Sand made from recycled concrete is perspective raw material for dry building mixes

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Abstract. The basic properties of sands from sifting of crushed concrete scraps are studied in comparison with sands from sifting crushed granite, which is traditionally used for floor screed production. It is established that the replacement of granite fine aggregate with sand from the screening of crushing concrete scrap leads to a decrease in the quality indices of solidified solutions by 10-30%. The optimal grain particles size of sands from sifting of crushed concrete scraps was elaborated for the properties improvement of the final material. The composition of dry building flooring sealing mix B12,5 strength class for leveling was developed on the basis of the composition of sands from crushed concrete in correspondence with the requirements of standards.

1. Introduction

Industrial waste utilization is an essential part of the Sustainable Development, which has been officially assumed by the United Nations Organization to be a World Development Strategy. The Russian Federation annually generates 7 billion tons of wastes, including 15-17 million tons of construction waste [1]. In accordance with upcoming renovation program of the housing stock, which started in our country in 2017, the quantity of construction scraps will increase every year. Therefore, the problem of its utilization and concrete recycling in particular becomes urgent. The crushed concrete products application as a large filler for various construction works is the most investigated [2-13]. However, despite the large quantity of positive results of laboratory studies, its application is mainly limited to backfilling in the roads and sidewalks construction; using waste concrete in new concrete production is not widely applied [14]. A possible reason for this is the presence of a certain amount of cement mortar on the surface of grains of the secondary aggregate, which increases the water demand of the concrete mix and reduces the ultimate strength and frost resistance of the concrete [15,16].

The multiple crushing of concrete scrap is proposed for the best cleaning of the secondary filler from cement mortar. With the increasing of crushing cycles number, the amount of fine-grained and dust fraction of concrete scrap is grow. The positive results of using the dust fraction of crushed concrete scrap as a filler in the production of self-compacting concrete are obtained [17,18]. A fine-grained fraction, or sand made from recycled concrete (SRC), is a predominantly crushed mortar consisting of a natural fine aggregate (most commonly quartz sand) and a hardened cement stone with inclusions of fragments of a large aggregate, usually granite. It is known that the SRC utilization lags behind the use of the corresponding coarse fraction [19]. It is shown that the compressive strength of
mortars decreases with increasing percentage of recycled sand [20-22]. Nevertheless, in our opinion, SRC is of great interest to researchers, since it can replace the natural sand produced in huge quantities for the production of concretes, mortars and dry building mixes (DBM). Replacement of natural raw materials with industrial waste will help to solve not only ecological but also economic problems: most of the Russian manufacturers of DBM experience difficulties for obtaining cheap dry fractionated sands, especially in winter.

The purpose of this work is to evaluate the effectiveness of the screened crushed concrete scrap application in modified DBM, which are widely used in construction. As is known, the inert part of the DBM in the form of fine aggregate and mineral filler predominates in their composition and can occupy up to 80-90% of the mix volume.

2. Initial materials and research methods characteristic
The wall demolition scraps of Ekaterinburg building from the 1950s were used in this work as the concrete fragments form with size of 70-120 mm, which were crushed 3 times with a laboratory jaw crusher and screened on standard sieves system; the fraction <5 mm was used for the study. For comparison with the obtained aggregate, the sand from sifting crushed granite (SCG) of the <5 mm fraction was used. Granite screening is traditionally used in Russian construction practice for the production of leveling floor coverings (screeds). As is known, floors are one of the most labor-intensive structural elements of the building; the total cost of floors is close to the cost of the bearing part of the overlap, and the cost of their installation is 2-4 times higher [23].

The cement (CEM I 32.5 N) provided by Sukholozhsky cement plant and plasticizing agent «POLYPLAST SP-1» were used to obtain DBM. The ratio of cement to fine filler was 3.5, the consumption of plasticizing agent ~ 0.7 % by weight of cement, regardless of the type of sand. The water flow when mixing with DBM were selected in such a way that the mobility of the mortar mixes comply with the requirements for installation of bearing and/or leveling of floor coverings (mobility class Pk2, GOST 28013-98). Samples with a size of 40x40x160 mm were formed from the obtained mortar mixtures and placed in air-moist storage conditions. Tests of the hardened mortars were carried out in accordance with the requirements of GOST 31358-2007 «Dry building flooring cement binder mixes. Specifications».

3. Experiment results and discussion
The test results of screenings showed that they meet the requirements of GOST 8736-2014 "Sand for construction works. Specifications" and belong to very large sand of the II class group (Table 1).

| Property               | SRC | SCG | GOST 8736-2014 requirements |
|------------------------|-----|-----|-----------------------------|
| Bulk density, kg/m3    | 1330| 1600| not rated                   |
| Real density, kg/m3    | 2550| 2650| not rated                   |
| Grain composition:     |     |     |                             |
| ≥5 mm grains content, %| -   | -   | II class                    |
| ≤0,16 mm grains content, % | 8.33| 9.67| up to 15                    |
| Bulk modulus (fineness modulus) | 4.24| 3.59| over 3.5 – very coarse      |
| Dust and clay particles content, % | 4.1 | 4.9 | not over 5 II class        |

SRC is lighter, i.e. its bulk density is 17 % lower in comparison with the SCG. This is due to the presence of a crushed primary mortar containing a hardened cement stone in the SRC. As it was
shown earlier, cement stone impurities in the secondary sand lead to an increase in its water demand. As a result, the strength of the mortar based on SRC to a decrease in by 15-20% compared to a similar composition containing quartz sand [20]. In this study, the water demand of DBM containing SRC was 14 % higher than that of a dry mixture containing SCG, all other things being equal (Table 2).

Table 2. Ready-to-use mixtures characteristics.

| Property                  | Mixture based on sand from shifting of crushed concrete scrap (SRC) | granite (SCG) |
|---------------------------|---------------------------------------------------------------|--------------|
| Mobility, mm              | 58 (Pк2)                                                      | 61 (Pк2)     |
| Water holding capacity, % | 96.2                                                          | 95.5         |
| Initial mobility retentivity, min | 64                                                           | 71           |
| Water-cement ratio        | 0.83                                                          | 0.71         |

In our opinion, the presence of cement stone can be explained, as well, a higher water-holding capacity and a shorter period of the initial mobility retentivity of the SRC-based mortar mix. Most likely, the microparticles of cement stone serve as the crystallization centers of hydrated clinker minerals.

The main properties of solidified solutions based on SRC were worse compared to similar compositions based on SCG: shrinkage deformation at the age of 28 days was higher by 22 %, adhesion strength to the concrete base at the age of 7 days was lower by 21 %, compressive strength at the age of 28 days was lower by 10 %, bending strength at the age of 28 days was lower by 36 % (Table 3).

Table 3. Test results of hardened mortars.

| Property                                                        | Mortar based on SRC | SCG  |
|----------------------------------------------------------------|---------------------|------|
| Density, kg/m3 (dried condition)                               | 1970                | 2080 |
| Tensile strength, MPa, at the age of 3 days                    | 1.6                 | 2.3  |
| Compressive strength, MPa, at the age of 3 days                 | 5.9                 | 7.5  |
| Tensile strength, MPa, at the age of 28 days                    | 3.5                 | 5.5  |
| Compressive strength, MPa, at the age of 28 days               | 16.1                | 17.9 |
| Shrinkage, mm/m, at the age of 28 days (in accordance with GOST 31358-2007 not more than 1,0 mm/m) | 0.76                | 0.59 |
| Bond strength to the base (adhesion), MPa at the age of 7 days (in accordance with GOST 31358-2007): |                |      |
| – not less 0.37 MPa for bearing;                                | 0.45                | 0.57 |
| – not less 0.30 MPa for leveling                                |                     |      |
| Water absorption, %                                            | 5.64                | 3.89 |

Nevertheless, the experimentally established quality indices of mortar mixtures and hardened mortars, both based on SCG and SRC-based, satisfy the requirements of GOST 31358. The lower average density of the SRC-based composition is a positive moment, since it can increase the heat and sound insulation ability floor covering (screed).

4. Conclusion

The main properties of sand from sifting crushed concrete waste were studied in comparison with sand from sifting crushed granite, which is traditionally used for the production of floors. Both batches of small aggregates obtained in laboratory conditions belonged to the group of large Sands (class II according to GOST 8736-2014). Admixtures of crushed cement stone in the SRC determined a 17%
decrease in the bulk density of the secondary fine aggregate compared to the granite fine aggregate. DBM and SRC-based solution had, on average, 10-30% worse quality than similar materials based on SCG. However, the quality of mortar mixtures and solidified solutions, both based on SCG and based on SRC, met the requirements of GOST 31358. Therefore, SRC can be considered as a sufficiently effective and promising material for the replacement of natural Sands in the technology of dry building mixtures.

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