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The effect of enrichment on quartz sand properties

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Abstract. The technological properties of quartz sand (without and after enrichment) by methods of emission spectral analysis, petrography, and X-ray phase analysis are investigated. The studied sand is a waste after extraction of titanium-containing components from raw materials. It is shown that the enrichment of quartz sand expands the field of its application. It has been established that quartz sand can be used as a filler of heavy, light, fine-grained, cellular and silicate concrete, mortar, and the preparation of dry construction mixtures. Also, sand can be claimed as a raw material component to produce ceramic tiles, porcelain stoneware, glazed ceramic products, wall ceramics, as well as proppants. Hydraulic enrichment leads to a decrease in the content of clay particles in the sand, which allows it to be used also for the construction of bases and coatings of roads and airfields. The integrated use of raw materials and waste allows solving the problem of creating non-waste and environmentally friendly technologies, which ensures the saving of natural raw materials, and on the other hand, allows it to be disposed of, improving the environmental situation.

1. Introduction

The quality of quartz sand used in various fields of industry is regulated by notations in accordance with the technical specifications. These requirements and quartz sand properties determine the technology and the necessity of enrichment. The final cost of the sand is determined by the method and degree of enrichment. The utilization of high-quality sands is limited by their high cost.

The most common impurities in the sands are associated with the presence of heavy and/or magnetic minerals (ilmenite, rutile, magnetite, hematite, goethite, etc.); weathered or layered minerals that absorbed iron (feldspar, mica); surface films covering quartz grains; clay; inclusions in the structure of quartz, etc. The enrichment of sand from clay impurities can be carried out by the dry method (air classification) or by the wet method (the hydraulic one). Dry enrichment methods, as a rule, are inferior in quality to sand enriched by the hydraulic method, especially on sands of complex mineral composition and sands with a high clay content.

Fine quartz sands are used, as a rule, in concrete production as a filler, in mortar production, in the production of ceramic materials as a non-shrinkage component, in the production of molding sands. The aim of this project is to determine the application of quartz sand in its natural form and to consider the effect of enrichment on the properties and applications.

Given the current state of consumption of natural raw materials, there is no doubt that the utilization and involvement of by-products in production is of value [1–3]. There are clay deposits in Tyumen region (Russia). Combined with extraction of titanium-containing components, the quartz waste comes into being [4]. It is important to find applications for this waste. It can be used in the construction industry [5–6]. The aim of this project is to study the possibility of using quartz waste of

raw materials to produce dry building mixtures, proppants, cement, silicate brick, glass and glassware, fine ceramics and as molding sand [7–13]. Quartz sands are used to obtain cristobalite as a composite filler, coating material, surface finishing medium and structural ceramics [14].

2. Experimental procedure

The chemical composition of quartz sand was determined by emission spectral analysis with inductively coupled plasma using Optima 4300 DV optical emission spectrometer (Perkin Elmer, USA). The grain composition, modulus of sand fineness and real density using the pycnometric method were determined in accordance with [15]. Petrographic studies of refractory products were carried out in reflected light by optical microscope Polam R-311[15, 16].

3. Results and discussion

Unenriched sand visually contains large flinders more than 5 mm in size. When sifted, these pieces are easily destroyed, and the entire sample of sand passes through a No. 5 sieve. Therefore, the unenriched sand does not contain particles larger than 5 mm. The clay content in pieces of unenriched sand is 5% (for fine and very fine sands it should not exceed 1%, whereas in the enriched sand there are no such lumps. The clay-aggregated sand sample sare failed upon enrichment in water.

Table 1. Grain composition of quartz sand.

Quartz sand type	Size modulus	Fraction content (wt.%, mm)							
		2.5	1.25	0.63	0.315	0.16	0.1	0.004	0
unenriched	0.44	3.50	2.00	1.50	1.20	12.10	67.47	11.97	0.26
enriched	0.11	–	0.03	0.11	0.22	10.44	75.5	13.63	0.07

The full residue on sieve No. 063 for unenriched sand is 7.0% as well as for enriched one is 0.14 %, which corresponds to a group of very fine sands. The decrease in the sand particles content of more than 0.63 mm in the enriched sample is associated with the destruction of clay-aggregated sand particles.

Particle content less than 0.16 mm for unenriched sand is 79.7% and for enriched one is 89.13%, therefore, sands under discussion are very fine sands and can be used as fillers. The class of studied sands corresponds to II according to [17].

The chemical composition of the sand is given in Table 2. After enrichment, the content of Al_2O_3, Fe_2O_3, TiO_2 in sand decreases. It is associated with the removal of the clay part. The silica content in this case, as one would expect, increases.

Table 2. Chemical composition of quartz sand.

Quartz sand type	Weight content (%)									
	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Mn_2O_3	Na_2O	SiO_2	TiO_2
unenriched	4.274	0.239	0.014	1.179	2.075	0.107	0.0437	0.679	88.181	1.122
enriched	3.876	0.209	0.015	0.813	2.061	0.070	0.037	0.675	89.741	0.829

The content of dusty and clay particles, determined by the method of elutriation, in non-enriched sand is 5.6%, in enriched one is 0.46%, which corresponds to the requirements of [17] (up to 10%).

By the presence of organic impurities, unenriched and enriched sands are suitable for use in concrete and mortars, since the liquid above the unenriched and enriched sand samples is slightly colored. The optical density of the liquid over the unenriched sand is 0.044 and over the enriched one is 0.040 in comparison with a reference solution of 0.6–0.68.

As a result of petrographic studies of enriched sand, it was found that the studied samples are represented by alluvial sands and sandstones with a SiO_2 content of 95–98%, from milky white to

beige and red (sandstone) in color with admixtures of muscovite and biotite. Mica (muscovite and biotite) are concentrated mainly in fine sand fractions of 0.16–0.315 (3–6 and 1–3 wt. %, respectively) and 0.315–0.63 (3–5 and 2–4 wt. %, respectively). Here, white and transparent quartz is concentrated in well-rounded grains with a high degree of crystallization. The 0.63–1.25 mm fraction is represented by a mixture of white milk and partially transparent, well crystallized quartz and sandstone aggregates from red to dark gray, consisting of cemented small (0.05–0.1 mm) rounded grains forms. Cement is weak, non-hydrated, aggregates are not durable. Sandstone content is 10–13 wt. % There are individual particles of biotite fractions of less than 0.315 mm. A fraction of more than 1.25–2.5 mm consists entirely of fragile agglomerates of sandstone.

According to the X-ray diffraction data, unenriched quartz sand contains up to 5% montmorilonite, ~ 77% quartz, ~ 18% feldspar and muscovite in total. The mineral composition of enriched quartz sand is as follows: quartz is about 81%, as well as feldspar and muscovite in the amount of up to 19%.

The real density of the unreached sand sample was determined by the pycnometric method (Table 3). The voidness of enriched sand is increased, and the bulk density is decreased due to leaching offine clay fractions filling the voids between large sand particles. An increase in the true density of sand also indicates the leaching of less dense clay particles.

Table 3. Physical properties of quartz sand.

Quartz sand type	Real density $(kg \cdot m^{-3})$	Bulk density$(kg \cdot m^{-3})$	Voidness (%)	Absolute humidity (%)
unenriched	2646.6	1338.90	49.4	0.5
enriched	2723.0	1275.18	53.3	0.1

The reactivity of unenriched and enriched sand is 37.66 and 37.24 $mmol \cdot L^{-1}$, respectively. It is in accordance with [17] (not more than 50 $mmol \cdot L^{-1}$). Consequently, the sands contain a permissible amount of amorphous varieties of silicon dioxide, soluble in alkalis (chalcedon, opal, flint, etc.) and sand can be used as a filler for concrete, as it is resistant to the chemical effects of alkali cement.

The content in unenriched and enriched sand of sulfide sulfur is 0.0043 and 0.0065%, respectively. The content of sulfate sulfur is 0.015% and 0.01%. According to [17], sulfur, sulfides, except pyrite (marcasite, pyrrhotite, etc.) and sulfates (gypsum, anhydrite, etc.) in terms of SO_3 should be not more than 1.0%, pyrite in terms of SO_3 – not more than 4% by weight). Therefore, both samples of sand are suitable for use as a filler for concrete and mortars.

For the suitability of quartz sand in road construction, the content of clay particles was determined by the swelling method according to [17]. An increase in the material volume in the sand was not observed. Therefore, the sands under study can be recommended for road construction.

To determine the suitability of sand as proppants, [18, 19] were used. According to the chemical composition (Table 2) in terms of MgO and Al_2O_3 content, these sands do not meet the requirements for either magnesia-quartz or aluminosilicate proppants. The minimum size of proppants according to [18, 19] corresponds to a size of 0.212 mm. The studied sands in the bulk consist of particles smaller than 0.16 mm (80–90%). Therefore, the sands under investigation cannot be used as proppants due to the discrepancy in grain and chemical compositions. But the studied sands can be recommended as silica-containing raw materials to produce aluminosilicate or magnesian proppants if necessary.

To determine the suitability of unenriched sand as molding one according to [20] the content of silicon dioxide should be at least 90.0%.With careful enrichment of the sand it is possible to bring this indicator to 90%,in the elutriated sand sample the content of silicon dioxide is 89.741%. The content of harmful impurities Fe_2O_3 decreases in the enriched sand sample from 1.179% to 0.813%. According to [20], the Fe_2O_3 content should be no more than 1%. Therefore, enriched sand according to this indicator meets the requirements. The content of alkaline and alkaline earth ($Na_2O + K_2O + + MgO + CaO$) according to [20] should be no more than 2%. In enriched sand it is 3.015%, in unenriched one is 3.1%. Therefore, the studied sands cannot be used as molding sand even after enrichment due to the

high content of alkaline and alkaline earth oxides. Alkaline oxides are found in the sand in the form of feldspar and muscovite. Other enrichment methods are needed to remove such minerals.

To utilize studied sands in Portland cement production as a silicate additive, it does not require enrichment, since the clay component contained in unenriched sand will partially play the role of an alumina additive.

The use of quartz sand in the production of ceramic tile is possible due to the content in the sand of up to 19% of feldspars with muscovite. It is known that the fluxes are introduced into the body composition, which are used as feldspars and hydromica (in our case, muscovite). The sand enrichment in this case reduces the content of iron oxide, which allows the use of sand under investigation in the porcelain production.

4. Conclusion

The unenriched quartz sand belongs to the group of very fine sands (class II) with a particle size modulus of 0.44. The particle content of less than 0.16 mm is 79.7%, and particles of more than 0.063 mm are 7.03%. The sand does not contain large inclusions of more than 5 mm; it belongs to sands with a clay content of 5% in lumps and 5.6% of dust and clay particles. Sand is characterized by a low content of organic impurities, a bulk density of 1338.9 kg·m^{-3}, a real density of 2646.6 kg·m^{-3} and a voidness of 49.4%. It has a low reactivity of 37.24 mmol·L^{-1}. The content of sulfur compounds is negligible.

Enriched quartz sand belongs to the group of very fine sands (class II) with a particle size modulus of 0.11, a particle content of less than 0.16 mm is 89.2%, and particles of more than 0.063 mm are 0.14%. Sand does not contain large inclusions more than 5 mm. There is no clay in the lumps in the sand, and dusty and clay particles are practically absent (0.46%). Sand is characterized by a low content of organic impurities, a bulk density of 1275.2 kg·m^{-3}, a real density of 2723 kg·m^{-3} and a voidness of 53.3%. It has a low reactivity of 37.66 mmol·L^{-1}.

Thus, the studied sands can be recommended as a filler for heavy, light, fine-grained, cellular and silicate concrete, mortar, and preparation of dry mixes. Sand after enrichment can also be recommended for the construction of bases and coatings for roads and airfields.

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