

Conference Paper

Prospects of Replacing Natural Sand with Crushed Rock Fines in the Composition of Fine-Grained Concrete

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Abstract

The expediency of replacing natural quartz Sands, whose reserves are gradually exhausted, by rock screenings as part of fine-grained concretes is shown. In particular, the characteristics of granite and quartzite crushing screenings in comparison with quartz river sand are presented, as well as the results of studying the strength and abrasion of the fine-grained concrete obtained. To exclude the effect of the grain composition on the properties of concrete, aggregate samples were pre-fractionated, and the conditions for producing concrete (cement consumption, water-cement ratio, concrete mix mobility) were the same. It was found that quartz sand having rounded grains with a relatively smooth surface promotes the formation of dense particle packing and increases the strength of fine-grained concrete by 9-14%, but at the same time reduces the abrasion of similar standard samples by 20-30% compared to screenings crushing of granite and quartzite. The maximum abrasion resistance showed concrete containing quartzite screening. Quartzite – metamorphic (metasomatic) dense rock crushing which produces angular particles with a rough surface. The absence of dense packaging reduces the compressive strength of concrete samples containing quartzite aggregate compared to quartz sand. At abrasion of similar samples in a thin layer the resistance to sliding of filler particles one relative to another increases. Therefore, when choosing crushed rock fines instead of natural quartz Sands, it is important to consider the purpose of the designed fine-grained concrete.

Keywords: crushing screenings, quartz sand, granite, quartzite, fine-grained concrete, strength, abrasion

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1. Introduction

The present-day ecological situation calls for a comprehensive approach to be applied to address the issues related to mining and processing of mineral resources; however, this challenge seems far from resolved. Putting forward companies excavating for nonmetalliferous constructional materials as an example, there are crushed stone fines generated as by-product of rock crushing, yielding appr. 80 - 90 million tons a year, while their utilization rate is reported to not exceed 20–30% [1]. Unutilized stone fines

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become waste to be discharged to dumps in the landfills. The companies have to pay taxes for using the land; and the expenditures incurred for the generation and storage of waste increase the input cost of the main product (crushed stone) by 15–30% [2]. At the same time, there are many research findings demonstrating that crushed rock waste, in particular, granite, is a valuable resource of minerals to be used as the raw materials for producing non-annealed constructional composites [3–8]. Of special interest are the applications of crushed rock wastes to produce fine concretes, which are used widely in making paving flag, repair compositions, floor leveling compounds, and other constructional materials. Most commonly, natural quartz sands are used as aggregate for fine concretes. Considering the creeping depletion of the available sand and gravel deposits, the prospects of shortage of naturally occurring sand may be in the offing. Because the cost of natural sand is three to four times greater than the cost of crushed-rock sands, the urgent need for the man-made materials substituting for natural sand is beyond question [9–11]. It should be noted that, for fine concretes, the characteristics of sand (such as fineness and density of particles, surface roughness, size composition, voidage) play a more important role and have a greater impact on the structural and technological properties of the manufactured composites as compared to the most commonly used concretes containing coarse aggregate.

2. Initial Materials and Research Methods Characteristic

The present report summarizes the results of a comparative study investigating the crushed granite fines from Kurmansky deposit and the sand of quartzites from Gora Khrustalnaya deposits as compared with quartz river sand from Luzhskoye deposit, in order to study the effect of the type of fine aggregate on the compressive strength and abrasion resistance characteristics of fine concretes.

The initial fine aggregate samples were previously dried and then their structural and technological properties were determined against the requirements of the normative documents. The experimental results demonstrated that the natural quartz sand corresponded to the standard requirements and had increased coarseness with a fineness modulus of 3.1. The artificial sands were found not to be corresponding to the standard requirements: the crushed quartzite fines did not show the required aggregate weight retained on sieve No. 0.63; and the crushed granite fines did not have the required aggregate weight retained on sieve No 0.16 (see Table 1).

To rule out the effect of sand's grain composition on the properties of fine concrete, the fractionated aggregate samples were selected. In order to do that, an initial aggregate sample was first scattered over the standard sieves, and then model mixture

was prepared to be composed of the various fractions. The quantity proportion of the fractions was chosen from the ideal gradation curve calculated following the Fuller's method [10]. The properties of obtained fractionated fine aggregate samples are shown in Table 2.

TABLE 1: Structural and technological properties of original fine aggregates.

Parameter	Quartz sand	Quartzite fines	Crushed granite fines	Standard Requirements GOST 8736-2014, GOST 31424-2010
Bulk density, kg/m ³	1504	1440	1635	Not normalized
True density, кг/м ³	2513	2622	2638	Not normalized
Cumulative percentage weight retained on sieve No 0.63, %	73.03	98.43	36.86	65-75 – increased sand 45-65 – coarse sand 30-45 – medium sand
Sieve residue No. 0.16, %	0.21	0.22	31.39	Not greater than 5 %
Fineness Modulus (M_f)	3.1	3.3	2.1	2.5-3.5 – coarse 2.0-2.5 – medium
Grain shape	rounded	angular	angular	Not normalized

TABLE 2: Fractionated fine aggregate characterization.

Parameter	Quartz sand	Quartzite fines	Crushed granite fines	Standard Requirements GOST 8736-2014, GOST 31424-2010
Bulk density, kg/m ³	1534	1512	1655	Not standardized
Cumulative percentage weight retained on sieve No 0.63, %	50.2			from 45 to 65
Fineness Modulus (M_f)	2.8			from 2.5 to 3.5 – coarse sand
Grain shape	rounded	angular	angular	Not standardized

The composition of fine concrete was selected as guided by the “Recommendations on selecting compositions of heavyweight and fine concretes according to GOST 27006-86” (Approved on 01.01.1990 by the Scientific Research Institute of Concrete and Reinforced Concrete GUP NII ZHB). The initial nominally calculated composition of concrete was tested using trial batches in order to specify and correct workability of the concrete compositions. The calculated and the actual compositions of concrete mixes using the different fractionated (model) aggregates are shown in Tables 3 and 4.

TABLE 3: Calculated concrete mix composition.

Concrete mix composition, kg/m ³			Concrete mix density, kg/m ³	Water/cement ratio	Concrete Grade
Cement	Aggregate	Water			
296	1670	234	2200	0.8	B 15

TABLE 4: Actual concrete mix compositions.

Aggregate	Concrete mix composition, kg/m ³			Concrete mix density, kg/m ³	Water/cement ratio
	Cement, kg/m ³	Aggregate, kg/m ³	Water, kg/m ³		
Natural quartz sand	301	1713	240	2223	
Quartzite fines	291	1650	233	2185	0.8
Crushed granite fines	290	1653	232	2196	

If workability of the trial batch did not correspond to the targeted value, then the initial composition of concrete was corrected. Samples in the form of cubes of 10-cm edge were formed out of the concrete mixes. The samples had been stored in wet air conditions and tested as they had become 28 days old. The solidified concrete samples were tested for their compressive strength according to GOST 10180-2012 “Concretes. Methods for determining strength using check samples”; and abrasion resistance of the samples was determined using a laboratory abrasive disk LKI –3M according to GOST 13087-81 “Concretes. Methods for determining abrasion resistance.”

3. Experiment Results and Discussion

Experimental tests have demonstrated that fine concrete samples made with fractionated natural quartz sand exhibit the maximum strength of 27.1 MPa. The strength of concrete based on the fractionated granite fines has been found to be less by 8.9%; and the fractionated quartzite fines-based concrete was smaller still, by 13.7 %. It was found that the ability of fine concrete to resist abrasion also depends on the type of aggregate; but the result was quite the opposite: the greatest abrasion resistance was revealed in the quartzite fines-based samples ($G_{av}=0.98 \text{ g/cm}^2$), then comes the value of abrasion resistance of the crushed granite fines-based concrete ($G_{cp}=1.18 \text{ g/cm}^2$), and the least value was demonstrated by the samples based on the natural quartz sand (see Table 5).

It has been found that, with similar compositions of the sands and with the equal water-to-cement ratios, the mechanical properties of fine concretes depend heavily

TABLE 5: Characterization of fine concretes based on different aggregates.

Aggregate	Concrete density, kg/m ³	Compressive strength, MPa	Abrasion resistance index g/cm ²
Quartz river sand	2211	27.1	1.27
Quartzite fines	2202	23.4	0.98
Crushed granite fines	2190	24.7	1.18

on the type of aggregates. Quartz river sand is sedimentary loose rock material of grains having rounded shape and smooth surface, which facilitate close packing of the grains and contribute to the increased strength of concrete under compression. Quartzites are a metamorphic (metasomatic) dense rock material, which, when crushed, form acute-angled, rough-surfaced particles. The lack of close packing of grains reduces the compressive strength of samples as compared to the behavior of quartz river sand samples; however, when subjected to abrasion in a thin layer, the resistance of the particles to sliding one relative to another is growing. Therefore, when selecting crushed rock fines as a substitute for natural quartz sands, it is very important to consider the functional purpose of using the fine concrete in the proposed design setting.

To sum up, the rationale and the necessity of utilizing by-products of rock crushing processes as structural materials are based not only on the environmental considerations but also on the prospects of improving the technical and economic performances in the construction industry as crushed-rock fines produced by mining companies are used as a substitute for natural sands in concretes.

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