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Suitability of basalt raw materials of the Kyrgyz Republic for the production of superthin and continuous fibers

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ABSTRACT: Introduction. Literature analysis and patent search revealed that basalt rock and its fibers have exceptional physical and technical characteristics and alongside abundant raw material reserves. Based on this, the use of basalt rocks and their fibers as a material for the development of advance composite materials with high performance characteristics is a promising direction. Diverse technological fields and economic sectors, as well as various material requirements, necessitate a spectrum of systems, compositions, and properties for basalt and its melts, whether for generating superthin or continuous fibers. **Methods and materials.** The chemical and mineralogical compositions of some basalt rocks from deposits in the Kyrgyz Republic were studied to determine their suitability for production of superthin fibers and continuous fibers. The acidity modulus and fusibility modulus were determined by calculation based on the chemical composition of basalts of the Kyrgyz Republic. Among them, the quality of basalts from the Suluu-Terek deposit and basalts from the Toru-Aigyr deposit fully meets the requirements for the quality of raw materials for creating the production of basalt superthin fibers (BSF) and basalt continuous fibers (CBF). In the research we used physical and chemical analysis methods to determine the chemical and mineralogical composition of basalt. By calculating the acidity and fusibility modulus of basalt raw materials from the Kyrgyz Republic, as well as comparing them with relevant standards, their suitability for the production of basalt superthin fiber (BSF) and basalt continuous fiber (CBF) was established. The object of the study was the basalts of the Sulu-Terek deposit. **Results** of the study include an analysis of the chemical and mineralogical compositions of certain basalt rocks from deposits in the Kyrgyz Republic in order to assess their suitability for the production of superthin and continuous fibers. The acidity modulus and fusibility modulus of basalts of the Kyrgyz Republic were determined by the calculation method. Among them, it was revealed that the quality of basalts from the Suluu-Terek deposit and basalts from the Toru-Aigyr deposit fully meets the requirements for the quality of raw materials for the production of basalt superthin fibers (BSF) and basalt continuous fibers (CBF). **Conclusion.** The suitability of basalt rocks from various deposits, especially Suluu-Terek, Taldy-Bulak and Kashka-Suu, was confirmed, with recommendations for use. The results also highlight the importance of compliance with standards when selecting deposits and setting production parameters.

KEYWORDS: criteria for the suitability of raw materials, rocks, chemical and mineralogical composition, loss on ignition, viscosity modulus, fusibility modulus, upper limit of crystallization temperature (ULCT), basalt superthin fiber (BSFF), basalt continuous fibers (BCF).

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INTRODUCTION

It is known that for prodiction of inorganic mineral fibers, various rocks are mainly used as raw materials. Of particular interest are wastes from energy and mining industries, such as ash and slag wastes and refuse ore [1, 2].

Diabases, basalts, andesite-basalts, gabbro-basalts, dolerites, ambifolites are used for the production of inorganic superthin and continuous fibers from single-component raw materials [3–10].

According to the chemical and mineralogical composition, basalt rocks are the best raw material for production of high-quality inorganic fibers from igneous rocks.

The mineral and chemical composition of basalt rocks for technology of obtaining inorganic fibers are important indicators, since each deposit has a certain mineral and chemical composition within the limits of igneous origin. In this connection, various rock deposits from the earth's crust used as raw materials for production of basalt fibers [3–13].

Considering some physical and technological characteristics of molten rocks, and based on the experimental and theoretical study results of rocks, authors of works [11–13] noted the following: 1) acidity and viscosity modules were calculated according to their chemical composition for a preliminary assessment of the rocks use in the production of basalt fibers; 2) the main criteria for the suitability of raw materials for production of basalt staple and continuous fibers are the melt surface tension, viscosity and its temperature dependence, crystallization and wetting abilities, which determine the lower and upper limits of the temperature range for fiber production.

An important indicator of the raw materials quality for obtaining superthin fibers is its chemical and mineralogical composition, pieces size, as well as the grains of its minerals. For preparation of raw materials crumbs, rocks are used, which, in terms of strength and hardness, should ensure the production of raw materials pieces with a size of 5–40 mm.

About 240 deposits and manifestations of diabases, basalts and basaltic porphyrites have been identified on the Kyrgyz Republic territory [12].

Deposits of diabases, basalts and basaltic porphyrites are located within such ridges as the Kyrgyz, Kungei-Ala-Too, Tasakemin, Terskey, Zhetim-Too, Atbashy, Alai and Atoynok. Manifestations of basalts are widespread within the ranges of Dzhumgal, Talas, Kaptakas, Chatkal, Karakatty, Suusamyr, Dzhumgal, as well as in the Ulug-too mountains. In addition, manifestations of basalts are widespread within such ranges as the Fergana, East Alai, Turkestan and Moldotoo [13].

Currently, the following types of fibers are produced from rocks (in diameter, in microns): microthin (up to 0.5), ultrathin (from 0.5 to 1), superthin (from 1 to 3), thin (from 9 to 15), thick (15 to 25), thick (25 to 150) and coarse (150 to 500). According to the length, the fibers are divided into continuous, reaching a length of 30 kilometers or more, and discrete (staple), having a length in the range from several millimeters to several centimeters. Depending on the diameter, they are used for different purposes.

Superthin fiber is used for manufacture of pierced heat-insulating and sound-absorbing products, cardboard, multilayer non-woven material, heat-insulating knitting-stitching material, long heat-insulating strips and bundles, soft heat-insulating hydrophobized plates, filters, artificial soil for hydroponic growing of vegetables, etc. These products are widely used in construction, aircraft and shipbuilding, metallurgy, medicine, agriculture, and in other fields of industry [11–26].

METHODS AND MATERIALS

The basalt fiber industry presents raw materials with a variety of requirements, which is associated with products diversity. There are a number of requirements on the raw materials chemical composition, the main substance content, harmful and ballast impurities, and on the uniformity of raw materials composition.

The raw materials are crushed, medium and metamorphosed ultrabasic rocks of volcanic origin: basalts, amphibolites, diabases, porphyrites. The sizes of raw materials fractions should be from 3–70 mm.

When characterizing chemical composition of raw materials suitable for production of a particular fiber type, the content of main oxides SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, CaO, Na_2O, K_2O, TiO_2 was taken into account.

The chemical composition study of basalt rock, basalt melt and its wastes was carried out using the methods of titrimetry, spectroscopy, photoelectrocolorimetry, and gravimetry [27–31].

Loss on ignition was no more than 5% by weight. The raw materials should not contain impurities in the form of metal objects, quartz, sandy-clayey and other rocks that differ in chemical composition.

Assessment of the material composition and quality indicators were determined according to the following standards [32, 33]:

- Technical Conditions-21-Ukrainian SSR-410-86 "Rock raw materials for production of superthin staple fibers";
- Russian Institute of Standardization Ukrainian SSR-5020-80 "Rock raw materials for the production of staple fibers";
- Technical Conditions-21-137-84 "Rock raw materials for production of continuous fiber".
- Technological properties assessment was determined according to the Technical Conditions-234-023-20357632-97 "Canvas from super-thin basalt fiber.

For mineral fiber production, basalts are used as raw materials, in which the content of iron oxides does not exceed 10-18%, and the ratio of acidic oxides amount (SiO_2 + Al_2O_3) to floodplains (TiO_2+Fe_2O_3+FeO+MgO+ CaO+K_2O) should not be less than 2.

Correspondence of acidic oxides to basic ones (acidity modulus) is calculated using the formula:

$$M_{кл} = \frac{SiO_2+Al_2O_3+TiO_2}{Fe_2O_3+FeO+MgO+CaO+K_2O+Na_2O} \qquad (1)$$

where SiO_2, Al_2O_3, TiO_2 are weight content of oxides, %.

The acidity modulus in the deposit ranges from 1.9 to 2.7, averaging 2.3, the minimum acidity modulus exceeds the standard modulus by almost one order (0.72%).

An important property in the production of rock melts is the melting rate, which depends on a set of processes leading to the formation of a homogeneous glass mass devoid of bubbles. The melting rate is estimated from the temperature range and duration of melting; it can be expressed as a function of the ratio of refractory oxides to more fusible ones. With regard to rocks, the fusibility constant $C_{fusibility}$ has the following form:

$$П_{пл} = \frac{SiO_2+Al_2O_3+TiO_2+Fe_2O_3+FeO}{MgO+CaO+K_2O+Na_2O}, \qquad (2)$$

where SiO_2, Al_2O_3, TiO_2 are weight content of oxides, %.

The lower the value of this constant, the easier the rock is melted.

The criteria for the suitability of minerals for obtaining fibers based on the requirements for the mineralogical and chemical composition of rocks, melting conditions, and properties of their melts (Table 1).

For mineral fiber production, basalts are used as raw materials, in which the content of iron oxides does not exceed 10–18%, and the ratio of acidic oxides amount (SiO_2+Al_2O_3) to floodplains (TiO_2+Fe_2O_3+FeO+MgO+ CaO+K_2O) should not be less than 2.

The mineralogical composition of basalt raw materials has been studied using petrographic analysis. Photographs (at ×40 magnification) made using a Nikon polarizing microscope (Optiphot2-pol series, Japan). Petrographic analyses performed by using polarized light in the following order: a specially prepared preparation studied using a Nikon microscope Optiphot2-pol series. The thin section was a cut in the form of a plate of rock with a thickness of about 0.03 mm, glued onto glass. In the manufacture of thin sections, Canadian balsam was used a special glue. This method of analysis gives an accurate idea of the mineral composition and structure of basalt rocks and basaltic melt [8–10, 14].

Determination of rocks mass loss in was determined during chemical analysis of thermogravimetric studies (up to 1000°C), as well as at 1300 and 1450°C when obtaining melts [34].

Table 1

Requirements for the chemical composition of rocks for the production of various fiber types

Components	Requirements for raw materials quality, (mass fraction, %)			
	Coarse	Continuous	Fine staple	Superthin Staple
Silicon dioxide (SiO_2)	48.0–53.2	47.5–55.0	43–51.0	46.0–52.0
Titanium dioxide (TiO_2)	0.5–2.0	0.2–2.0	0.2–3.0	0.5–2.5
Aluminiun oxide Al_2O_3	13.0–18.0	14.0–20.0	10.0–17.0	13.0–18.0
Iron oxides (Fe_2O_3+FeO)	8.0–15.0	7.0–13.5	10.0–18.0	8.0–15.0
Calcium oxide (CaO)	6.5–11.0	7.0–1.5	10.0–18.0	8.0–15.0
Magnesium oxide (MgO)	3.0–10.0	3.0–8.5	4.0–15.0	3.5–10.0
Sodium and potassium oxides (Na_2O +K_2O)	2.0–7.5	2.5–7.5	2.0–5.0	2.0–10.0
Manganese oxide (MnO), no more than	0.5	0.25	0.4	0.5
Sulfur oxide (SO_3), no more than	1.0	0.2	1.0	0.5
Gain loss during annealing, not more than	5.0	5.0	5.0	5.0
Free quartz, no more than	3.0	2.0	3.0	3.0
Viscosity modulus, Mv	1.9–2.5	2.3–2.7	1.7–2.0	1.8–2.4

Glass preparation was carried out in laboratory conditions in platinum glasses. The weight of the rock was about 300 g. In the temperature range from 1170° to 1350°C, melting of rocks and intense gas evolution were observed, leading to abundant foaming of melt. This is especially characteristic of the almond stone basalt sample 371, due to release of CO_2 during decomposition of $CaCO_3$. Taking into account the small volume of platinum glasses (500 ml), it took a long time (up to 16 hours) to obtain a homogeneous melt.

The viscosity of studied rock melts was determined on an improved Margules-Volarovich viscometer with working surfaces of the "cylinder-cylinder" type. At the viscosity measurement points, the melt was held isothermally for 30 minutes to establish temperature equilibrium. The method of measuring viscosity is relative. We use polymethylsiloxane PMS-500, PMS-700, PMS-1000 (viscosity range 5–10 pauses) and K-15 glass for calibrating viscometers (GOST 3-3593-77, viscosity range 50–2000 pauses) as calibration substances. The viscosity measurement error does not exceed 7% [35].

The temperature of upper limit crystallization (ETCL) was found using the quenching method (the samples were isothermally held at a given temperature for two hours and then cooled rapidly). The presence of the crystalline phase in the glass samples obtained using this method was determined by the optical method (under an MBI-6 microscope at 750-fold magnification in transmitted light) and by X-ray phase analysis [35].

RESULTS

Results obtained after study of the basalts chemical composition from the Suluu-Terek, Taldy-Bulak, Kashka-Suu deposits are presented in Table 1.

As a one-component raw material for the production of various types of fibers, basalts with different content of components were selected (Table 2).

From the Table 2 it is seen that, according to the chemical composition, studied rocks belong to low-iron igneous rocks, since the content of iron oxides does not exceed 18%, and the content of SiO_2 in them is generally less than 50%. The content of floodplains is on average 20% and fits within the limits regulated by technical conditions (15–25%).

Basalt of the Kashka-Suu deposit is characterized by high acidity, however, the introduction of the simplest corrective additives in the form of limestone makes it possible to reduce the acidity modulus, which provides a melt with optimal physical and chemical properties.

Table 2
Chemical composition of basalt rocks for the production of superthin fibers

Components	Basalt, mass fraction, %			
	Chemical composition requirements for superthin fibers	Sulu Terek	Taldy Bulak	Kashka Suu
Silicon dioxide (SiO_2)	46.0–52.0	45.00	48.27	48.85
Titanium dioxide (TiO_2)	0.5–2.5	2.00	1.75	1.98
Aluminiun oxide Al_2O_3	13.0–18.0	14.00	13.98	15.72
Iron oxides (Fe_2O_3+FeO)	8.0–15.0	12.94	15.28	10.55
Calcium oxide (CaO)	8.0–15.0	11.0	9.49	7.28
Magnesium oxide (MgO)	3.5–10.0	4.0	5.32	5.14
Sodium and potassium oxides (Na_2O+K_2O)	2.0–10.0	4	4.45	4.41
Manganese oxide (MnO), no more than	0.5	–		–
Sulfur oxide (SO_3), no more than	0.5	–	0.42	0.87
Gain loss during annealing, not more than	5.0	5.0	–	5.2
Free quartz, no more than	3.0	1.6	–	–
Phosphorus oxide P_2O_5	–	–	–	–
%	100	100	100	100
Acidity modulus, $M_{acidity}$	1.8–2.4	1.90	1.85	2.41
Viscosity modulus, M_v	< 4.5	3.89	4.11	4.58

Table 3
Chemical composition of rocks for production of superthin fibers

Components	Quality requirements for chemical composition (basalt, mass fraction, %)			
	For superthin staple fibers	Siltstone-basalt Tashbulak	Toruaigyr	Semizbel
Silicon dioxide (SiO_2)	46.0–52.0	45.82	47.0	42.99
Titanium dioxide (TiO_2)	0.5–2.5	1.99	1.91	1.72
Aluminiun oxide Al_2O_3	13.0–18.0	13.86	13.7	13.53
Iron oxides (Fe_2O_3+FeO)	8.0–15.0	11.82	10.18	12.54
Calcium oxide (CaO)	8.0–15.0	9.57	13.40	9.89
Magnesium oxide (MgO)	3.5–10.0	7.89	3.68	11.23
Sodium and potassium oxides (Na_2O +K_2O)	2.0–10.0	3.03	4.12	5.38
Manganese oxide (MnO), no more than	0.5	0.18	0.10	
Sulfur oxide (SO_3), no more than	0.5	0.1	0.21	0.57
Gain loss during annealing, not more than	5.0	4.82	5.40	2.16
Free quartz, no more than	3.0	0.5	–	–
Phosphorus oxide P_2O_5	–	0,21	0.30	–
%		100	100	100
Acidity modulus, $M_{acidity}$	1.8–2.4	1.90	1.99	1.49
Viscosity modulus, M_v	< 4.5	3.58	3.43	2.67

In terms of oxide content, the basalts from the Taldy-Bulak and Kashka-Suu deposits differ from the basalts from the Suluu-Terek deposit in the higher content of silicon oxides and the lower content of calcium oxides (Table 2). Table 3 shows the basalts chemical composition from Tash-Bulak, Toru-Aigyr, and Semizbel deposits.

From the data presented in Table 3, we can conclude that chemical composition of the Toru-Aigyr deposit fully satisfies the quality requirements for single-component raw materials. However, remaining basalt deposits (Tash-Bulak, Semizbel) require additional introduction of components to meet specified standards, which can be preliminarily calculated through batching.

Basalt from the Suluu-Terek deposit fully meets the requirements for mineralogical composition necessary for production of superthin fibers. However, to produce continuous fibers from this basalt, it will be necessary to carry out a blending process, as indicated Table 4.

DISCUSSION

Thus, according to the chemical composition, the studied rocks belong to low-ferruginous basic igneous rocks, since the content of SiO_2 in them is mainly less than 40 to 50%, and the content of iron oxide does not exceed 18%, fluctuations in the chemical composition of the studied samples are small, which creates favorable conditions for maintaining the constancy of the charge in the production of mineral wool.

The Kyrgyz Institute "Orgtekhvodstroy" of the basalt deposit Suluu-Terek, based on the geological location of the basalt layer, identified three varieties of basalt (Table 5):

According to the geological location of basalt layer, three kinds of basalts were found in the Suluterek deposit (Table 5):

1. Cryptocrystalline basalt of dark gray color with carbonate admixtures;
2. Fine-crystalline to cryptocrystalline basalt, weathered to varying degrees, with medium and small amygdalae made of carbonate;
3. Almond shaped basalt with amygdalaes made of carbonate.

Viscosity and TVIC study results shown in Table 6. The melt properties coincide with the properties of basalts from the Berestovetsk deposit in Ukraine, which are used in all variants.

According to the viscosity (Table 6) absolute values and the temperature dependence course, we can conclude that it is possible to use basalts from the Suluterek deposit as raw materials for production of continuous and superthin fibers. In addition, amygdaloid basalts, which form

Table 4

Suitability of basalt rocks by mineralogical composition for the production of basalt superthin fibers (BSF) and basalt continuous fibers (BCF)

Minerals	Requirements for the quality of raw materials (basalt, limiting mineral content, vol. %)				
	Requirements for mineralogical composition		Basalt deposit		
	For superthin staple fibers	To obtain continuous fibers	Sulu Terek	Taldy Bulak	Kashka Suu
Plagioclase	20–55	35–70	30	40	30
Pyroxenes	5–40	1–35	40	20	30
Ore minerals	0–12	0–12	10	10	10
Olivines	0–15	0–15	–	30	30
Natural glass	2–45	0–50	20	–	20
Quartz	0–2	0–2	–	–	–
Amphiboles	0–15	0–10	–	–	–
Biotite	0–3	0–3	–	–	1
Palagonite	0–20	0–25	–	–	–
Chlorite	0–35	0–35	–	–	–
Epidotzoisitis	0–15	0–5	–	–	–
Carbonate	0–10	0–8	–	–	–

Table 5

Basalt varieties according to geological location

Basalt kinds / Components	Cryptocrystalline basalt with carbonate admixtures	Fine-crystalline to cryptocrystalline basalt with rare almond texture	Almond texture basalt
SiO_2	46.83	48.11	43.82
TiO_2	1.79	2.22	1.87
Al_2O_3	16.82	18.19	16.55
FeO	2.09	1.48	0.28
Fe_2O_3	7.73	9.41	9.87
CaO	10.54	8.58	12.81
MgO	5.33	4.32	3.91
Na_2O	2.57	2.95	2.22
K_2O	1.52	1.84	2.00
MnO	0.24	0.16	0.11
SO_3	00.5	0.08	0.11
Gain loss after ignition	3.68	2.49	7.21
Total	99	99.8	100.85

less viscous melts, can be recommended for producing fibers using the vertical air blowing (VAB) method.

The analysis revealed that in order to ensure the industrial production of basalt superthin fibers (BSF), it is recommended to use single-component raw materials without blending, mainly from the Suluu-Terek and Toru-Aigyr basalt deposits. For other deposits, the chemical composition should be calculated according to the necessary requirements by introducing additional components. It is recommended to use the technological parameters of basalts from the Suluu-Terek deposit for production of continuous basalt fibers (CBF).

Table 6
Viscosity and TVI of basalt melts from the Suluterek deposit

No	Names of rocks	Viscosity					Crystallization temperature upper limit
		1450	1400	1350	1300	1250	
1	Cryptocrystalline basalt with carbonate admixtures	55	96	165	303	580	1220
2	Fine-crystalline to cryptocrystalline basalt with rare minerals	73	125	206	383	715	1230
3	Almond basalt	30	54	96	182	350	1190
	Basalt Berestovetsky (Ukraine)	36	62	106	190	354	1275

CONCLUSION

Technical requirements for the quality of raw materials are given and research methods for the suitability of basalt raw materials are selected. The physicochemical and technological characteristics of the Kyrgyz Republic igneous rocks used for production of superthin fibers were studied.

The general characteristics of the main igneous rocks on the Kyrgyz Republic territory have been established. The physical, chemical and technological characteristics of igneous rocks of the Kyrgyz Republic and the selection of raw material deposits for the production of superthin and continuous fibers are presented. Technological parameters have been selected for the production technology of superthin and continuous basalt fibers from the Suluu-Terek deposit.

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