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OF THE REPUBLIC OF KAZAKHSTAN

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HIGH-TEMPERATURE TESTS OF THE GABBRO-BASALT GROUP OF KAZAKHSTAN FOR PRODUCTION OF MINERAL WOOL

Abstract. The results of studying the rocks of the gabbro-basalt group in the territory of Kazakhstan are described: 1) their material composition and thermal behavior in the temperature range 20–1000 °C; 2) high-temperature tests were performed on the LNT 04/16 installation in heating modes from 40 to 1500 °C. For this, rocks from different regions of Kazakhstan were selected, differing in chemical content and the degree of perfection of their mineral inclusions in accordance with existing standards. As a potential raw material, rock samples were used near major economic centers in Northern, Central and Southern Kazakhstan. Calculations of the viscosity of rocks of the gabbro-basaltic series were carried out by the method of E. S. Persikov. For the production of basalt fibers with specified characteristics for strength, chemical and thermal resistance and certain electrical insulating properties, it is proposed to use basalt rocks with characteristics in terms of chemical composition and properties of raw materials. Analysis of the available data showed that in many regions of Kazakhstan there are deposits of rocks of the gabbro-basalt group, suitable for the production of mineral wool, whose reserves amount to many tens of millions of tons. Technologies for the production of basalt fibers, especially continuous fibers, are quite new, they have a number of principal features related to the raw material. For each type of basalt requires its own special technological regimes and parameters of fiber production. The processes of melting, homogenization and preparation of the melt pass at high temperatures of 1400 °C and are associated with certain energy inputs. Technologies for processing basalt fibers in materials and products are not associated with high-temperature processes and are produced using "cold technologies". Thus, the production of basalt wool is essentially energy-saving and environmentally friendly.

Key words: mineral wool and fibers, basalt, diabase, gabbro, amphibolite, geological and petrological characteristics, chemical, thermal, X-ray diffractometric and microprobe analyzes.

The magmatic rocks of the gabbro-basalt group are the raw feedstock for the production of basalt fibers. They have high natural chemical and thermal resistance. The main energy functions of primary melting of rocks of the gabbro-basaltic series were fulfilled by nature. The rocks of the gabbro-basalt group are a ready-made natural raw material for the production of fibers. At the same time, the cost of extracting basalt raw materials is meager.

The results of studying the material composition and thermal behavior in the temperature range 20–1000 °C of the rocks of the gabbro-basalt group from some regions of Kazakhstan are described in the works [1-4]. The article gives the results of high-temperature tests at the LNT 04/16 installation in heating modes up to 1500 °C. For this purpose authors used the rock samples from different regions of Kazakhstan, different in chemical content and the degree of sophistication of their mineral spots according to existing standards and earlier studies [5-8].

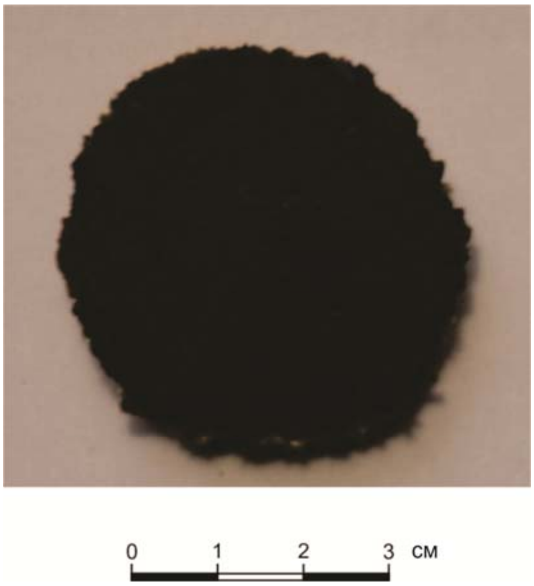
As raw materials, authors selected rock samples near the economic centers in the Northern region (Schuchinsk District), Central region (Pribalkhash) and South region (south-east of the Chu-Ili Mountains) of Kazakhstan (Table 1). Figures 1–8 contain sample photos of the firing of selected samples and the high-temperature heating schemes.

Table 1 – X-ray spectral analysis (silicate)

	Content, %										
Sample #	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	п.п.п.
Northern Kazakhstan											
K-13-15, gabbro-amphibolite	2,38	6,76	13,90	48,62	0,34	1,91	10,09	1,32	0,17	11,88	2,63
K-14-15-1-2, basalt	3,54	10,34	13,84	46,72	0,15	0,40	13,72	0,98	0,14	8,78	1,39
Central Kazakhstan											
K-12-15, dacite	2,93	1,16	13,89	66,13	0,22	4,55	1,08	0,78	0,17	8,13	0,96
K-16-15, andesibasalt	3,75	5,34	14,70	57,20	0,22	0,24	6,90	0,79	0,09	7,46	3,31
K-17-15, basalt tuff	3,55	5,56	19,31	52,81	0,26	0,24	1,18	1,38	0,26	10,20	5,25
Southern Kazakhstan											
K-3-15, Gabbro	2,30	11,45	16,27	52,10	0,05	0,18	2,51	1,08	0,16	11,76	2,14
K-20-16-1, basalt	3,40	4,05	18,12	54,16	0,34	0,24	3,73	1,90	0,11	9,68	4,27
K-20-16-2, basalt	3,97	4,21	14,32	55,41	0,27	0,39	6,35	1,53	0,11	7,83	5,61

Northern Kazakhstan

Saga basalt suite (sample K-14-15-1) under conditions of dynamic heating of the feed from 20 to 1400 °C for 50 minutes and isothermal time exposure of this temperature within 30 minutes changed its appearance, which is related to the transition of the test system from crystalline into an amorphous state. After cooling down, fusion mixture transformed to the dense mass of dark brown color with an opaque shade. Brown shades prevail on the outer surface of the obtained product, which adjoined the air during warming up. The effect caused by the presence of hematite, which with the loss of part of the oxygen transforms into magnetite. The described sintered product has acquired the qualities of a solid, fine-porous ceramic mass, the durability of which does not concede to petrosites [6-8], obtained by sintering of granites. When the fusion mixture is fired at 750° C, its weight decreases by ~ 12.5%, as a result of the destruction of lizardite and dehydration of tremolite, and at 1,400° C the mass of the product decreases by another 3%. As a result, the complete firing cycle reduces the weight of the tested rock by 15.5% (Figure 1).



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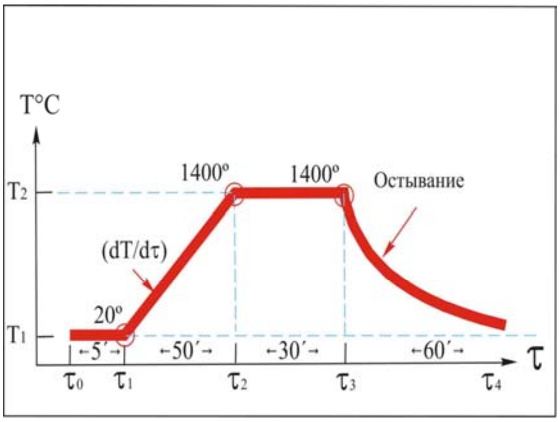

b

Figure 1 – a) photo illustrations of burned basalt product, Saga suite (O2-3sg); b) high-temperature heating circuit. Temperature and chronological parameters of basalt (sample K-14-15-1) burning under heating conditions of 1400° C (5', 50', 30') - the first number means the upper-temperature limit of the temperature effect, the numbers in parentheses correspond to the waiting time, dynamic heating, the stage of isothermal calcination of the sample. The cooling time is shown in the diagram

The chosen mode of calcination of the sample K-14-15-1 is applicable for obtaining ceramic material from this type of raw material. The procedure for securing fiber products of this kind of basalt requires, upon calcination, the attainment of a complete molten state of the fusion mixture. It is used in the production of mineral wool of more finely grinding stone material. To this end, for our sample, we have proposed a different firing scheme, which provides the dynamic heating of the furnace from 20 to 1500 °C for 100 minutes, with the further transition, at this temperature, to an isothermal heating mode lasting 20 minutes. The nature of cooling of the system remains the same, i.e., not forced – in the mode of exponential cooling of the furnace space to room temperature. Thermal testing of the fusion mixture under heating conditions at 1400–1500 °C led to its complete homogenization (Figure 2).

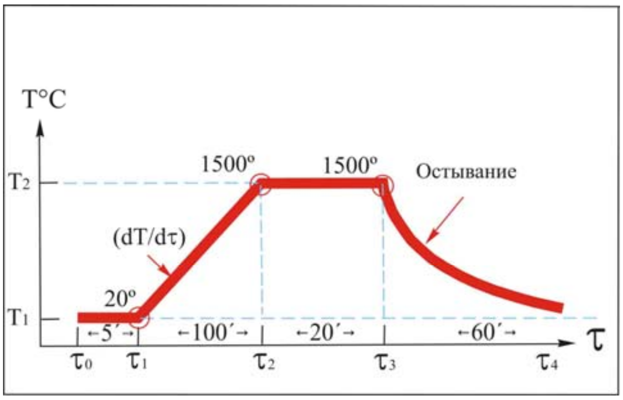

Figure 2 – Scheme of the burning of the Saga basalt suite (O2-3sg), sample K-14-15-1.
Temperature and chronological parameters under high-temperature heating conditions of 1500 °C (5', 100', 20')

The Saga basalt suite (sample K-14-15-2) under heating in the burning mode of 1400 °C (5', 50', 30') undergoes a series of transformations, resulted with the destruction of clinochlore (Mg, Fe) 5Al [$AlSi_3O_{10}$] (OH) 8 and muscovite $KAl_2(AlSi_3O_{10})(OH)_2$), as well as the dehydration of the Olenite $NaAl_3Al_6$ (Si_6O_{18}) (BO_3) 3 (O, OH) 4. The amount of these thermally susceptible inclusions in the rock is over 40% (21.2, 12.8, and 10.5%, respectively). The substance obtained after burning is a solid, densely formed mass of dark brown color. The outer surface of the formed ingot, in particular, free from contact with the crucible, is perfectly smooth and gives the product a look of a dark glaze (Figure 3). The set temperature and chronological regime of 1400 °C (5', 50', 30') for heating the batch and the degree of crushing of the rock to a fraction of 0.5–2.0 mm are acceptable for the hot casting of building products. This temperature and chronological scheme of fusion mixture calcination can be changed in favor of an energy-saving mode of production of basalt mineral wool, taking into account the time of isothermal heating of the furnace, the rate of temperature increase, the degree of grinding of the fusion mixture, which in the end will reduce energy costs to obtain the required viscosity of the basalt melt.

Figure 3 –
Photographic illustration of the burned product of the Saga basalt suite. The temperature and chronological parameters of burning under high-temperature heating conditions of 1400 °C (5', 50', 30'), sample K-14-15-2

The gabbro-amphibolite (sample K-13-15), when heated at 1400° C (5', 30', 20') transforms into a dense mass of dark orange color. The outer surface of this formation, which did not touch the body of the crucible while heating, was covered with a layer of glaze, figure 4. The hardness of the resulting ingot is comparable to the hardness of all the glass masses made from basalt powder. The product obtained has a high mechanical strength. The ingot with a diameter of 20 mm and a thickness of ~ 2 mm cannot be broken manually. These physical parameters of the cooled gabbro-amphibolite melt, in the first approximation, correspond to the characteristics of the glass mass, which in turn correspond to the requirements for the production of fiber products from them. Besides, this basalt glass for many technical parameters is wholly consistent with modern materials, the products of which are widely used in finishing construction works.

The chosen mode of furnace heating, even at the early stages of the thermal transformation of the powder sample, provided the test sample with the opportunity to free itself of the minerals-impurities (by thermal destruction of their structures), which made it possible to partially (by ~ 3%) facilitate the fusion mixture by removing molecules from the clay inclusions H_2O, OH and CO_2, as well as to slightly improve the quality of the fusion mixture, due to the silicon-oxygen residues of thermally degraded clays.

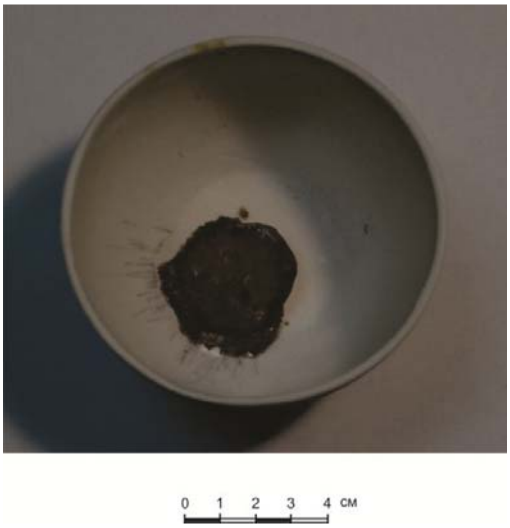

Figure 4 – Photo illustrations of the gabbro-amphibolite calcination product. The temperature-chronological parameters of roasting under high-temperature heating conditions are 1400 °C (5 ', 30', 20 '), sample K-13-15

Due to the low content of thermally active minerals in the parent rock, the volatile constituents were removed from their structures, which provided the sample with a small percentage of weight loss to 3%. Such share, of substance which left the system, cannot negatively affect the cost of produced products (basalt glass). The energy cost associated with the emission of such gas is negligible. The low content of these inclusions in the gabbro-amphibolite increases the economic attractiveness of this rock as a raw material in the production of basalt glass.

Central Kazakhstan

Basalt tuff (sample K-17-15) was formed into a dense brown mass after the heat treatment at 1400 °C (5', 50', 20') (Figure 5). The outer part of its surface, which did not touch the inner cavity of the crucible while burning, is covered with glaze. The resulting product, like the rest basalt ingots we made, proved to be strong for fracture and endowed with high hardness. Since the composition of the product contains silicic mineral formations (quartz, albite, and olenite), the products of hypergenic origin (chlorite, kaolinite, muscovite and goethite), the realization of the melting of this group of minerals requires additional energy expended in the decomposition of their structures. It is consumed within the temperature range of 40–950° C. At the same time, the heat blown from the system is not that great. It is equivalent to the amount of structural water (5.7%) emitted by secondary minerals in the specified temperature range. Such part of the heat, in addition to other forced energy costs, is consumed by melting the presented stone material. From the technological and economic standpoint, this flow rate is compensated by the impro-

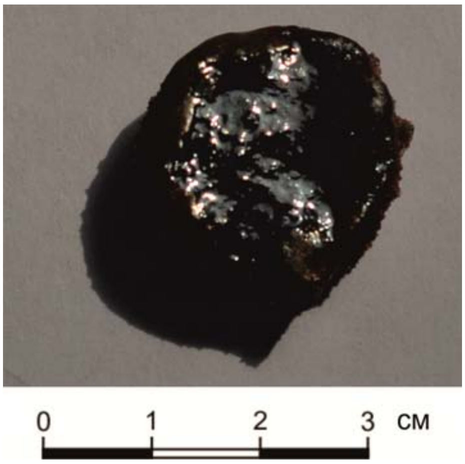

Figure 5 – Photo illustrations of the burned basalt tuff product. The temperature and chronological parameters of calcination under high-temperature heating conditions of 1400 °C (5', 50', 30'), sample K-17-15

vement in the quality of the glass mass, a decrease in the temperature of the planned viscosity of the melt. This is facilitated by silicic acid residues of the destroyed structures of chlorite, kaolinite, muscovite and iron oxides.

Dacite (sample K-12-15), after heated at 1400 °C (5', 50', 30') transformed into a dense isotropic mass of dark orange color. The top surface of the resulting ingot is covered with glaze. The hardness of this product is not inferior to the hardness of the natural sample (figure 6).

Figure 6 – Photo illustrations of the burned dacite product.
The temperature and chronological parameters of burning
under high-temperature heating conditions of 1400 °C (5', 50', 30'), sample K-12-15

The process of formation of a new amorphous compound begins in the early stages of heating the dacite fusion mixture. At temperatures below 1000° C, only a small fraction (13%) of secondary minerals – hydromica (6.9%), kaolinite (3%), chlorite (3%) and muscovite (~ 1%) undergo thermal destruction. Thermal dissociation decreases the weight by 0.8%, 0.8%, 0.3% and 1.0%, respectively, due to the removal of adsorption and constitutional water from their structures. The weight loss of the heated fusion mixture also continued outside the limits of 1000 °C, in the range up to 1400 °C, it was about ~ 2% (mainly due to the sublimation of the melted product). The total weight loss of the fusion mixture was 4% of its mass. Thermal degradation of crystalline structures of secondary minerals containing silicon enriched the resulting product with the elements necessary to produce a high-quality fiber semi-finished product.

To test the effect of the upper-temperature limit on the crystallization quality of the molten formation, melting of the fusion mixture at a temperature of 1450 °C was also performed. The temperature was 50 degrees higher than the temperature limit of the previous tests. As a result, we obtained a material with quite the same qualities as before. Thus, regarding technological and economic norms for the production of basalt glass, the first option for thermal processing of andesite should be considered the most correct.

The results of the tests are acceptable for their introduction into manufacturing fiberglass products. Molten dacite is also suitable for casting technical heat and electrical insulating products for various purposes.

South Kazakhstan

Gabbro (sample K-3-15) mostly consisting (90%) of tremolite and plagioclase, and also of secondary minerals (~ 10%) (clinochlore, muscovite, calcite and dolomite) under conditions of high-temperature burning at 1300° C 5', 40', 30') has undergone a change, caused primarily by the melting of the main component of the test rock - the siliceous crystalline formation. Within these temperatures, all the named clay and carbonate inclusions in the form of impurities decompose entirely, leaving oxides of silicon, calcium, and magnesium as a part of fusion mixture. The destruction of these inclusions reduces the mass of the sample by 3.2%. Tremolite in this temperature range behaves exclusively as a thermally inert substance, which reacts to heat only at the beginning of the heating cycle, giving up two water molecules before reaching 180° C. When the temperature of the furnace reaches 1000° C, the studied mixture assumes an ocherous tinge and is consolidated into a semi-surface aggregate (figure 7).

Gradient heating of a high-temperature furnace to a level of 1300 °C leads to a gradual melting of the mixture to a low viscosity state. The further reduction in viscosity to the extent required by the experiment depends on the time of isothermal heating of the melt. In turn, to obtain an isotropic mass of the cooled product, it is required to calibrate the selection of the cooling mode. To save the energy in the technological process for the production of semi-finished products used for fiber products and for improving their quality, highly significant to choose the melting temperature of the mixture and the program the cooling rate of the molten rock substrate.

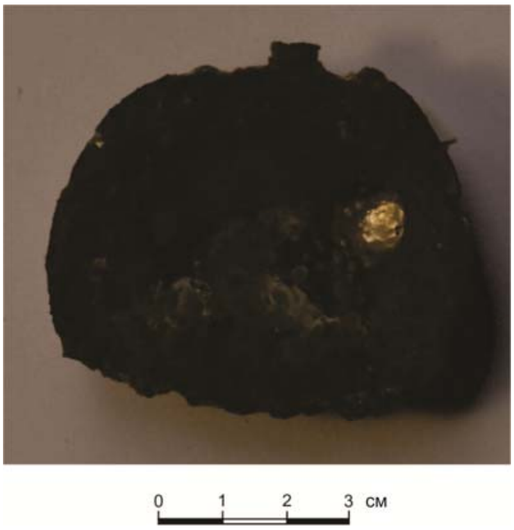

Figure 7 – Photo illustrations of the burned Paleozoic gabbro product. The temperature and chronological parameters of burning under high-temperature heating conditions of 1300 °C (5', 40', 30'), sample K-3-15

The final product of calcination of the test sample under the fulfilled heating regime was a dense sintered product of a brown-green color. Solid, the outer part of its surface that did not contact the crucible, is covered with a layer of glaze. The temperature and chronological mode of testing this sample is not entirely acceptable for the production of ingots suitable for the production of fiberglass products. The burning technology of the tested gabbro to obtain an alloy suitable for the production of basalt fiber is under development. However, for the preparation of building cladding material, roofing tiles, wall and floor coverings, this material can be used in the construction of residential buildings and industrial facilities in many ways (mechanical strength, water resistance, resistance to weather changes, chemical, and fire safety). According to the listed properties, this product can also be recommended for the production of heat and electrical insulating materials for the production of electrical products used in various industries.

This natural raw material can be used for the production of basalt glass melt and the proposed method for obtaining the required quality of the melt from it can be used not only for the production of fiber products but also for castings of heat-resistant heat and electrical insulating products resistant to the various chemically aggressive environment.

Basalt mandelstein (sample K-20-16-1) and massive basalt (sample K-20-16-2). The calcination products of these rocks were obtained under conditions of dynamic heating of the furnace in the range of 20–1400° C and up to 1450 °C (for 50 minutes), followed by the isothermal aging of this temperature (for 30 minutes), figures 8, 9. The quality of the melt in both cases reached the condition in which the incomplete crystalline basalt wholly transformed into an amorphous state. Basalt achieves similar state after

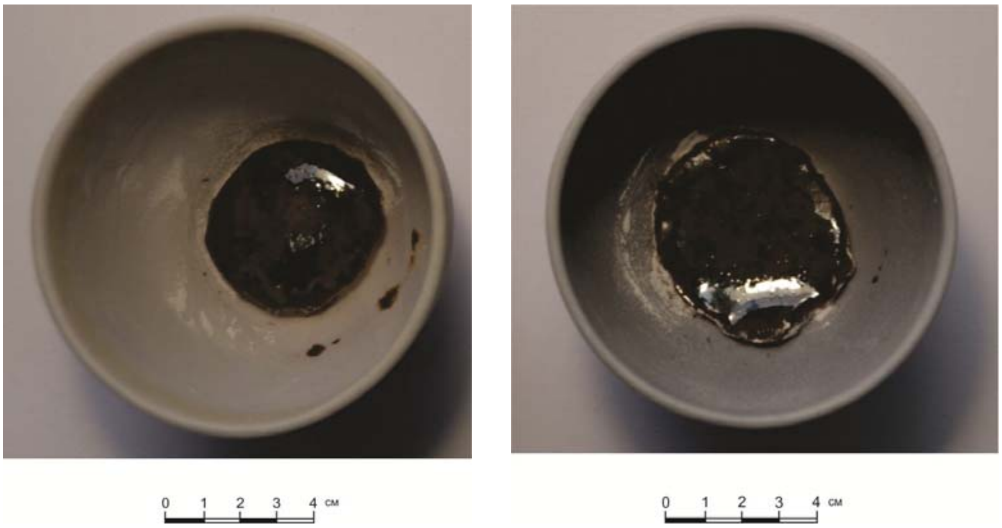

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Figure 8 – Photographic illustration of the burned Basalt mandelstein product (a) and massive basalt (b) of the Koktas suite (D1-2kt); Temperature and chronological parameters of calcination of rock material under high-temperature heating conditions – 1400 °C (5', 50', 30'), samples K-20-16-1 and 2

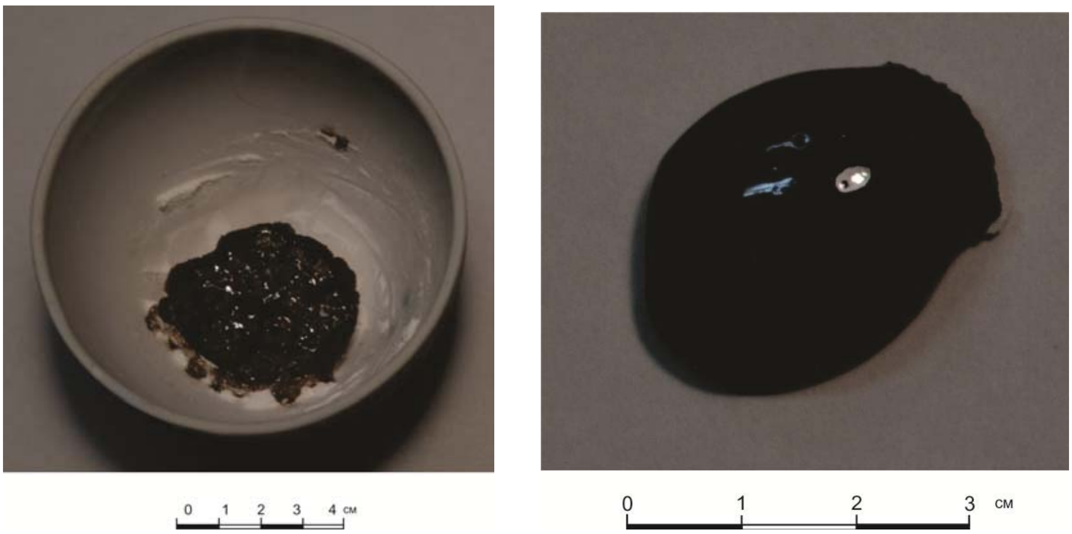

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Figure 9 – Photographic illustration of the burned Basalt mandelstein product (a) and massive basalt (b) of the Koktas suite (D1-2kt); Temperature and chronological parameters of calcination of rock material under high-temperature heating conditions of 1450° C (5', 50', 30'), sample K-20-16-1, 2

complete melting. The change in the external appearance of the powder mixture after burning confirms the fact of melting of the sample in the selected heating mode. The color of these ingots is brown with a yellowish-green tinge. Dark speckles are seen in the background depicting fan-shaped and needle-like shapes of the surface pattern. The hardness of these formations is not inferior to the ingot from the basalt sample (K-14-15-2). At the high-temperature burning of the considered basalt samples, their mass (individually) decreased by ~ 9% (6.3% in the range of 20–800 °C and 3% within 880–1400 °C). The first stage of weight loss is caused by the release of H_2O, OH, and CO_2 into the atmosphere, and as a result of the destruction of hydromica (5.9%), chlorite (13.1%), goethite (1.1%) and calcite (6, 8%) – sample K-20-16-1, as well as hydromica (5.0%), goethite (1.1%) and calcite (7.4%) - sample K-20-16-2. The second - the high-temperature stage of decreasing the mass of the test sample (by ~ 2.7%) is conditioned to the degassing of porous basalt spaces.

The obtained basalt ingots, according to their physical and mechanical properties, entirely correspond to the quality of the melt, which is required for the production of fiber products. If we take into account that the dimensions of the produced basalt thread (fiber length and diameter) do not have particularly severe limitations in the production of mineral wool, the proposed stone material can be used as an intermediate raw material (basalt ingots) for the output of heat-insulating products (table 2).

Table 2 – Data for the gabbro-basaltic series viscosity (Pa·s) calculation by the method of E.S. Persikov [9, 10]

Sample number and name of the rock	Temperature range, °C					
	1100	1250	1300	1350	1400	1450
K-3-15, gabbro	1012	184,2	112,5	70,06	45,65	30,2
K-13-15, gabbro-amphibolite	479,9	94,2	58,6	37,6	24,1	16,7
K-14-15, basalt	837	19,5	12,8	8,6	5,9	4,2
K-16-15, andesibasalt	1151	208	126	79	50,7	35,6
K-17-15, Basalt tuff	2431310	205918	100404	51171	27152	14947
K-20-16-1, Basalt mandelstein	325591	33614	17362	9340	5214	3011
K-20-16-2, massive basalt	1236	221	133,9	83,7	53,8	35,5

Basaltic rocks with the required characteristics regarding chemical composition and properties of raw materials can be used to produce basalt fibers with specified attributes for strength, chemical, and thermal stability, specific electrical insulating properties [9, 10]. Analysis of available data showed that many regions of Kazakhstan contain deposits of rocks of the gabbro-basalt group, suitable for the production of mineral wool. The reserves of raw materials are tens of millions of tons.

Technologies for the production of basalt fibers, especially continuous fibers, are quite new, they have many principal features associated with the raw material. The peculiarities of basalts are that the primary energy inputs for their preparation for the production of fibers met by nature. Each type of basalt requires its particular technological regimes and parameters of fiber production. The processes of melting, homogenization, and preparation of the melt occurred at high temperatures of 1400 °C and associated with particular energy inputs. Technologies for processing basalt fibers in materials and products are not associated with high-temperature processes and are produced using "cold technologies." Thus, the technologies for the production of basalt wool are essentially energy-saving and environmentally friendly. A problematic issue of modern technology is the efficiency of the melting units. According to [11, 12], the average energy consumption for melting basalt in Russia is 15 MJ/kg. For comparison, in Europe, this value is less than 10 MJ/kg, in some prospectuses of Rockwool company indicated the megawatt-hour per ton of melt or 3,6 MJ/kg. The determining factor in the production of mineral wool is the energy consumption, which should be taken into account in assessing the economic efficiency of production.

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МИНЕРАЛДЫ МАҚТА ӨНДІРІСІ ҮШІН ГАББРО-БАЗАЛЬТ ТОБЫНА ЖАТАТЫН ТАУ ЖЫНЫСТАРЫН ЖОҒАРЫ ТЕМПЕРАТУРАЛЫҚ СЫНАҚТАН ӨТКІЗУ

Аннотация. Қазақстан аймағындағы габбро-базальт тобына жататын тау жыныстарын зерттеру нәтижелері баяндалған: 1) 20–1000 ^{o}C температура аралығындағы заттық құрамы мен термиялық жағдайы; 2) LNT 04/16 құрылғысында 40–1500 ^{o}C аралығында жоғары температуралық сынақтар жүргізілген. Жұмыс барысында Қазақстанның түрлі аймақтарынан минералдық және химиялық құрамы әртүрлі тау жыныстары іріктеліп алынды. Шикізат көзі ретінде Орталық, Оңтүстік және Солүстік Қазақстаннан үлгілер алынды. Габбро-базальт тобындағы тау жыныстарының тұтқырлығы Э. С. Персиков әдісімен анықталды. Берік, химиялық және термиялық тұрақты, электр оқшаулығыш қасиеттері бар базальт талшықтарын өндіру үшін шикізат ретінде аталып өткен қасиеттері бар базальтты қолдану қажет. Мәліметтерді талдау барысында Қазақстан аумағында минералды мақта өндірісіне жарамды габбро-базальт тобындағы тау жыныстарының шоғыры бар екені анықталды. Шикізат қоры ондаған миллион тоннаны құрайды. Базальт талшықтарын өндіру технологиясы бастапқы шикізаттын қасиеттеріне негізделген. Базальттың әртүрі үшін өзіндік талшық өндіру параметрлері мен режимдері қажет. Балқу, гомогенизация және балқытпаны дайындау үрдістері жоғары температураларда 1400 ^{o}C жүзеге асады және қуат шығынын қажет етеді. Базальт талшықтарының технологиясы жоғары температуралық процестермен байланысты емес және «салқын технология» негізінде жүзеге асады. Сондықтан базальт мақталарын өндіру технологиясы қуат үнемдеуші және экологиялық таза болып табылады.

Түйін сөздер: минералды мақта мен талшық, базальт, диабаз, габбро, амфиболит, геология-петрологиялық сипаттама, химиялық, термиялық, рентгендідифракометриялық микрозондты талдау.

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ВЫСОКОТЕМПЕРАТУРНЫЕ ИСПЫТАНИЯ ПОРОД ГАББРО-БАЗАЛЬТОВОЙ ГРУППЫ КАЗАХСТАНА ДЛЯ ПРОИЗВОДСТВА МИНЕРАЛЬНОЙ ВАТЫ

Аннотация. Изложены результаты изучения пород габбро-базальтовой группы на территории Казахстана: 1) их вещественного состава и термического поведения в диапазоне температур 20–1000 °С; 2) осуществлены высокотемпературные испытания на установке LNT 04/16 в режимах нагревания от 40 до 1500 °С. Для этого были отобраны породы из разных регионов Казахстана, различающиеся химическим наполнением и степенью совершенства их минеральных включений в соответствии с существующими стандартами. В качестве возможного сырья использовались образцы горных пород вблизи крупных экономических центров в Северном, Центральном и Южном Казахстане. Были осуществлены расчеты вязкости пород габбро-базальтового ряда по методике Э. С. Персикова. Для производства базальтовых волокон с заданными характеристиками по прочности, химической и термической стойкости и определенными электроизолирующими свойствами, предлагается использовать базальтовые породы с характеристиками по химическому составу и свойствам сырья. Анализ имеющихся данных показал, что во многих регионах Казахстана имеются залежи пород габбро-базальтовой группы, пригодных для производства минеральной ваты, запасы которых составляют многие десятки миллионов тонн. Технологии производства базальтовых волокон, особенно непрерывных волокон, достаточно новы, имеют ряд принципиальных особенностей, связанных с исходным сырьем. Для каждого типа базальтов необходимы свои особые технологические режимы и параметры производства волокон. Процессы плавления, гомогенизации и подготовки расплава проходят при высоких температурах 1400 °С и связаны с определенными энергозатратами. Технологии переработки базальтовых волокон в материалы и изделия не связаны с высокотемпературными процессами и производятся с применением «холодных технологий». Таким образом, производство базальтовой ваты являются по сути энергосберегающими и экологически чистыми.

Ключевые слова: минеральная вата и волокна, базальт, диабаз, габбро, амфиболит, геолого-петрологические характеристики, химический, термический, рентгенодифрактометрический и микрозондовый анализы.

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