk is chemically more active than without treatment. The use of chemical additives made it possible to neutralize the effect of aggregate extractive substances on cement by forming additional chemical bonds in the contact zone and reducing their toxic effect on cement as it moves away from this zone.

The most effective thermal treatment of arbolite is the heating of articles at a temperature of 45 °C and relative humidity of 60 %. The recommended rational mode of thermal treatment during electric heating with alternating current should be considered: preliminary aging of articles – 2 hours, warm-up – 2 hours.

Known proven methods for determining the adhesion of wood rods and wood cubes to cement stone [38] are not suitable for rice husks since the particle size of rice husk does not exceed 5 mm. The technique devised by the Research Institute of Building Materials and Projects [39] is used to determine the adhesion of rice husk to cement. The strength of the adhesion of the rice husk to the cement stone was determined on a breaking machine according to the generally accepted procedure. To determine the effect of the amount of cement on the adhesive strength, cube samples were made from modified rice husks with the addition of calcium chloride and liquid sodium glass. One of the reserves for improving the strength of arbolite is to modify the surface of the aggregate in order to increase its adhesion to the cement, which would help enhance the strength of arbolite.

The achieved effect is provided by finding ways to refine the rice husk, the specific properties of which, as compared with other aggregates of plant nature, require special approaches to the operations of its preliminary preparation before preparing the arbolite mixture.

Our research could be advanced by searching for new binders, not affected by extracts, and the need to form flexible adhesive bonds that perceive wet deformations of wood.

7. Conclusions

To increase the strength of arbolite on rice husk, a new method of modifying the surface of the aggregate by heat treatment of rice husk was used. The arbolite of class B 2.0 was obtained, which significantly expands the scope of its application as a wall material for enclosing the structures of low-rise construction.

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