SELECTION OF MINERAL FIBERS FOR COMPOSITE MATERIALS

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Abstract. This article is devoted to the experimental and theoretical justification of the choice of mineral fibers and inorganic binders in the production of composite materials. Composite materials are characterized by high mechanical, thermal and chemical properties, therefore the choice of components used in their composition is very important. Mineral fibers (for example, glass fibers, carbon fibers, etc.) play an important role in ensuring the strength, durability and stability of composite materials. At the same time, inorganic binders (for example, silicate, cement, aluminum oxide, etc.) increase the cohesion and strength of materials, improve their durability.

The article reviews the main factors to consider when selecting mineral fibers and inorganic binders, including the mechanical properties of the materials, their environmental impact, the economics of the production process, and environmental sustainability. On an experimental basis, their suitability and effectiveness are determined by testing and physicochemical analysis of the materials. On a theoretical basis, it explains how the structural properties of the materials and their interaction with each other affect the quality of the composite material.

This article provides a detailed analysis of the importance of mineral fibers and inorganic binders in the production of composite materials, the requirements placed on them, and the factors that should be considered when selecting them. The article will help develop new methods and approaches to improve the quality of composite materials and expand their application areas.

ISSN 3030-3907

Key words. Composite materials, mineral fibers, inorganic binders, glass fibers, carbon fibers, mechanical properties, durability, thermal stability, environmental stability, experimental tests, material mix, strength, stability, mineral fibers and inorganic binders.

Аннотация. Данная статья посвящена экспериментально-теоретическому обоснованию выбора минеральных волокон и неорганических связующих при производстве композиционных материалов. Композитные материалы характеризуются высокими механическими, термическими и химическими свойствами, поэтому выбор компонентов, используемых в их составе, очень важен. Минеральные волокна (например, стекловолокно, углеродное волокно и т. д.)) играет важную роль в обеспечении прочности, долговечности и стабильности композитных материалов. Однако неорганические связующие (например, силикат, цемент, оксид алюминия и т. д.) Также могут быть использованы.) повышение гармоничности и прочности материалов, повышение их долговечности. В статье рассматриваются основные факторы, которые следует учитывать при выборе минеральных волокон и неорганических связующих, включая механические свойства материалов, их воздействие на окружающую среду, экономичность производственного процесса и экологическую устойчивость. На экспериментальной основе их пригодность и эффективность определяют путем испытаний и физико-химического анализа материалов. Теоретически он объясняет, как структурные свойства материалов и их взаимодействие друг с другом влияют на качество композитного материала. В этой статье подробно анализируется важность минеральных волокон и неорганических связующих при производстве композитных материалов, требования к ним и факторы, которые следует учитывать при их выборе. Статья поможет разработать новые методы и подходы к улучшению качества композитных материалов и расширению областей их применения.

Ключевые слова. Композитные материалы, минеральные волокна, неорганические связующие, стекловолокно, углеродные волокна, механические свойства, долговечность, термическая стабильность, экологическая стабильность, экспериментальные испытания, смесь материалов, прочность, стабильность, минеральные волокна и неорганические связующие.

Annotatsiya. Ushbu maqola kompozit materiallar ishlab chiqarishda mineral tolalar va noorganik bog'lovchilarni tanlashni eksperimental va nazariy asoslashga bag'ishlangan. Kompozit materiallar yuqori mexanik, issiqlik va kimyoviy xususiyatlar bilan ajralib turadi, shuning uchun ularning tarkibida ishlatiladigan

ISSN 3030-3907

komponentlarni tanlash juda muhimdir. Mineral tolalar (masalan, shisha tolalar, uglerod tolalari va boshqalar.) kompozit materiallarning mustahkamligi, chidamliligi va barqarorligini ta'minlashda muhim rol o'ynaydi. Shu bilan birga, noorganik bog'lovchilar (masalan, silikat, tsement, alyuminiy oksidi va boshqalar.) materiallarning uyg'unligi va mustahkamligini oshirish, ularning chidamliligini oshirish. Maqolada mineral tolalar va noorganik bog'lovchilarni tanlashda e'tiborga olish kerak bo'lgan asosiy omillar, shu jumladan materiallarning mexanik xususiyatlari, ularning atrof-muhitga ta'siri, ishlab chiqarish jarayonining iqtisodiyoti va ekologik barqarorlik ko'rib chiqiladi. Eksperimental asosda ularning yaroqliligi va samaradorligi materiallarni sinash va fizik-kimyoviy tahlil qilish orqali aniqlanadi. Nazariy asosda u materiallarning strukturaviy xususiyatlari va ularning bir-biri bilan o'zaro ta'siri kompozit materialning sifatiga qanday ta'sir qilishini tushuntiradi. Ushbu maqolada mineral tolalar va noorganik bog'lovchilarning kompozit materiallar ishlab chiqarishdagi ahamiyati, ularga qo'yiladigan talablar va ularni tanlashda e'tiborga olinishi kerak bo'lgan omillar batafsil tahlil qilingan. Maqola kompozit materiallar sifatini yaxshilash va ularni qo'llash sohalarini kengaytirish uchun yangi usul va yondashuvlarni ishlab chiqishga yordam beradi.

Kalit so'zlar. Kompozit materiallar, mineral tolalar, noorganik bog'lovchilar, shisha tolalar, uglerod tolalari, mexanik xususiyatlar, chidamlilik, termal barqarorlik, ekologik barqarorlik, eksperimental sinovlar, materiallar aralashmasi, mustahkamlik, barqarorlik, mineral tolalar va noorganik bog'lovchilar.

Introduction

Mineral fibers, binders used in the technology of composite filter materials. In the manufacture of filter materials, valuable, biologically inert, chemically and thermally stable, mineral fibers with a small diameter and relatively short fiber length are used. Their materials provide 99.999% efficiency in purifying the air from microorganisms, as well as solid and liquid particles with a size of 0.01-2 microns.

Glass fibers are of great interest for the production of filter grades of paper and cardboard. They are easily processed in conventional papermaking equipment. Glass fibers with a diameter of 0.1-9 μm are used in the production of filter materials, and glass fibers with a diameter of 0.1-1 μm are used in fine cleaning materials. The specific surface area of the fibers, measured by the BET method for nitrogen absorption, reaches up to 50 m2/g.

Basalt fibers have all the positive properties of glass fibers, but differ in a number of advantages. They are characterized by high heat resistance. Low stable hygroscopicity (not more than 1%) allows the production of hydrophobic materials

ISSN 3030-3907

from them. In addition, basalt fibers are characterized by high resistance to aggressive environments, superheated steam, and sharply elevated temperatures [3-7].

These indicators indicate the suitability of new types of materials based on basalt fiber for cleaning.

Micro-, ultra- and superfine basalt fibers are used in the manufacture of filter materials. Basalt fibers, like glass fibers, have a negative electric kinetic potential in an aqueous environment. This indicator has a maximum in absolute value at pH7 [5-6]. Therefore, the dispersion of basalt fibers is carried out in a neutral environment and is one of the advantages.

Basalt fibers are included in the compositions of many types of paper and cardboard filters. In industrial conditions, filters based on paper-like materials made of basalt fibers perform as effectively as woven filters in the process of air purification and sterilization. In this case, paper and cardboard obtained on the basis of basalt fiber compositions have higher mechanical strength and lower aerodynamic resistance compared to woven fibers [7-8]. Due to the high order of the structure, the small volume of the filter material also reduces the volume of filtration.

Fluorinated latex, isoprennitrile latex with nitrile of 40% acrylic acid, divinyl methacrylate latex are used for strong filtering materials based on basalt fiber, and sodium bentonite can be used in the amount of 2-15% to increase the strength of the paper-like filtering material at high temperature [9]. Basalt filter materials are recommended to be used for cleaning and sterilization of technological air in individual cleaning filters [10-11].

The use of aluminum compounds as binders is analyzed in the following chapters. The use of aluminum compound binders is expanding in paper production. Inorganic adhesives are one of the large classes of inorganic compounds. In organic adhesives, the solvent and the adhesive are usually separated. In inorganic adhesives, the solvent cannot be separated from the binder or material. Inorganic adhesives are viscous, concentrated solutions of inorganic polymers. In general, binders are divided into three groups:

- an acidic environment, where a polymer is formed as a result of hydrolytic polymerization;
- an alkaline environment, where a polymer anion is formed as a result of polycondensation;
- a neutral environment.

Inorganic adhesives can be dissolved in CuO, Al2O3, B2O3 and polymer compounds with a branched structure. In this case, an aqueous solution of an active

ISSN 3030-3907

solvent - alkali - is used to break the bonds between the molecules. The three-dimensional structure changes to a linear one, and an anionic polymer derivative and a cationic monomer solution are obtained. The transformation of two- and three-dimensional polymers into linear ones under the influence of coordination and anion occurs as dehydration polymerization.

It is a concentrated, usually saturated solution. Solutions of alkali silicates and aluminum silicates, stabilized by a pair of π-bonds that appear in the free orbital of the silicon atom and the lone pair of electrons of the oxygen atom, consist of non-localized polymer anions and heterochains. This, in comparison with the large value of the Cu-O-Cu valence angle, confirms the information about the tendency of the silicon atom to form heterochain polymers. Along with the CuO4 tetrahedron, the participation of the AlO4 tetrahedron in the formation of polymer chains can be observed. The aluminum environment of the p-elements occupies the main place. The aluminum hydrate ion binds to water by forming a shell with a branched network of strong hydrogen bonds, which can be explained by the low polarity of the 2p6 electron structure. Aluminum has the ability to enter the composition of polysilicic acid and form heteropolymer compounds.

Aluminum silicate solutions provide an equilibrium between the monomer and the polymer hydrocomplex, which is determined in an alkaline environment. They are interesting in that they form a complex in an alkaline environment. Such binders are prepared by mixing liquid glass and sodium aluminate solutions in a specific volume ratio. This is a fairly stable binder.

Two-component single-layer materials. Composite materials were cast using the binders selected for the experiment and the results were analyzed. There is relatively good experience in using aluminum compounds as a binder in the preparation of filter materials based on mineral fiber (basalt fiber). A sufficiently widely used binder of this quality has not yet been studied [9]. Therefore, it is necessary to study the properties of the aluminosilicate binder to compete with aluminum compounds as a reinforcing agent. The table below presents and explains some strength indicators of materials obtained by incorporating various natural fibrous raw materials and aluminum compound binders (Fig. 1). In filter materials based on basalt fiber and flax cellulose (flax cellulose was obtained from annual plants for the experiment when incorporating it into the composition), aluminum sulfate compositions are 20-50 times more effective, depending on their ratio [14]. Analysis of the results of this table shows that the reinforcing type of aluminum sulfate binder outperformed the aluminosilicate binders in all compositions. Even the highest strength index achieved with the aluminosilicate binder (120 kPa for 75% basalt fiber d_v=0.25 μm samples) is the lowest index determined for

ISSN 3030-3907

aluminum sulfate (167 kPa for basalt fiber d_v=0.25 μm). At the same time, with a decrease in the proportion of microfine (d_v=0.25 μm) fibers in basalt fibrous materials or an increase in the proportion of cellulose, the effectiveness of the aluminosilicate binder drops sharply.

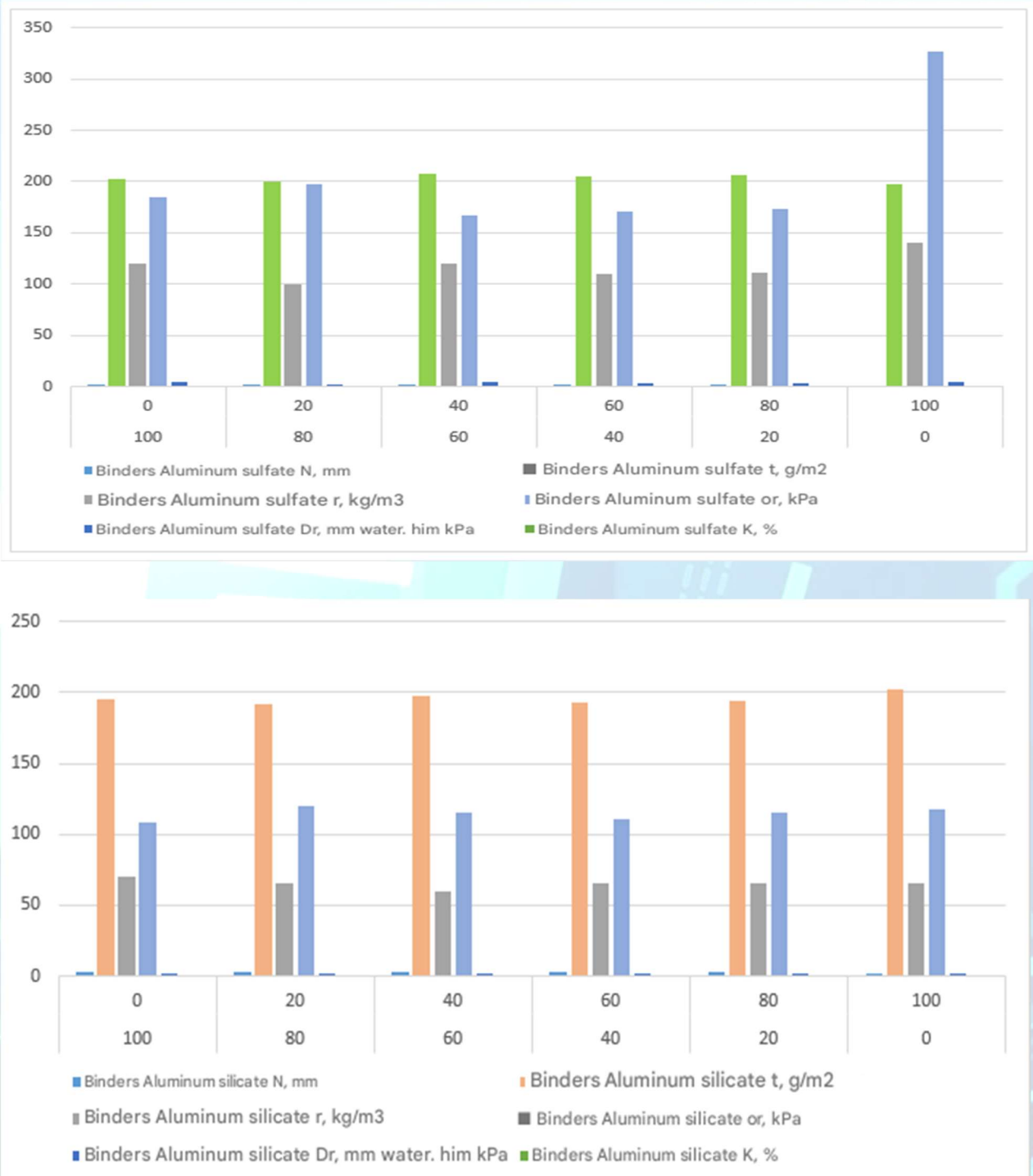


Figure 1. The influence of composition and composition without binder on the quality of filter material

If the strength of individual 100% microfine basalt composites with both binders is almost the same, in 100% ultrafine basalt fiber composites, the sample with aluminum sulfate is 2.5 times stronger than the aluminosilicate sample.

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It should be noted that basalt fiber materials with the participation of aluminosilicate binder have a significantly low permeability coefficient.

In general, aluminosilicate binder cannot provide a sufficient set of properties for fine purification of the gas-air environment, primarily due to its low reinforcing properties. Therefore, we did not use it in subsequent experiments. We used only aluminum hydroxide as an inorganic reinforcing agent.

During the experiment, in addition to the results of the samples shown in the table (consisting of basalt fibers with a diameter of 0.25 and 0.75 μm and cellulose of the flax plant or cellulose of cotton fluff, respectively), we checked the effectiveness of aluminum sulfate in the compositions. The test results of the indicated composite filter materials are presented in Tables 2 and 3. They allow us to identify some regularities.

In basalt fiber compositions, the increase in the amount of fibers with d=0.75 μm shows a law close to linear growth, so that a material with 100% d=0.75 μm is 1.5 times stronger than a material with 100% d=0.25 μm.

Although the resistance to air flow increases 3 times (from 1.85 to 5.25 mm Hg), the sample still fully meets the requirements. At first glance, the law of change in the strength of the filter materials is not very clear. Indeed, with a decrease in the diameter of the fibers, the number of hydroxyl groups coordinating with the aluminum polyhydrocomplexes on their surface increases, and the relative surface area increases. Therefore, in practice, samples with more microfibers should be stronger.

However, maximum strength can be achieved only if the amount of aluminum hydroxide in the mass does not exceed the specified "saturation consumption". In this case, all the surface active hydroxyl groups of the fibers are used to build the internal coordination sphere of the aluminum complex. In such conditions, the additional amount of hydroxide plays the role of an inert filler, not a binder.

In the case under consideration, the consumption of aluminum, which is 10% of the weight of the fibers, exceeds the “saturation consumption”. In this case, the strength of the material is determined by the excess amount of retained aluminum hydroxide. In samples with a higher percentage of micron-thin basalt fibers with less porosity, the sample has a lower strength due to the higher number of such hydroxide groups.

The change in strength in the indicated compositions depends on the diameter of the basalt fiber used and the ratio of cellulose to basalt fiber used. The maximum is 500 kPa for a material with 75% cellulose and 25% basalt fibers with a diameter of 0.25 μm. Increasing the amount of basalt fibers in the material reduces

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its strength, the permeability coefficient of the filter material at maximum strength is very low and the resistance to air flow is 3 times higher than the acceptable level (Table1).

Table 1

Effect of fiber and composite binder composition on filter material quality

Composition content, %		Fiber diameter					
Flax plant cellulose	Basalt fiber	0.25 μm					
		H, MM	m, g/m²	P, kg/m³	σp, kPa	Dr, mm of water. him	k, %
100	0	1.4	196.0	140	320	5.0	0.125
80	20	1.5	194.0	132	500	18.5	3.5
60	40	2.0	198.5	134	370	35.8	6.3
40	60	1.8	193.5	136	186	4.3	0.08
20	80	1.8	198.5	137	188	4.36	0.88
0	100	1.9	204.5	136	95	1.85	11.2
0.75 μm							
100	0	1.4	202.5	142	337	5.0	0.225
80	20	1.8	200.0	138	450	3.5	0.105
60	40	1.9	207.5	140	400	4.25	0.030
40	60	2.0	205.0	141	220	5.5	0.00224
20	80	2.0	205.5	142	222	5.55	0.00324
0	100	2.0	197.5	140	105	5.25	0.050

The addition of basalt fibers with a diameter of d_v=0.75 μm to flax cellulose in any amount also leads to a weakening of the material. Such materials have low air resistance and there is no clear ratio of fiber components. However, the permeability coefficient in all studied samples is very high, which means that the

ISSN 3030-3907

studied materials cannot be used in the process of fine cleaning. Materials made from a composition of basalt and cotton wool cellulose are also characterized by similar properties. From the general data shown in the figures, it can be seen that by changing the ratios of mineral fibers and using aluminum sulfate, a whole family of filter materials can be obtained that differ in properties over a wide range and

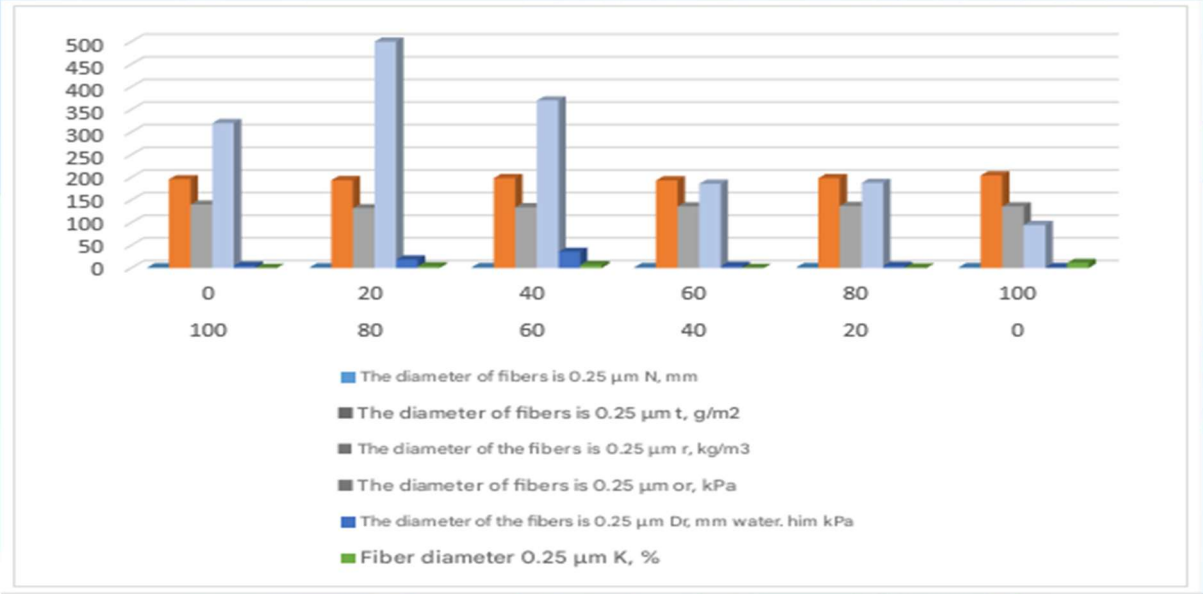


Figure 2A. Effect of fiber and composite binder composition on filter material quality

can be used for various practical purposes. The tensile strength of samples obtained in laboratory conditions ranges from 95 to 500 kPa, the air resistance varies from 1.85 to 5.25 mm above water, and the permeability coefficient is from 2.8 to 6.3%.

However, we came to the conclusion that none of the obtained samples is suitable for filtering alcohol products, not for cleaning gas-air flows.

Two-component two-layer materials. It is well known that in two or more layered types of paper, fibers obtained on the basis of plants have the best quality indicators, a single-layer material with an area of 1 m2, when compared with a multilayer material of the same size, is devoid of the shortcomings listed in the above experiments. This can be explained by the fact that in the process of obtaining multilayer materials, the random structure of one of the layers is covered by the qualitative area of other layers, in general, the structure of the multilayer material has fewer flaws and defects than that of a single-layer material.

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Filter materials made of basalt fibers with d=0.25 and 0.75 μm are less sensitive to the shape change method. The air flow resistance and permeability coefficient differ little between single-layer and double-layer samples, and the

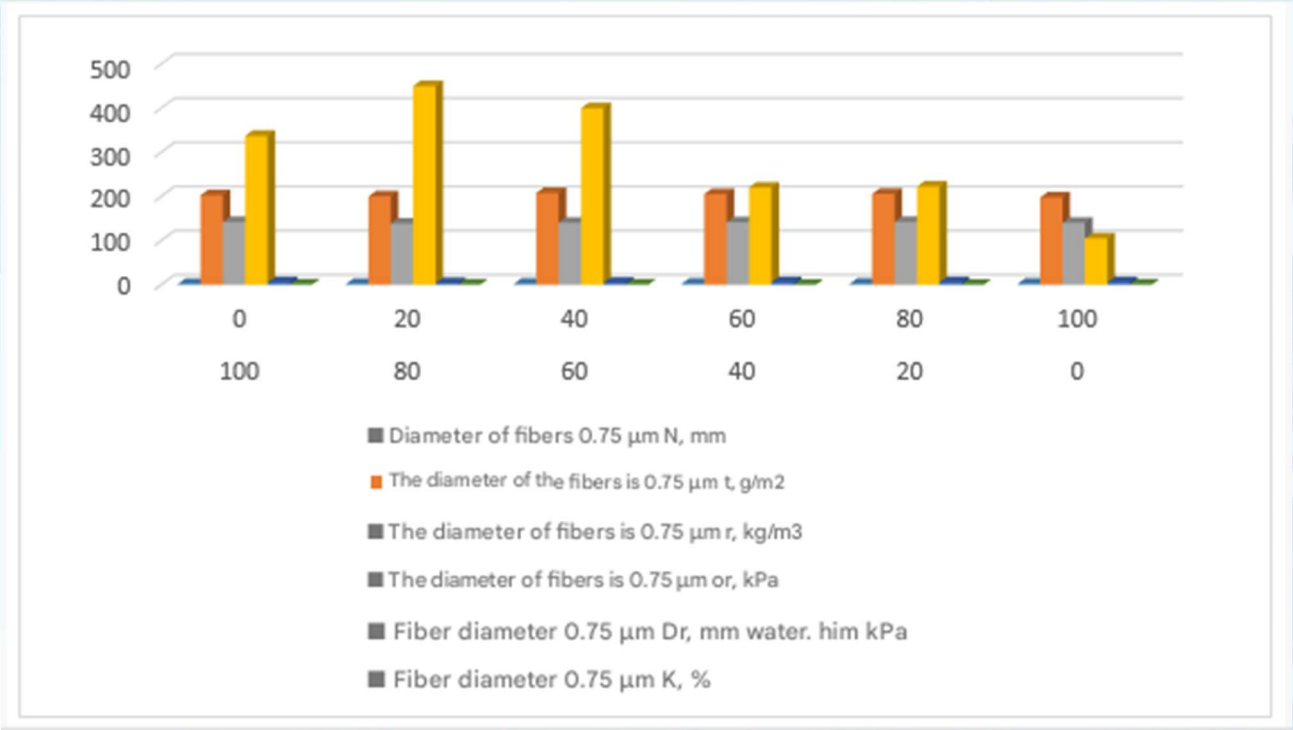


Figure 2B. Effect of fiber and composite binder composition on filter material quality

difference that does exist does not determine the regularity of the pattern [16].

The obvious correlation is determined by the strength analysis of the forming method. It is not difficult to notice that in samples with a fraction of less than 25%, basalt fibers d=0.75 μm during two-layer forming, the strength is significantly lower. In the same case, the strength of ultra-thin and micro-thin basalt fibers does not depend on the paper forming method. With a fraction of basalt fibers above 75% d=0.75 μm, two-layer forming is preferable, if we discuss the strength.

It can be said that the strength correlation in the composition of basalt fibers d=0.75 μm during single-layer and two-layer forming is the same: with an increase in the fiber fraction, the strength increases, but with a two-layer forming, an increase in strength is achieved.

In filter materials, the two-layer formation method has a clear advantage, since in two-layer materials consisting of a mixture of basalt and flax cellulose with a diameter of 0.2 μm, the strength ratio is significantly higher in all tested ranges, compared to single-layer ones.

Formation of strength in paper-like materials. It is known from the literature that mineral fibers do not actively interact with water and that it is impossible to

ISSN 3030-3907

obtain paper products only from mineral fibers. This is confirmed by industrial experience, as cited in a number of industry sources. The main problem in the production of sheet or roll materials based on mineral fibers by the papermaking method is the selection of suitable binders. Without reinforcing additives, sheet materials based on mineral fibers cannot be produced or are practically unsuitable for use.

The use of vegetable or thermoplastic synthetic fibers and aluminum compounds as reinforcing additives allows strengthening materials based on mineral fibers. Vegetable fibers themselves do not have the necessary thermal, chemical, biological stability. Therefore, in this case, the above problems can be solved if materials are obtained from a composition of vegetable fibers and basalt fibers. We carried out the experiments as follows.

At the first stage of the tests, aluminum compounds, which are considered active reinforcing agents in paper compositions based on cellulose fibers, were studied according to literature data. These are aluminum sulfate, sodium aluminate and aluminum chloride. The casting of the samples was carried out in a weakly alkaline environment (pH 8.5-9.5), since it was found that under these conditions the strengthening effect reaches its maximum value even without the introduction of aluminum compounds into the cellulose-based paper composition. To obtain a laboratory sample (cast), sheet casting was performed on a LAO-2 apparatus.

In many cases, when performing parallel measurements, random errors occurred, which led to a large difference in the values of the data obtained. In order to prevent the measurement results from significantly differing from each other, they were checked according to the Student's t-test using the following formula:

$$\frac{n - \bar{n}}{S} \geq t_{0.05},$$

where: n- the measurement result whose reliability is in doubt; $\bar{n}$- the average static value of the measured parameter; S- the standard error of the test; t is the value of the Student's t-test at the level of 0.05=5%.

The standard return is determined by the following formula:

$$\sigma^2 = \frac{\sum(x - \bar{x})^2}{n},$$

where: σ^2-standard deviation; x -experimental value of the quantity; $\bar{x}$- mean value of the quantity; n -number of determinations.

The variance is determined by the following formula:

$$D = \frac{\sum \sigma^2}{n}$$

ISSN 3030-3907

Table 2 presents the results of the test variants obtained by introducing three aluminum compounds into the mass. The consumption relative to the absolute dry mass of fiber was 10% (mass %). It was chosen by analogy with the consumption when producing paper and cardboard from plant fibers. In this case and in the future, the consumption of reinforcing additives is shown recalculated to the oxide of the corresponding metal.

Table 2

The effect of aluminum compounds on the strength of samples made of fibers of different nature

Type of fiber	For options, kPa, br		
	$Al_2(SO_4)_3$	$NaAlO_2$	$AlCl_3$
Basalt fiber, dv=0.25 μm	460	367	325
Flax cellulose fiber, Dv=0.25 μm and basalt	633	609	599
Flax cellulose fiber, dv=0.75 μm and basalt	526	590	568
Basalt fiber, dv=0.75 μm	299	242	154
Wheat straw cellulose and basalt fiber, Dv=0.75 μm	360	300	264
Wheat straw cellulose and basalt fiber, Dv=0.25 μm	647	594	582

The strength of the resulting material depends on the nature of the fiber, as well as on the nature of the aluminum compounds used as a reinforcing additive. It was found that samples made of basalt and flax cellulose with a diameter of 0.25 μm have the highest strength, and the lowest strength is found in samples made of basalt fiber with a diameter of 0.75 μm. Reducing the diameter of the basalt fiber used from 0.75 to 0.25 under the same conditions leads to a significant increase in strength, i.e. 2.1 -3.5 times. Although a decrease in the diameter of the basalt fiber also leads to a decrease in strength, the relative surface area of the fiber increases significantly. The increase in the relative surface area is characterized by an increase in the amount of ligands capable of coordinating interaction with polynuclear aluminum complexes located on the surface of the fiber and contributing to the strength of the materials.

Conclusion. The selection of mineral fibers and inorganic binders is of great importance in the production of composite materials. The right components must be selected to optimize the mechanical, thermal and chemical properties of these materials. Mineral fibers (e.g. glass and carbon fibers) play an important role in increasing the strength and durability of composite materials, providing high mechanical and stable properties while maintaining the lightness of the materials. Inorganic binders, such as silicates, cements and aluminum oxide, strengthen the

ISSN 3030-3907

cohesion of the material, ensuring its durability and long service life. On an experimental basis, when selecting mineral fibers and inorganic binders, their compatibility, physicochemical properties and the efficiency of the production process are taken into account. Theoretically, the interactions between these components and the structural properties of the materials directly affect the overall quality of the material. At the same time, the environmental aspects of the selection of mineral fibers and inorganic binders also play an important role. Reducing their environmental impact and developing recyclable materials will help create environmentally friendly and efficient composite materials that meet the needs of modern industry. In general, experimental and theoretical justification of the choice of mineral fibers and inorganic binders will allow to improve the quality of composite materials, expand their areas of application and make production processes more efficient.

In conclusion, it should be noted that in a number of cases, the transition from one-layer to two-layer material allows to expand the scope of use of mineral fiber composite filter materials. Therefore, such filter materials can be recommended for filtering alcoholic products and oils.

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