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Research of heat conductivity of quartz material

In the article the results of a study of heat conductivity and thermal resistance of quartz-containing materials were presented. The object of the study was a quartz mineral from the Aktas deposit, located in the Ulytau district of the Karaganda region. The initial size was a piece of quartz mineral measuring 5–10 mm, which was disassembled mechanically. To prepare the samples under study, quartz powder 0.2 mm thick, crushed by the electric pulse method, was used. Electropulse technology is one of the methods based on the influence of Yutkin, accompanied by the formation of a specially formed high-voltage pulsed electrical discharge inside a volume of liquid. The pulse discharge frequency of the electrohydropulse installation for grinding the mineral to the required fraction was f = 3 Hz, the pulse capacitor capacitance C = 0.4 μF, the pulse discharge voltage U = 18–37 kV. The samples under study were made in the following dimensions: width 100 mm, length 100 mm, height 25 mm. To evaluate the thermophysical properties of manufactured samples in a stationary mode, the ITP-MG4 "100" installation was used, which determines the heat conductivity and thermal resistance of materials for thermal insulation of industrial equipment and pipelines in accordance with GOST 7076, based on the thermoelectric method, and GOST 30256, based on the thermal probe method. As a result of the study, a graph of the temperature dependence of heat conductivity and thermal resistance of quartz-containing materials was obtained. Based on the results obtained, it was established that the thermophysical parameters of the sample containing quartz are lower compared to the sample consisting of cement.

Keywords: heat conductivity, thermal resistance, quartz powder, electrical pulse, granulometric composition.

Introduction

Currently, there is a large number of building structures that provides the required level of thermal protection of buildings [1]. One of the most important problems in the production of building materials is the reduction of energy costs and material intensity in the production of products and structures. Particular attention is paid to obtaining materials for construction based on local raw materials. One such raw material is quartz [2].

Natural quartz is a crystalline mineral composed of silicon dioxide. It has a number of physical, chemical and optical characteristics and is an important industrial raw material. Due to its high quality and affordable price, it is widely used in various industries such as ceramics, chemistry, metallurgy and electronics. At the same time, quartz powder is also widely used in construction. For the production of many building materials, a sufficient amount of natural components is added to its composition. The quartz mineral ranks 7th in terms of hardness on the Mohs scale. Its hardness and strength have an important role in production. This feature makes it effective for businesses that require high-strength materials. It is added to cement, concrete and other building materials in the construction sector. In this case, quartz powder is used as a filler in the construction industry, combining the volume and strength of the mixture with other materials. Mixtures of these raw materials in large volumes increase the strength of various materials by about 100 times. Thanks to the quartz powder added to the composition, these materials become durable and elastic, which makes them resistant to abrasion and atmospheric influences.

Fine fractions of quartz powder are used for the production of dry construction mixtures [3]. They are used in concrete restoration, for laying stoves and fireplaces, floor screed equipment, waterproofing structures, as well as for interior and exterior decoration. The high physical and chemical properties of quartz sand find their application in a wide variety of industrial fields. Moreover, its use in a specific industry directly depends on the type of quartz and its physical characteristics [4]. At the same time, quartz powder is widely used to improve the strength, weather resistance, texture and appearance of paints, coatings and sealants.

Kazakhstan is one of the states known for its mineral resources. Owing to the country's vast reserves, it is able to meet the global demand for quartz powder in various industries. Quartz is a multifaceted mineral used in a variety of industries, both industrially and in everyday life. Kazakhstan continues to make a significant contribution to meeting the needs of industries around the world with its quartz powder exporters to the global market. Quartz powder remains an indispensable raw material for strengthening structures in construction or demonstrating its importance in our daily lives and in various fields.

As a versatile material, quartz powder has many properties that make it popular in various industries. The heatphysical properties of materials play an important role in various fields such as engineering, physics, chemistry and technology. Understanding these properties makes it possible to improve heat transfer processes and develop more efficient materials at different temperatures. Heat conductivity is also an important value taken into account when planning thermal insulation work [5]. Selecting the right material is very important; it determines how much thermal energy you will have to expend to heat the finished room.

Experimental methods for determining λ values are based on measuring the amount of heat passing through a test sample of normalized dimensions in a certain time at a given temperature difference [6]. Reduced heat conductivity reduces the rate of heat transfer between the internal and external environments. Thus, the use of the studied materials, especially thermal conductivity measurements, potentially improves the thermal performance of the building envelope. It also helps to reduce energy costs spent on air conditioning over many years of operation of the structure [7].

Analysis of heat transfer through building elements is of great importance in solving construction problems, such as energy efficient design, thermal load of structures, thermal comfort planning [8–10].

The purpose of the work is an experimental research of heat conductivity and thermal resistance of quartz-containing materials.

To achieve this aim, it is necessary to solve the following tasks:

– production of quartz-based samples processed using the electric pulse method;

– investigation of the heat physical properties of quartz-containing materials.

Experimental

The object of the research was the quartz mineral of the Aktas deposit (Fig. 1). Since quartz mineral is used in construction in different sizes, powdered raw materials were obtained using the electric pulse method [11]. This technology is one of the most environmentally efficient methods of crushing natural ores and household waste [12–14]. Since the raw material has large dimensions (70–150 mm) before processing by the electric pulse method, a piece of quartz was mechanically crushed to 5–10 mm so that it could fit into the working cell of the installation (Fig. 2).

The production of quartz powder by the electric pulse method was carried out in the following parameters: frequency of pulse discharges $f = 3$ Hz; pulse capacitor capacity $C = 0.4$ μF; pulse discharge voltage $U = 18–37$ kV [15]. The granulometric composition of quartz powder obtained by the electric pulse method was determined by the sieve method according to GOST 12536-2014 “Methods for laboratory determination of granulometric (grain) and microaggregate composition”.

In construction, quartz powder 0.2 mm in size is used in the manufacture of various products (plaster materials, replacing a certain amount of cement with quartz flour, in the production of concrete and ceramic materials). The resulting powder was passed through standard sieves with a mesh opening diameter of 0.2 mm (Fig. 3).

To assess the heatphysical properties of a granular sample, the ITP-MG4 “100” device was used, which allows determining the heat conductivity and thermal resistance of materials for thermal insulation of industrial equipment and pipelines in stationary mode according to GOST 7076 and by the heating probe method according to GOST 30256, based on the thermoelectric method (Fig. 4).

Figure 1. Piece of quartz from Aktas mine

Figure 2. Pieces of quartz 5–10 mm

Figure 3. Powder size 0.2 mm quartz

Figure 4. Heat conductivity meter ITP-MG4 100

Various samples were prepared to investigate the heat conductivity of quartz-containing samples:

Sample 1 is a mixture of 50 % quartz and 50 % Portland cement of the M400 brand;

Sample 2 is a mixture of 70 % quartz and 30 % Portland cement of the M400 brand.

The samples had a width of 100 mm, a length of 100 mm and a height of 25 mm (Fig. 5). When developing mixtures, the amount of water was the same for each sample: 100 ml.

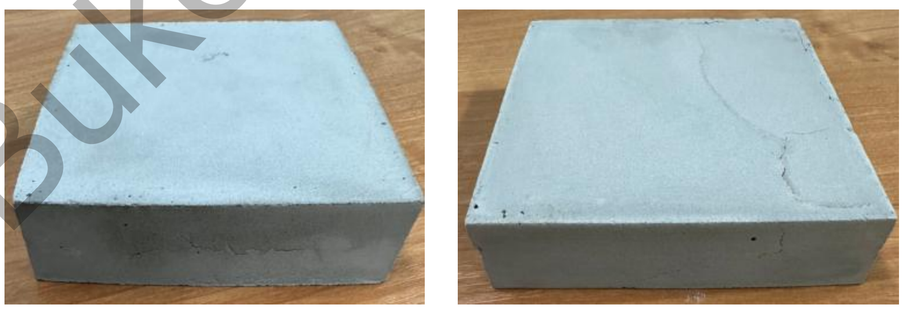

Figure 5. Investigated specimens

To study the thermal conductivity of the samples at a constant temperature of the cooler in the device (15 °C), the temperature of the heater was changed from 25 °C to 45 °C. The graph (Fig. 6 and 7) below shows the temperature dependence of the thermal conductivity and thermal resistance of the samples according to the experimental results. The heatphysical parameters of the studied samples were compared with those of a sample consisting of 100 % cement. *1* — a sample consisting of 100 % cement in the figures; *2* — a sample consisting of 50 % quartz powder; *3* — A sample consisting of 70 % quartz powder.

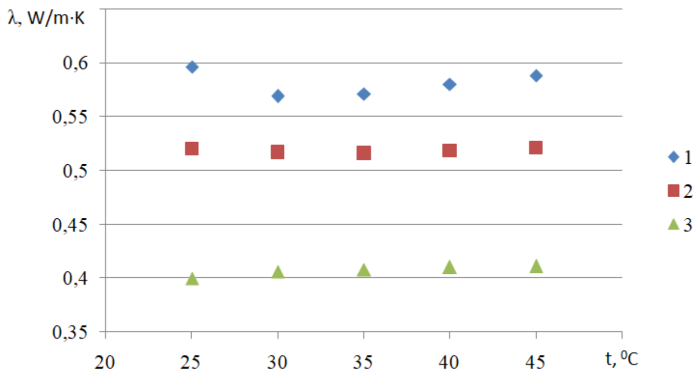

Figure 6. Temperature-dependent change in heat conductivity of samples

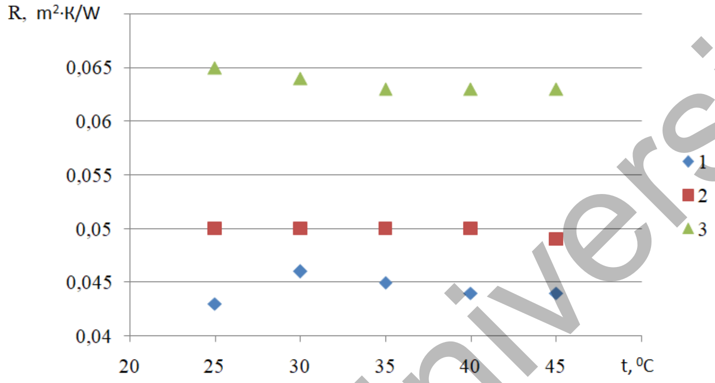

Figure 7. Temperature-dependent change in the thermal resistance of samples

It follows from the experimental data that the thermal conductivity of acid-free Portland cement in the considered temperature ranges was λ = 0.569–0.596 W/m·K. The thermal conductivity of the quartz-containing material varied in the following intervals: λ = 0.516–0.521 W/m·K for a mixture of Portland cement of the 50 % M400 brand and λ = 0.400–0.411 W/m·K for a mixture of Portland cement of the 50 % M400 brand; λ = 0.400–0.411 W/m·K. from the data given, it follows that thermal conductivity of cement it has been established that composite samples have low thermal conductivity. These results prove that a certain amount of cement can be replaced with quartz powder [16].

Conclusions

The heat conductivity and thermal resistance of quartz-containing samples were investigated in scientific work. When quartz was added to cement in the range of 50–70 %, construction raw materials with favorable heatphysical parameters were obtained.

It was found that the thermal resistance of a material containing 70 % quartz is higher than the temperature dependence of the thermal resistance of the samples. The thermal resistance of a material is a parameter of the thermal conductivity resistance. The results obtained indicate the effectiveness of using quartz as a heat-insulating material in construction.

From the above fraction, it was found that the addition of quartz powder to the material has a low thermal conductivity. The experimental data can be used in the development of materials containing natural minerals.

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References

1 Мальцев А.В. Теплопроводность увлажненного материала наружных ограждающих конструкций при промерзании и ее влияние на тепловые потери / А.В. Мальцев, М.Н. Карев // Новый университет. Сер. Технические науки. — 2015. — № 3–4 (37–38). — С. 83–86.

2 Митина Н.А. Строительные материалы на основе активированного кварцевого песка / Н.А. Митина, В.И. Верещагин // Изв. Том. политех. ун-та. — 2009. — Т. 314, № 3. — С. 1–4.

3 Лотов В.А. Нанодисперсные системы в технологии строительных материалов и изделий / В.А. Лотов // Изв. Том. политех. ун-та. — 2007. — Т. 311, № 3. — С. 84–88.

4 Хавкин Л.М. Технология силикатного кирпича / Л.М. Хавкин. — М.: Стройиздат, 1982. — 384 с.

5 Исаченко В.П. Теплопередача / В.П. Исаченко, В.А. Осипова, А.С. Сукомел. — М.: Энергия, 1975. — 488 с.

6 Баранова А.А. Теплопроводность и термическое сопротивление неавтоклавного пенобетона на основе микрокремнезёма / А.А. Баранова // Изв. вузов. Инвестиции. Строительство. Недвижимость. — 2020. — Т. 10. — № 3. — С. 370–377.

7 Толстова Ю.И. Основы строительной теплофизики / Ю.И. Толстова, Р.Н. Шумилов. — Екатеринбург: Изд-во Урал. ун-та, 2014. — 104 с.

8 Demirboga R. The effects of expanded perlite aggregate, silica fume and fly ash on the thermal conductivity of lightweight concrete / R. Demirboga, R. Gül // Cement Concr. — 2003. — Res. 33. — P. 723–727.

9 Khan M. Factors affecting the thermal properties of concrete and applicability of its prediction models / M. Khan // Building and Environment. — 2002. — Vol. 37. — P. 607–614.

10 Kim K. An experimental study on thermal conductivity of concrete / K. Kim, S. Jeon, J. Kim, S. Yang // Cement Concr. — 2003. — Res. 33. — P. 363–371.

11 Bulkairova G. A research of the effect of an underwater electric explosion on the selectivity of destruction of quartz raw materials / G. Bulkairova, B. Nussupbekov, M. Bolatbekova, A. Khassenov, U. Nussupbekov, D. Karabekova // Eastern-European Journal of Enterprise Technologies. — 2023. — 3(12(123)). — P. 30–37.

12 Юткин Л.А. Электрогидравлический эффект и его применение в промышленности / Л.А. Юткин. — Л.: Машиностроение, 1986. — 253 с.

13 Khassenov A.K. Electro-pulse method for obtaining raw materials for subsequent flotation enrichment of ore / A.K. Khassenov, M. Stoev, D.Zh. Karabekova, G.A. Bulkairova, D.A. Nurbalayeva // Bulletin of the University of Karaganda–Physics. — 2021. — Vol. 1. — Iss. 101. — P. 57–62.

14 Курец В.И. Электроразрывные технологии обработки и разрушения материалов / В.И. Курец, М.А. Соловьев, А.И. Жучков, А.В. Барская. — Томск: Том. политех. ун-т, 2012. — 272 с.

15 Khassenov A.K. Investigation of the influences of pulsed electrical discharges on the grinding of quartz raw materials / A.K. Khassenov, D.Zh. Karabekova, B.R. Nussupbekov, G.A. Bulkairova, A.S. Kudussov, G.K. Alpyssova, M.M. Bolatbekova // Bulletin of the University of Karaganda–Physics. — 2023. — Vol. 2. – Iss. 110. — P. 93–99.

16 Пустовгар А.П. Исследование возможности частичного замещения портландцемента кварцевой мукой SILVERBOND в составе тампонажных материалов / А.П. Пустовгар, А.Ю. Абрамова, Н.Е. Ерёмина, С.Р. Ганиев // Строительство нефтяных и газовых скважин на суше и на море. — 2019. — № 8. — С. 27–36.

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Кварц құрамды материалдың жылу өткізгіштігін зерттеу

Мақалада кварц құрамды материалдардың жылу өткізгіштігі мен термиялық кедергісін зерттеу нәтижелері келтірілген. Зерттеу нысаны ретінде Ұлытау облысының Ұлытау ауданында орналасқан Ақтас кен орнынан алынған кварц минералы алынды. Бастапқы өлшемі ретінде механикалық әдіпен бөлшектенген 5-10 мм болатын кварц минералының кесегі пайдаланылды. Зерттелетін үлгілерді дайындау үшін электроимпульс әдісімен ұнтақталған 0,2 мм кварц ұнтағы қолданылды. Электроимпульстік технология Юткиннің әсеріне негізделген, сұйық көлемінің ішінде арнайы қалыптасқан жоғары вольтты импульстік электр разрядының пайда болуымен жүретін әдістің бірі. Минералды қажетті фракцияға ұнтақтау үшін электрогидроимпульстік қондырғының импульстік разряд жиілігі $f = 3$ Гц, импульстік конденсатордың сыйымдылығы $C = 0{,}4$ мкФ, импульстік разрядтардың кернеуі $U = 18$–37 кВ болды. Зерттелетін үлгілер келесі өлшемде дайындалды: ені 100 мм, ұзындығы 100 мм, биіктігі 25 мм. Дайындалған үлгілердің жылу физикалық қасиетін зерттеу үшін стационарлық режимде термоэлектрлік әдіске негізделген МЕМСТ 7076 мемлекеттік стандарттарға сәйкес және жылу зонд әдіске негізделген МЕМСТ 30256 мемлекеттік стандарттарға сәйкес өнеркәсіптік жабдықтар мен құбырларды жылу оқшаулауға арналған материалдардың жылу өткізгіштігін және жылу кедергісін анықтайтын ИТП-МГ4 «100» қондырғысы қолданылды. Зерттеу нәтижесінде кварц құрамды материалдардың жылу өткізгіштігі мен термиялық кедергісінің температураға тәуелділік графигі алынды. Алынған нәтижелер негізінде құрамында кварц бар үлгінің жылу физикалық көрсеткіштерінің цементтен тұратын үлгімен салыстырғанда төмен екендігі анықталды.

Кілт сөздер: жылу өткізгіштік, термиялық кедергі, кварц ұнтағы, электримпульс, гранулометриялық құрам.

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Исследование теплопроводности кварцевого материала

В статье представлены результаты исследования теплопроводности и термического сопротивления кварцсодержащих образцов. Объект исследования — природный минерал кварцит месторождения Актас, расположенного в Улытауском районе Карагандинской области. В качестве первоначального размера использовался кусок кварцевого минерала размером 5–10 мм, который был измельчен механическим способом. Для изготовления образцов применялся кварцевый песок диаметром 0,2 мм, измельченный электроимпульсным методом. Электроимпульсная технология является одним из методов, основанных на эффекте Юткина, сопровождающегося образованием специально сформированного высоковольтного импульсного электрического разряда в объеме жидкости. Частота импульсного разряда электрогидроимпульсной установки для измельчения минерала до нужной фракции составляла $f = 3$ Гц, емкость импульсного конденсатора $C = 0{,}4$ мкФ, напряжение импульсных разрядов $U = 18$–37 кВ. Исследуемые образцы были изготовлены в следующих размерах: ширина 100 мм, длина 100 мм, высота 25 мм. Для оценки теплофизических свойств изготовленных образцов в стационарном режиме применена установка ИТП-МГ4 «100», определяющая теплопроводность и тепловое сопротивление материалов для теплоизоляции промышленного оборудования и трубопроводов в соответствии с ГОСТ 7076, основанным на термоэлектрическом методе, и ГОСТ 30256, основанным на тепловом зондовом методе. В результате исследования получен график температурной зависимости теплопроводности и термического сопротивления кварцсодержащих материалов. На основании полученных результатов установлено, что теплофизические показатели образца, содержащего кварц, ниже, по сравнению с образцом, состоящим из цемента.

Ключевые слова: теплопроводность, термическое сопротивление, кварцевый порошок, электроимпульс, гранулометрический состав.

References

1 Maltsev, A.V., & Karev, M.N. (2015). Teploprovodnost uvlazhnennogo materiala naruzhnykh ograzhdaiushchikh konstruktsii pri promerzanii i ee vliianie na teplovye poteri [Thermal conductivity of the moistened material of external enclosing structures during freezing and its effect on heat losses]. *Novyi universitet. Seriia Tekhnicheskie nauki — A new university. Series: Technical sciences*, 3–4 (37-38), 83–86 [in Russian].

2 Mitina, N.A., & Vereshchagin, V.I. (2009). Stroitelnye materialy na osnove aktivirovannogo kvartsevogo peska [Building materials based on activated quartz sand]. *Izvestiia Tomskogo politekhnicheskogo universiteta — Proceedings of Tomsk Polytechnic University*, *314*(3), 1–4 [in Russian].

3 Lotov, V.A. (2007). Nanodispersnye sistemy v tekhnologii stroitelnykh materialov i izdelii [Nanodisperse systems in the technology of building materials and materials]. *Izvestiia Tomskogo politekhnicheskogo universiteta — Proceedings of Tomsk Polytechnic University*, *311*(3), 84–88 [in Russian].

4 Khavkin, L.M. (1982). *Tekhnologiia silikatnogo kirpicha [Technology of silicate bricks]*. Moscow: Stroiizdat [in Russian].

5 Isachenko, V.P., Osipova, V.A. & Sukomel, A.S. (1975). Teploperedacha [Heat Transfer]. Moscow: Energiia [in Russian].

6 Baranova, A.A. (2020). Teploprovodnost i termicheskoe soprotivlenie neavtoklavnogo penobetona na osnove mikrokremnezema [Thermal conductivity and thermal correction of non-autoclaved foam concrete based on silica. Izvestiia vuzov. *Investitsii. Stroitelstvo. Nedvizhimost — News of universities. Investment. Construction. Realty, 10*(3), 370–377 [in Russian].

7 Tolstova, Yu.I. (2014). *Osnovy stroitelnoi teplofiziki [Fundamentals of building thermophysics]*. Ekaterinburg: Izdatelstvo Uralskogo universiteta [in Russian].

8 Demirboga, R., & Gül, R. (2003). The effects of expanded perlite aggregate, silica fume and fly ash on the thermal conductivity of lightweight concrete. *Cement Concr.*, 33, 723–727.

9 Khan, M. (2002). Factors affecting the thermal properties of concrete and applicability of its prediction models. *Building and Environment*, *37*, 607–614.

10 Kim, K., Jeon, S., Kim, J., & Yang, S. (2003). An experimental study on thermal conductivity of concrete. *Cement Concr, Res*., 33, 363–371.

11 Bulkairova, G., Nussupbekov, B., Bolatbekova, M., Khassenov A., Nussupbekov, U., & Karabekova, D.Zh. (2023) A research of the effect of an underwater electric explosion on the selectivity of destruction of quartz raw materials. *Eastern-European Journal of Enterprise Technologies*, 3(12(123)), 30–37.

12 Yutkin, L.A. (1986). *Elektrogidpavlicheckii effekt i ego primenenie v promyshlennosti [Electrohydraulic effect and its application in industry]*. Leningrad: Mashinostroenie [in Russian].

13 Khassenov, A.K., Stoev, M., Karabekova, D.Zh., Bulkairova, G.A., & Nurbalayeva, D.A. (2021). Electro-pulse method for obtaining raw materials for subsequent flotation enrichment of ore. *Bulletin of the University of Karaganda–Physics*, *1*(101), 57–62.

14 Kurets, V.I., Solovyov, M.A., Zhuchkov, A.I., & Barskaya, A.V. (2012). *Elektrorazryvnye tekhnologii obrabotki i razrusheniia materialov [Electrical fracturing technologies for processing and destruction of materials]*. Tomsk: Tomskii politekhnicheskii universitet [in Russian].

15 Khassenov, A.K., Karabekova, D.Zh., Nussupbekov, B.R., Bulkairova, G.A., Kudussov, A.S., Alpyssova, G.K., & Bolatbekova, M.M. (2023). Investigation of the influences of pulsed electrical discharges on the grinding of quartz raw materials. *Bulletin of the University Of Karaganda–Physics, 2*(110), 93–99.

16 Pustovgar, A.P., Abramova, A.Yu., Eremina, N.E., & Ganiev, S.R. (2019). Issledovanie vozmozhnosti chastichnogo zameshcheniia portlandtsementa kvartsevoi mukoi SILVERBOND v sostave tamponazhnykh materialov [Investigation of the possibility of partial substitution of Portland cement with quartz flour SILVERBOND as part of grouting materials]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more — Construction of oil and gas wells on land and at sea*, 8, 27–36 [in Russian].

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