The influence of different natural fibers applied on the quality index of the paper

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Abstract. In the study, the effectiveness of aluminum hydroxide as a binder, the optimal consumption of the binder and the determination of the main technological parameters were studied. In the paper, the formation of hemiacetal bonds between moisture-resistant fibers and the change in the shape and energy of the bond in the semi-core complex of aluminum were found.

Keywords: topinabour cellulose, cotton linters cellulose, basalt fiber, strength, composite filter paper, fiber hydration, aluminum hydroxide, filler.

Introduction. According to the literature analysis and experimental results, we can see that the composite material made of kaolin fibers is more durable, but when experimented with aluminum compounds - a positive result can be achieved in compositions made of basalt fibers. Thus, aluminum sulfate shows good results in experiments with kaolin fibers, while with all other fibers, bad results are obtained. When aluminum sulfate is replaced by sodium aluminate in basalt fiber samples, the strength of the material increases by 2.5 times, while in kaolin fiber samples it decreases. In general, the degree of inefficiency of a particular reinforcement additive significantly depends on the nature of the fiber, which determines the preferred compound for the strength of the composites. Experiments have shown that aluminum hydroxide can be used to strengthen mineral fiber-based paper materials.The next stage of the work was devoted to determining the conditions that would maximize the effectiveness of aluminum hydroxide as a binder. To do this, first of all, it is necessary to determine the optimal consumption of the binder and the basic technological parameters.

Material and Methods. Raw materials, materials and reagents, their preparation for research: In our experimental research, we used the following types of basalt fibers: ultra-fine basalt fiber, fine basalt fiber, coarse basalt fiber;

One of the main advantages of these fibers is that they do not lengthen during operation. Ultra-fine basalt fiber according to TU 6-11-483-79, fine basalt fiber according to TU 6-11-389-76, coarse basalt fiber according to RST USSR 5013-81 standard requirements.

Cellulose. The peculiarity of cellulose obtained from annual plants is that they contain more non-cellulose, ie pentosans (20-30%), lignin (13-24%) and ash (5-6%) than wood cellulose. Fiber raw materials are sufficient in the Republic to obtain cellulose and paper from plants. We selected the following for our research: Jerusalem artichoke stalks, cotton stalks, safflower stalks, wheat straw and cotton wool. Cellulose from the above plants is the standard method used in practice.

Sodium alkali NaOH, GOST 2268-79. Hydrogen peroxide H_2O_2, GOST 177-88. Binders are aluminum sulfate $A1_2\ (SO_4)_3$, GOST 12966-85. Aluminum chloride -

$AlCl_3$, GOST 3759-75. Sodium aluminate- $NaAlO_2$ GOST 216318-85. Flocculants - polyethylene terephthalate PETF-1, PETF-2

Results and Discussion. The study examined the mechanism of moisture resistance of vegetable fiber paper samples containing aluminum compounds when heat-treated at 150-200°C for a short period of time. In the paper, it was found that resistance to moisture occurs as a result of the formation of hemiacetal bonds between the fibers and a change in the shape and energy of the bond in the semi-core complex of aluminum. Under the influence of heat treatment, the bond between the fiber and the aluminum ion passes from the ‘ol’ form through the hydroxyl to the water-insoluble ‘dioxo’ form with oxygen as the energy bond increases from 35-39 kDj / mol to 44-49 kDj / mol. As the strength of the samples increases in the wet state, so does their strength in the dry state. At the same time, the contribution of the mechanisms shown in the strength of the paper in wet and dry conditions has not been determined. Therefore, the study of the influence of heat treatment on the strength of mineral fiber samples, which is an aluminum composite additive, is undoubtedly of theoretical and practical importance. Based on the above, the influence of three main factors was studied. The value of the factors is in a wide range, the binder consumption is from 5 to 30% of the mass of mineral fiber, the environment in which the paper-like material is moulding is less acidic (pH 4.5-5), neutral (pH 6.5-7) and less alkaline (pH 9-9, 5), heat treatment was carried out at a temperature of 200°C. According to the results of thermogravimetric analysis, a certain part of the molecules in the internal coordination sphere of the aluminum semi-nuclear hydrocomplex is released, even at temperatures up to 180°C. Therefore, some of the samples are processed in an electric dryer at a temperature of 120°C in addition to the usual temperature of 200°C for 15 minutes. The influence of the studied factors on the strength of paper materials with coarse basalt fiber as a reinforcement is given in Table 1. Heat treatment has a positive influence on the strength of the material only in options where aluminum sulfate serves as a binder. In all other options, a weakly acidic environment is preferred when pouring the material. In the general case, the increase in strength is correlated with the binding cost. However, there are also “jumping” values within the boundaries of certain binders. If the material obtained in a weakly acidic environment for $A1_2(SO_4)_3$ reaches its maximum strength when the binder consumption is 10-15%, and conversely, a 30% increase in consumption decreases it, then the strength in a weakly acidic environment increases linearly in all ranges of binder value. The trend for the $NaAlO_2$ binding variant is less pronounced. The nature of the mineral fiber makes its own corrections to the observed bonds. In particular, when fine basalt fiber was used for the composition (Table 2), it was not observed that the strength of the material was related to the $A1_2(SO_4)_3$ material obtained in a weakly acidic environment.

Table 1

Strength of coarse basalt fiber composite material

Heat treatment (when moulding paper materials)	**moulding environ**	**Connector type**		
		$Al_2(SO_4)_3$	**$NaAlO_2$**	**$AlCl_3$**
		Amount of binder %%		

			10	20	30	10	20	30	10	20	30
When not heated	σp, kPa	4,5-5	530	710	790	170	230	380	155	190	310
When heated			670	810	790	170	300	400	190	240	350
When not heated	σp, kPa	6,5-7	290	760	780	620	320	1780	840	1070	1420
When heated			270	840	350	620	310	1200	750	1160	1540
When not heated	σp, kPa	9-9,5	820	1000	1210	900	2120	2140	1540	1280	1810
When heated			830	980	1490	1230	2080	1990	1170	1510	1460

In all options, heat treatment does not provide durability. The nature of the binder has a different effect on the strength of the material when coarse basalt fiber is used. For example, in the coarse basalt fiber variant, the consumption is 30% and the strength is maximal in a weakly alkaline environment, while in the fine basalt fiber it is minimal and slightly lower. The strength of cellulose paper is associated with the formation of more stable hemiacetal bonds and changes in the shape and energy of a large number of hydroxyls with aluminum ions.

Hemiacetal bonds cannot be formed in mineral fiber samples, and the number of hydroxyls on the surface is much lower than in cellulose fibers, which leads to the practically unchanging strength of paper materials. This factor was later excluded from the study because heat treatment was inefficient for mineral fiber samples.

The scope of research has been expanded to show that the material extraction environment affects its strength and that this effect is not permanent. The results are presented in Table 3.

Table 2

Strength of fine basalt fiber composite material

Heat treatment (when moulding paper materials)		**Paper casting envint, pH**	**Connector type**								
			$Al_2(SO_4)_3$			**$NaAlO_2$**			**$AlCl_3$**		
			Amount of binder %								
			10	20	30	10	20	30	10	20	30
When not heated	σp, kPa	4,5-5	310	600	770	80	240	200	190	200	620
When heated			400	790	840	70	280	110	140	120	510
When not heated	σp, kPa	6,5-7	430	850	860	250	630	610	560	810	1160
When heated			550	780	910	210	630	550	350	800	900
When not heated	σp, kPa	9-9,5	440	920	920	510	780	1200	180	440	450
When heated			580	820	720	480	640	1030	120	410	440

General data on the effect of ultra-fine basalt fiber size on material strength indicate that there is an additional factor that reduces the strength of the specific surface in bond formation. For example, if the specific surface diameter of a very fine basalt fiber is 0.2, that is, 3.6 times larger than a very fine basalt fiber with a diameter of 0.7, when such fibrous materials are pulled, their strength is only 2 times higher on average. The marked difference between the specific surface area of ultra-fine basalt fibers and the strength of its bonds may also be related to the structure forming the composite paper (the contact of hard fibers is linear rather than surface) because of the violation of proportionality. In that case, the change in strength is proportional to the change in the number of contacts.

Table 3

Strength of ultra-fine basalt fiber material

Heat treatment (when moulding paper materials)		**Paper moulding environment, pH**	**Connector type**								
			$Al_2(SO_4)_3$			**$Al_2(SO_4)_3$**			**$Al_2(SO_4)_3$**		
			Amount of binder %%								
			10	20	30	10	20	30	10	20	30
0.25	σp, kPa	4,5-5	520	500	470	600	580	500	550	530	440
0.75			260	240	200	390	370	310	280	250	150
0.25	σp, kPa	6,5-7	580	520	490	630	620	540	620	600	420
0.75			290	200	170	400	370	330	350	330	240
0.25	σp, kPa	9-9,5	560	510	420	590	510	390	550	530	420
0.75			300	270	220	380	370	300	380	340	220

Based on the data in the study, we can attribute the mentioned difference to technological reasons in fiber production and defects in it that lead to a decrease in the strength of ultra-fine basalt fiber or a change in the microrelief of the fiber surface. However, based on experimental data, it can be said that it is not correct to look for the cause only in the individual strength of the individual fibers.

Table 4 shows the effect of the method of drying the material obtained using fine basalt fiber in different environments (pH 4.5-9.2) on its strength. The effect is manifested in the intensity of the drying process. The effects of 5 types of drying were investigated: convective drying in an oven at 105°C under an infrared lamp and in the air, and two more contact methods using electricity and vacuum at 45-50°C in a Rapid-Ketten paper sheet dryer.

Under other equal conditions, only a change in the drying method can significantly change the strength of the material (sodium aluminate samples, moulding at pH 9.2). In some cases, when dried outdoors or under vacuum, the samples had such low strength that it was not possible to determine the strength in practice.

Table 4

Drying method and the influence of pH on the strength of fine basalt fiber material

Drying method	**Pouring medium**	**$σ_p$, kPa, in mass moulding**

	(pN)	10% $Al_2(SO_4)_3$		20% $Al_2(SO_4)_3$		20% $NaAlO_2$	
		Dry sample	**Wet sample**	**Dry sample**	**Wet sample**	**Dry sample**	**Wet sample**
In the closet		290	210	400	360	160	170
Under the lamp		170	170	350	310	170	190
Burner	4,5	180	200	420	300	300	430
Outdoors		-	-	470	270	50	160
Under vacuum		110	60	-	-	-	-
In the closet		230	170	380	350	230	160
Under the lamp		240	190	350	400	250	260
Burner	6,3	200	210	530	500	390	110
Outdoors		-	-	360	360	220	290
Under vacuum		230	90	-	-	- '	-
In the closet		180	210	630	200	330	70
Under the lamp		160	24	520	440	320	100
Burner	7,5	160	170	490	160	820	280
Outdoors		-	-	330	260	250	290
Under vacuum		140	60	-	-	-	-
In the closet		160	100	510	200	560	160
Under the lamp		220	100	380	370	640	150
Burner	9,2	270	120	510	160	300	80
Outdoors		-	-	350	240	80	70
Under vacuum		110	50	-	-	-	-

In samples containing sodium aluminate, the performance associated with the change in drying method was greater than in samples with aluminum sulfate addition. Apparently, this is due to the higher level of hydroxyl hydration obtained from aluminum sodium. This has been instructed in the literature.

For about half of the samples obtained, the maximum strength was achieved by the contact (burner) method of drying, while in other samples by the convective method of drying. The results in determining the strength of wet samples are somewhat specific. To test the samples in the wet state, the samples are soaked in water at a temperature of 18–20°C for two hours in a cuvette, and then the water is squeezed between 3 sheets of filtered paper and examined immediately after compression.

According to current standards, moisture-resistant paper is paper that retains at least 15% of its original dry state when fully soaked. All types of fiber-based paper, except for specially treated ones, are not resistant to moisture and almost completely lose their strength after water absorption.

Samples of materials such as fine basalt fiber and two types of binder-based paper retain their full strength even when wet. Even the largest value of the decrease in strength in the wet state does not exceed 15%, and such paper is called moisture resistant.

For basalt fibers, the maximum pH-dependent maximum strength corresponds to neutral and low-alkaline areas that shift slightly to one side or the other when the aluminum compound is replaced. The maximum strength in fine basalt fibers, and especially in coarse basalt fibers, shifted toward an alkaline area than in similarly very fine basalt fiber samples. It can be assumed that a bond can be formed by the above mechanism at the binder consumption present in the very fine basalt fiber samples. The reason is that the isoelectric point is close to the neutral field, and it is in this zone that there may be an electrical interaction that will lead to a shock in the future. The production of fine basalt fibers and coarse basalt fibers depends in many respects on the activity of semi-nuclear hydrocomplexes, which can have a maximum pH in the field of 9.0-9.5.

This hypothesis is confirmed by the sensitivity of the strength of materials made of mineral fibers to changes in pH. For example, in the pH range of 4.5 to 9.5, according to experimental results, ultra-fine basalt fiber materials with a diameter of 0.2 μm have a strength index of 1.04 to 1.38 times, that of fine basalt fiber materials is 1.4 to 12 times that of coarse basalt fiber and materials 1.4 to 16.1 times. Such a large impact of the environment on the strength of basalt fiber and plant cellulose-based materials is probably due to the increased contribution of aluminum hydrocomplexes in garden formation.

The nature of fibrous materials leaves a certain mark on the effectiveness of aluminum compounds used as binders. For example, in the coarse basalt fiber variants (see Table 2) there is the following order of decreasing strength: aluminum sulfate, sodium aluminate, aluminum chloride. However, in combination with fine basalt fiber, this range looks different (see Table 3): aluminum sulphate, sodium aluminate, aluminum chloride in the range of pH 4.5-7, sodium aluminate in the range of pH 7-9.5, aluminum sulfate, aluminum chloride. There is no such clear connection for ultra-fine basalt fiber. This means that there is a slightly different bond formation mechanism. Such placement of aluminum compounds may be due to differences in the chemical nature of the ligands located on the corresponding fiber surface.

In general, the considered results show that with the help of aluminum compounds, the strength of mineral fiber-based materials can be changed on a large scale by varying its consumption and pH mass during moulding. In some cases, for example in an alkaline environment with the addition of a 30% aluminum compound, the strength of the composite is comparable to the strength of materials such as paper obtained on the basis of plant fibers when preparing a material based on basalt fibers.

Of course, such strength of mineral fiber-based materials is no exception to the rule. However, it should be noted that the problem of obtaining materials from the composition of mineral fibers and cellulose of annual plants, the strength of which is sufficient for the production of products using traditional paper production technology methods, has been resolved.

The implementation of the decision requires a certain technological research. If the use of traditional paper-making machines in the formation of sheets from a material such as paper is proposed, then the choice of drying mode is directly related to the changes that occur under the influence of heat with aluminum preservative binders.

Studies on the mechanism of paper hardening obtained from plant fibers under the influence of aluminum compounds have shown that when the temperature rises as a result of dehydration of aluminum semi-nuclear complexes, some of the hydroxyl bonds become stronger and more water-resistant, making the paper more resistant to moisture. In our study, the effect of moisture resistance of materials such as mineral fiber-based paper was found. To explain this, we turn to plant fiber paper technology.

Strength indicators are formed more rapidly in the contact method of drying. This is especially true for specimens with poor surface development, which are potentially capable of forming a garden. In the case of materials made of plant fibers, these may include, for example, fluctuations made of sanitary paper or waste paper. At the same time, a well-ground kraft cellulose bag shows high strength when convectively dried in a paper cupboard. Such an effect of the drying type can in many cases be under the influence of surface tensile forces. The fibers, which are able to form a solid material, come close to each other intensively under the influence of capillary contraction forces and form a bond. Sheet materials made of such fibers are characterized by high penetration capacity. Fibers that cannot form a fiber bond without binders form a porous system. In such a system, there is no intrusion, and when the water inside begins to evaporate, the menisci retreat into the pores.

After the liquid moistening the walls evaporates, the menisci pull the liquid column from the open capillary of radius g in such a way that it is as if a pressure of 2 t/g is acting on the surface on the side of the capillary. If the elasticity of the walls is sufficient, then the capillaries are compressed by the evaporation of the liquid, and the radius of curvature leads to an increase in the pressure in the capillary, which in turn leads to a new decrease in radius. It is precisely the convergence of the capillary walls in subsequent fluid removal that allows them to have contacts capable of forming hydrogen bonds. The described mechanism can be easily applied to paper made of finely ground cellulose fibers.

In the case of mineral fibers, however, this mechanism is also applicable to wet parts that have developed at the air-water boundary and are proportional to the moisture content after wetting the samples under study and then squeezing the water between the paper layers. The bonds formed by the binders introduced during the wetting of the samples are partially or completely severed and replaced by bonds formed under the influence of external gravitational forces. The mechanism of initial moisture resistance of paper derived from plant fibers is similar. The principal difference is that the initial moisture resistance of the paper is slightly lower than that of the dry paper, and the performance of mineral fiber materials with a similar level of moisture resistance is sufficiently higher than that of materials such as paper made from them. Sometimes the moisture resistance of mineral fiber materials is higher than that of analog dry materials, and this does not contradict the proposed mechanism.

Thus, determining and considering the effect of the drying type on the strength of mineral fiber materials, in this case basalt fiber materials, involves a number of factors. Due to the contradictions of their role, it is difficult to specify the recommendations. However, it should be noted that the effect of the drying method on the strength of the material should be taken into account in the development of technological regulations for the production of composites such as mineral fiber paper on certain paper and cardboard machines, because drying methods are different on different types of machines: contact, convective, light.

Conclusion. Concluding our research on the formation of composite materials such as paper, it should be noted that another factor related to the geometry of mineral fibers needs to be taken into account. In particular, mineral fibers are longer than other fibers and tend to be fragmented, which reduces the uniformity of the macrostructure.

The factor of macrostructural unevenness is very important in the formation of strength indicators and cannot be ignored in the assessment of situations that affect the strength of materials. The depiction of a composite element at the level of two fibers where the effect of inter-fiber bonds is weak determines the critical length of the fibers involved in this interaction. The amount of energy interacting along the entire length of the fiber should not be less than the strength of the individual fiber itself. Given the lack of integrity in the contacts between the two fibers, the critical length of the fiber can also be assigned to be slightly larger than the energy of the interactions determined between the fibers.

For such a calculation, it is necessary to conduct research to determine the inter-fiber interaction corresponding to the elemental contact area in the formation of the bond. An example of this is the reversible joint of a polymer fiber. In this case, it is sufficient to obtain a result that can be corrected later.

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