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CONCRETE ON QUARTZITE AGGREGATES

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In the post-war period, Ukraine will need a large number of aggregates to repair and rebuild destroyed and damaged objects of transport infrastructure, including roads, airfields, and parking lots. To expand the raw material base of such construction, in addition to traditional high-quality aggregates from crushed granite, quartz sand and manufactured sand, it is advisable to use some types of waste and secondary products from various industries. They must meet the basic requirements for density, strength, frost resistance. These include a by-product of iron ore mining, quartzite. The use of quartzites as aggregates for cement concretes has certain difficulties due to their characteristics. This is reflected, first of all, on the strength of the concretes in which they are included. In this article, the features of the influence of quartzite aggregates on the strength of cement concretes are considered. Studies that have been carried out on mixtures of different mobility have shown that dusty particles, which are part of quartzite, have a positive effect on the structure of concrete.

Keywords: dusty particles, separate technology, compressive strength, flexural strength, contact zone, particle size distribution.

Introduction

In the aftermath of the war, Ukraine will require a substantial quantity of aggregates to restore and reconstruct damaged transportation infrastructure, encompassing roads, airfields, and transportation facilities. To diversify the pool of construction resources, alongside the conventional high-grade aggregates derived from crushed granite, quartz sand, and manufactured sand, it is prudent to consider the utilization of specific waste and secondary materials from various industries. These materials need to conform to fundamental criteria concerning density, strength, and resistance to freezing. Among them is a by-product of iron ore mining – quartzite. However, the incorporation of quartzites as aggregates in cement concretes presents certain challenges due to their inherent characteristics.

The strength results of concrete using quartzite aggregates compared to traditional aggregates show that the values of compressive strength obtained in 28 days were smaller than the reference concrete, but not significantly so, with the maximum difference being 21.88 % and the minimum difference being only 10.42 %. Additionally, the results of the shape index (length x thickness ratio) of the coarse aggregate showed that values lower than the limit established by local standards resulted in higher compression strengths in the concretes, while values higher than 3.0 obtained compressive strengths lower in the concretes (Collares, 2012).

Testing the interfacial bond strength made by (Hong et.al, 2014) revealed that as the aggregate surface roughness increased, the tensile and shear bond strengths at the interface also increased and stabilized. Among the tested materials, quartzite exhibited the highest tensile and shear bond strengths at the interface, followed by limestone and basalt. Furthermore, the statistical analysis characterized the roughness of crushed basalt and quartzite aggregate as following normal and log-normal distributions, respectively.

Shareef et al (Shareef et al, 2019) explored quartzite from Indian quarry as a substitute for coarse aggregate in concrete. Experimental investigations were conducted on plain cement concrete, with coarse granite aggregate replaced by quartzite up to 100 %. Test results showed that optimal proportion of quartzite replacement for coarse aggregate was 20 %, it was observed that the compressive strength increased, reaching 53.2 N/mm2 at 20 % replacement and 48.8 N/mm2 at 100 % replacement.

Quality tests revealed minimal distinctions between the unweathered quartzite aggregates from Ghana (Adom-Asamoah et al, 2014) and the sound granite aggregates. However, the partially weathered aggregates demonstrated lower quality, with notably high water absorption rates. The 28-day compressive strength of concrete containing partially weathered quartzite averaged 86 % of that with granite aggregates. It can be concluded that unless the degree of weathering is significantly high, partially weathered quartzite can serve as coarse aggregates in low-stress concrete applications.

According to a study (Tufali et al, 2017) on the effect of elevated temperatures on the mechanical properties of limestone, quartzite, and granite concrete, the type of coarse aggregate used has a significant impact on the mechanical properties of concrete. At 28 days and no elevated temperature exposure, granite and quartzite concrete, respectively, yielded 41 % and 72 % higher compressive strength, 27 % and 62 % higher tensile strength, and 36 % and 66 % higher elastic modulus in comparison to limestone concrete. This indicates that properties of aggregate substantially impact the mechanical properties of concrete.

Quartzites of the Poltava Mining and Processing Plant (MPP) mainly have an average density of 2900 ... 2950 kg / m3. The true density of the rock is 2970…3000 kg/m3. These quartzites were formed from granites and amphibolites (Otchet, 1982). Quartzites have a very imperfect cleavage, and therefore, when crushing quartzites, special quality crushed stone is obtained. The negative property of this rubble is that it contains a large number of flaky particles. However, the main feature of quartzite aggregates is that the surface of the particles is heavily contaminated. Moreover, the standard method for estimating the amount of dusty particles using elutriation shows that their amount does not exceed 1 %. However, if the filler is thoroughly washed, then in fact the total amount of dusty particles in it can reach 2 ... 3.5 %. Quartzites of the Poltava MPP are highly resistant to ferruginous and silicate decay. Their frost resistance corresponds to the F300 brand. Quartzite crushed stone has a strength grade of M1200. It is highly resistant to wear and impact loads. However, the high contamination of the surface of quartzite aggregates is the main obstacle to their wide application in cement concretes and mortars. First of all, this applies to heavy concretes and mortars for transport construction.

The purpose of this study is to evaluate the effect of quartzite aggregates on the strength of cement concretes.

Materials and methods

For the manufacture of cement mortars and concretes, quartzite sand and quartz sand were used. Quartz sand has a uniform granulometry. The largest partial residues were found on three sieves: on a sieve of 2.5 mm – 25 %, on a sieve of 1.25 mm – 30 % and on a sieve of 0.63 mm – 20 %. The fineness modulus of this sand Mf = 3.1. For comparison, were used quartz sand with fineness modulus Mf = 1.35. The largest partial residues in this sand were on sieves: on a sieve of 0.315 mm – 40 % and on a sieve of 0.16 m – 35 %. Interestingly, the number of particles that passed through a sieve with a diameter of 0.16 mm, and which can be attributed to dusty particles, was: in quartzite sand – 8 ... 10 %, and in quartz sand – 13 ... 15 %.

Granite crushed stone and quartzite crushed stone with a fraction of 5-10 mm were also used. The brand for the strength of crushed stone was the same – M1200.

Mortar and concrete mixtures were made from these materials. Samples-beams 40x40x160 mm in size were prepared from these mixtures, which hardened under normal conditions. After a certain hardening time, the flexural and compressive strength of the specimens was determined by the standard method.

Results and discussions

Since the main disadvantage of quartzite aggregates is the high contamination of their surface, when producing concrete it is advisable to use separate technology for preparing concrete mixtures. The experiment showed that contamination of the surface of quartzite crushed stone affects, first of all, on the flexural strength of concrete (Table 1).

Table 1

Strength of concrete using different methods of preparing concrete mixtures

Rubble	Technology	W/C	Strength of aged concrete, MPa					
			3 days		7 days		28 days	
			Rts	Rcs	Rts	Rcs	Rts	Rcs
Granite	plain	0,45	2,25	15,1	3,16	21,7	4,21	31,2
Quartzite	plain	0,45	1,78	14,2	2,62	20,1	3,57	28,6
Granite	separate	0,46	2,11	15,1	2,90	21,2	4,06	30,8
Quartzite	separate	0,46	2,41	16,1	3,21	22,9	4,58	32,5

It is known that the tensile strength of concrete in bending depends on the quality of the contact zone between the cement stone and the aggregate. If the aggregate has a contaminated surface, such as quartzite, then this zone will be characterized by higher porosity, low-strength new formations such as portlandite, and higher water content (Scrivener, 2004; Decker, 2018). Thus, the contact zone is the weakest point in the structure of concrete, where microcracks mainly form, especially under the influence of aggressive environments. In this case, the roughness of the aggregate surface has a great influence on the strength due to the so-called wall effect. In accordance with it, the density of the material on a flat smooth surface is much less than in the bulk or on a rough surface (Elsharief, 2003). The deterioration of the quality of the contact zone primarily affects the tensile strength of concrete during bending (Elsharief, 2003; Grushko et al, 1973). As can be seen from the data in Table 1, the tensile strength of concrete on quartzite is 16...21 % less than that of concrete on granite. Compressive strength is also lower by 6...8 %.

It is known that with separate technology for preparing concrete mixtures, crushed stone and a small amount of water are first fed into the mixer. First, crushed stone is mixed with water, and then the remaining aggregates and the rest of the water are fed into the mixer. After this, final mixing of the mixture is performed. It is obvious that the use of separate technology for pure granite crushed stone does not affect the compressive strength of concrete. But the tensile strength of concrete decreases by 5...8 %.

This decrease in strength is probably due to the fact that since the surface of crushed granite is not contaminated, additional treatment of such a surface with water led to the formation of a liquid film on it and a slowdown in the processes taking place in the contact zone and transition zone. In addition, it is necessary to take into account that with such processing the thickness of the transition zone increases. This zone includes part of the contact zone and part of the cement stone in volume. This zone is the least strong in the system "crushed stone surface – contact zone – transition zone – volumetric part of cement stone." From the point of view of colloidal chemistry, the transition zone is similar to the diffuse part of the electrical double layer, which is formed near a solid surface in the presence of a liquid phase. The strength of electrostatic interaction in this zone also possibly decreases in proportion to the square of the distance (according to Coulomb's law). Therefore, as the thickness of the transition zone increases, its strength decreases. Then it is logical to assume that destruction in concrete will occur not along the contact zone, but along the transition zone(Olginskiy, 1994).

For concrete on quartzite crushed stone, on the contrary, the use of separate technology leads to an increase in tensile strength by 22…35 %. At the same time, compressive strength also increases by 13 %. This can be explained by the fact that with separate technology, contamination is washed away from the surface of quartzite crushed stone, which leads to its cleaning. In this case, the contact zone between the cement stone and quartzite becomes denser and stronger. This leads to an increase in the strength of concrete.

Interestingly, surface treatment of quartzite crushed stone resulted in its surface being cleared of dusty particles, and this made it possible to ensure direct contact between the surface of the crushed stone and the cement paste. This improves the contact area. In addition, on the surface of quartzite crushed stone the thickness of the water film is less than on a clean granite surface, because part of the water during processing forms a suspension with dust particles. This suspension passes into the volume of cement paste and mortar part. At the same time, sawdust particles play the role of a microfiller and compact the micro- and mesostructure of concrete. Therefore, the tensile strength of concrete on quartzite crushed stone during bending increases and exceeds the strength of concrete on granite crushed stone.

The hypothetical assumptions made can be confirmed by studying the properties of cement mortars on quartzite sand.

Table 2

Strength of mortars on different sands

№	Sand	W/C	Amount of cone immersion, cm	Rts, 28, MPa	Rcs 28, MPa
1	Quartz	0,54	2,5	4,10	17,8
2	Quartzite	0,42	3,0	5,51	30,5
3	Quartz	0.62	5,0	3,45	14,5
4	Quartzite	0,48	4,5	4,91	22,2
5	Quartz	0,70	8,5	3,71	15,0
6	Quartzite	0,54	9,0	4,50	24,3

The mobility of mortar mixtures was determined by the amount of immersion of a standard cone into the mortar mixture. In order for the compared mortar mixtures to have the same mobility, during their manufacture the water-cement ratio was changed within the range of 0.42 ... 0.54 (for mixtures on quartzite sands) and 0.54-0.7 (for mixtures on natural quartz sands). The amount of immersion of the cone was also varied from 2...3 cm to 8...9 cm. The cement consumption in both types of mortar mixtures was the same.

All cement mortars based on quartzite sand have a strength significantly higher than mortars based on quartz sand (Table 2). Thus, the tensile strength of cement mortars on quartzite sand from the least mobile mixtures (compositions 1 and 2) is higher than the strength of mortars on quartz sand by 35 % (5.51 and 4.1 MPa, respectively). Moreover, the difference in the compressive strength of the solutions is even greater: 70 % (30.5 and 17.8 MPa, respectively).

An increase of the mobility of mortar mixtures leads to an increase in the difference of the tensile strength of mortars (compositions 3 and 4). This difference is 42 % (4.91 and 3.45 MPa, respectively), although the absolute strength values decrease in accordance with the law of the water-cement ratio. At the same time, the difference of the compressive strength of mortars on quartzite sand in comparison with the strength of mortars on quartz sand decreases and amounts to 52 % (22.2 and 14.5 MPa, respectively).

A further increase of the mobility of mortar mixtures to a cone immersion to level of 8...9 cm leads to a decrease in the difference of tensile strength between the mortar mixtures (compositions 5 and 6). It is 22 % (4.5 and 3.71 MPa, respectively). At the same time, the difference of compressive strength of mortars on quartzite and quartz sand increases slightly and reaches 60 % (24.3 and 15 MPa, respectively). It is interesting to note that as the mobility of mortar mixtures increases, and therefore the amount of water in the compositions increases, the absolute values of the strength of the mortars do not decrease.

Table 3

Average density of cement mortars at different mobility of the mixture

№	Sand	Average density, кg/м3, immersion of the cone		
		2…3 cm	4.5…5 cm	8…9 cm
1	Quartz	2260	2300	2340
2	Quartzite	2550	2510	2480

It is obvious that this nature of the change in the strength of mortars is due to the peculiarity of the granulometric composition of quartzite sand and the shape of its grains. The crushed grains it contains have an angular shape and contain a large number of particles larger than 0.63 mm. In this case, up to 25 % of the sand mass is located on a 2.5 mm sieve. In accordance with the standards of European countries, such a fraction of 2.5-5 mm should be classified as fine crushed stone. In fact, quartzite sand mortar mixtures should be classified as fine-grained concrete with a basal structure. According to I. Grushko's (Grushko, 1989) classification, in this structure the grains of fine crushed stone (in our case, this is a fraction of 2.5-5 mm) seem to "float" in the mortar part. All these factors allow quartzite sand to create a rigid frame that can withstand both compressive and tensile loads. This leads to an overall increase in the strength of the solution.

In addition, it is likely that with increasing mobility of mortar mixtures on quartzite sand, the average density of mortars should decrease. The conducted studies confirmed this (Table 3).

If we compare these changes of the average density of mortars on different sands with the change in the mobility of mortar mixtures, it becomes obvious that with minimal mobility of mortar mixtures (2-3 cm), the average density of mortars on quartz sands is minimal. In this case, the average density of mortars on quartzite sands, on the contrary, is maximum. In this case, the maximum difference in strength between the mortars on these sands is observed. The most likely explanation for this could be the following.

1. Quartz sand contains a large amount of dust particles, which have a high water requirement. Accordingly, they must bind a large amount of mixing water. If there is little water in the mortar mixture (the mobility of mortar mixtures is low), then it is all bound with cement and sand. However, it is not enough to fill all the voids of the structure that is being formed and at the same time ensure high mobility of the mortar mixture. In this case, voids and air pores may form in the structure of the dissolved mixture and mortar. It is also not enough for water to be adsorbed on all dust particles. As the amount of water increases, the voids are filled, which helps to increase the mobility of the mortar mixture due to better sliding of particles one by one over films of water. This leads to an increase of average density, to an optimal value, and, accordingly, an increase the strength. In this case, dust particles play the role of a microfiller and compact the micro- and mesostructure of the mortar. This also explains that the strength of mortars on quartz sand not only does not decrease with increasing mobility of the mortar mixture, but, on the contrary, increases. A further increase in the amount of water should lead to a decrease in the density and strength of the mortars. But in the considered range of water flow rates, its quantity is not enough for its excess to lead to negative consequences for the mortar mixture, for example, to delamination or decompaction.

2. In mortar mixtures based on quartzite sand, the amount of dust particles is obviously optimal in order to bind the required amount of mixing water and fill the gaps in the volume of the solution. The thickness of the water films on all particles is probably close to optimal in terms of density, but not sufficient to cause wedging or delamination. Therefore, in this case, when the amount of mixing water increases, its amount is no longer optimal. Its quantity becomes excessive, which leads to decompression of the structure and the average density of mortars decreases. However, a decrease in strength in such solutions does not occur with an increase in W/C from 0.48 to 0.54, possibly because after 21 days, not only

the appearance of new formations as a result of the interaction of cement with water, but also the formation of hydrosilicates in as a result of the pozzolanic reaction of reactive dispersed quartzite particles in an aqueous environment with calcium hydroxide. Since this reaction occurs slowly under normal conditions, its consequences can only be assessed on the 28th day of hardening and after that.

Thus, with increasing mobility of mortar mixtures, the average density of mortars on quartz sands increases, and on quartzite sands it decreases. This leads to a decrease in the difference of the strength of mortars on different sands. The decrease in absolute strength values for both types of sands can be explained by an increase of the amount of mixing water in their compositions, which is consistent with the law of the water-cement ratio.

An increase the strength of concrete with increasing W/C due to the presence of a certain amount of microfiller in the composition is shown in work (El Mira, 2015). Data have been obtained that the introduction of finely ground quartz powder into the concrete mixture leads to a decrease of water absorption and a decrease the porosity of concrete (Popek, 2017).

Increasing the cohesion and homogeneity of concrete mixtures containing crushing screenings, as well as mixtures in which there is a sufficient amount of dust particles in the fine aggregate, is indicated in the book (Dvorkin, 2017). It also shows that in this case there is no need to introduce microsilica or metakaolin into the mixture. At the same time, from such concrete mixtures it is possible to obtain high-strength concrete of classes B60...B70, despite the absence of coarse aggregate in their compositions.

From a practical point of view, two important negative features of mortar mixtures based on quartzite sand should be emphasized. Despite the high strength values of mortars on quartzite sand, mortar mixtures on it, as well as on all artificial sands (screenings), have poor workability. This is due to the peculiarities of the granulometry of these sands, in which large particles predominate, and also, first of all, to the angular shape of their grains.

Another feature of all artificial sands is their low water requirement and low water holding capacity. The latter feature is often the cause of water separation in mortar and concrete mixtures, which include artificial sand. In our case, despite these features, water separation was not observed in the studied range of mobility of mortar mixtures on quartzite sands. Perhaps this is due to the presence on the surface of sand particles of a tightly bound film consisting of dusty particles. This film cannot be separated by standard tests such as dry sieving or elutriation.

Therefore, the most effective way to use quartzite sands is to mix them with natural quartz sand. The granulometry of quartz sand should differ from the granulometry of quartzite sands by an increased number of particles less than 0.63 mm. But in each specific case, the optimal ratio between quartz and quartzite sands must be determined experimentally.

Conclusions

Studies have shown that the contaminated surface of quartzite degrades the quality of the contact zone "hardened cement paste – aggregate". This negatively affects the strength of concrete, primarily tensile strength. The use of separate technology for preparing concrete mixtures eliminates this disadvantage. The presence of dusty particles on the surface and in the volume of quartzite sand grains helps to increase the cohesiveness of concrete and mortar mixtures, increases the density and strength of mortars and concrete, depending on their mobility in a certain range of water-cement ratio.

References

Collares, E., Júnior, I., Motta, L. (2012). Evaluation of the aggregate produced from wastes of quartzite mining sites to use in concrete. Soils and Rocks: An International Journal of Geotechnical and Geoenvironmental Engineering, São Paulo, 35(3), 251-266. DOI: 10.28927/SR.353251

Hong, L., Gu, X., Lin, F. (2014). Influence of aggregate surface roughness on mechanical properties of interface and concrete. Construction and Building Materials, 65, 338-349. https://doi.org/10.1016/j.conbuildmat.2014.04.131

Shareef, U., Raju, S. G., Cheela, V. S. (2019). Study on the utilisation of quartzite as replacement for coarse aggregate in concrete. International Journal of Environment and Waste Management, 24(1), 107-115. https://doi.org/10.1504/IJEWM.2019.100664

Adom-Asamoah, M., Tuffour, Y. A., Afrifa, R. O., Kankam, C. K. (2014). Strength characteristics of hand-quarried partially-weathered quartzite aggregates in concrete. American Journal of Civil Engineering, 2(5), 134-142. doi: 10.11648/j.ajce.20140205.12

Tufail, M., Shahzada, K., Gencturk, B.(2017). Effect of Elevated Temperature on Mechanical Properties of Limestone, Quartzite and Granite Concrete. Int J Concr Struct Mater 11, 17–28. https://doi.org/10.1007/s40069-016-0175-2

Otchet Dnepropetrovskogo NIISP. (1982). Izuchenie otxodov Poltavskogo GOKa, kak materiala dlya doroznogo stroitelstva

Scrivener, K., Crumbie, A., Laugesen, P. (2004). The interfacial transition zone (ITZ) between cement paste and aggregate in concrete. Interface science, 12(4), 411-421. https://doi.org/10.1023/B:INTS.0000042339.92990.4c

Decker, M., Bauer, D., Hilbig, H., Heinz, D. (2018). Salt Migration in the Concrete Interfacial Transition Zone, Investigations with Laser Ablation-ICP-MS, 12-14 September 2018, Bundesrepublik Deutschland.

Elsharief, A., Cohen, M., Olek, J. (2003). Influence of aggregate size, water cement ratio and age on the microstructure of the interfacial transition zone. Cement and Concrete Research, 33(11), p. 1837-1849. https://doi.org/10.1016/S0008-8846(03)00205-9

Grushko I. (1973). Prochnost betonov na rastyazenie. Kharkov, HGU,-1973.

Olginskiy A.(1994). Ozenka i regulirovanie struktury zony kontakta zementnogo kamny s mineralami zapolnitely (Doctoral dissertation). Available from ProQuest Dissertations & Theses database. (UMI No. 327681) http://www.disslib.org/otsenka-y-rehulyrovanye-struktury-zony-kontakta-tsementnoho-kamnja-s-myneralamy.html

Grushko I., Kondratieva I., Tolmachov S.(1989) Vlianie pylevidnyx fracziy peska na porovuu strukturu betona. Stroitelnye materially i construkzii,3, 37-38

El Mira, A., Nehmea, S. (2015). Porosity of self-compacting concrete. Procedia Engineering, 123, 145 – 152. https://doi.org/10.1016/j.proeng.2015.10.071

Popek, M., Sadowski, L. (2017). Selected physical properties of concrete modified using mineral powders. Procedia Engineering, 172, 891 – 896 . https://doi.org/10.1016/j.proeng.2017.02.097

Dvorkín, L., Babich, Ê., Zhitkovs'kiy, V., Bordyuzhenko, O., Kochkar'ov, D., Fílípchuk, S., Kovalik, Í., Koval'chuk, T., Skripnik, M. (2017). Visokomítsní shvidkotverdnuchí betoni ta fíbrobetoni. Rívne, NUVGP, 2017..

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БЕТОНИ НА КВАРЦИТОВИХ ЗАПОВНЮВАЧАХ

У період після війни, Україні знадобиться велика кількість заповнювачів для ремонту та відновлення зруйнованих та пошкоджених об'єктів транспортної інфраструктури. Для розширення сировинної бази доцільно використовувати деякі види вторинних продуктів різних виробництв, наприклад побічний продукт видобутку залізняку – кварцит. Застосування таких заповнювачів у цементних бетонах має певні труднощі через їх особливості, що відбивається, насамперед на міцності одержуваних бетонів. Тому в цій статті розглядаються особливості впливу кварцитових наповнювачів на міцність піщаних цементних бетонів. Дослідження, проведені на сумішах різної рухливості показали позитивний вплив пилуватих частинок на структуру бетонів.. Дослідження показали, що забруднена поверхня кварцитів погіршує якість зони контакту "цементний камінь-заповнювач" та негативно впливає на міцність бетонів, насамперед при згині. Застосування роздільної технології виготовлення бетонних сумішей дозволяє усунути цей недолік. Показано, що розчини на кварцитовому піску мають значно вищу міцність, ніж на кварцовому піску, різниця в міцності при згині становить до 35 %. Підвищення рухливості розчинів збільшує різницю в міцності при згині, що обумовлено гранулометричним складом кварцитового піску та формою його зерен. Розчини на кварцитовому піску є дрібнозернистими бетонами з жорстким каркасом, здатним сприймати навантаження стиску і розтягу. Встановлено, що із збільшенням рухливості середня густина розчинів на кварцових пісках збільшується, а на кварцитових – зменшується, що викликає зменшення різниці у міцності розчинів. Показано, що незважаючи на високі значення міцності розчинів на кварцитовому піску, розчинні суміші на його основі характеризуються незадовільною зручноукладальністю. Це пов'язано як з особливістю гранулометрії цих пісків, в якій переважають великі частинки, так і, в першу чергу, з неправильною формою їх зерен. Наявність пилуватих частинок на поверхні та в обсязі зерен піску підвищує зв'язність, щільність та міцність розчинів залежно від рухливості розчинних сумішей у певному діапазоні водоцементного відношення.

Ключові слова: кварцитові заповнювачі, пилуваті частки, роздільна технологія, міцність при стиску, міцність при згині, зона контакту, гранулометричний склад.