Use of ceramic dust waste in the composition of road plates

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Abstract. The use of industrial waste – ceramic dust in the production of cement concrete mixtures is considered. A comparison of the characteristics of ceramic dust and building sand is done. The analysis of the physicomechanical characteristics of the cement-concrete mixture with a ceramic dust content of 10 and 50 % of the amount of building sand in the mixture was performed. Samples from this mixture were tested in a certified construction laboratory. It is shown that the use of ceramic dust in the composition of the cement-concrete mixture as a filler increases the average concrete strength up to 44 %, without significantly changing neither its structure, nor other physicomechanical properties. The possibility of using cement-concrete in construction practice, in which 50 % of sand is replaced by waste, has been proved.

1. Introduction
Waste management implies their complete or partial elimination, minimization or, where possible, reuse of materials that could otherwise become waste. Waste recycling or reuse is an essential element of sustainable resource management [1, 2].

Reuse of industrial waste in construction is widespread in the form of various additives and substitutes in building materials [3]. Thus, in the manufacture of concrete mixtures, granular blast furnace slag [4], spent polymers [5], and ceramic waste [6–9] are used. Wastes generated in the process of coal mining in the form of coarse-grained or finely dispersed fractions (coal dust) are widely used in the production of road-building materials. Along with these wastes, a by-product of foundry-quartz sand is actively used as a fine aggregate in concrete mixtures [10]. Full or partial replacement of natural aggregates in a self-compacting concrete mixture with industrial waste showed that replacing 50 or 100 % of natural aggregates with recycled concrete aggregates gives concrete with properties comparable to the reference sample [11].

The quality of the aggregate material has a significant impact on the physicomechanical properties of concrete, since aggregate occupies almost 70–80 percent of the total concrete volume. The influence of small aggregates on the properties of concrete is studied in articles [12–13]. The calculation method for determining the sand content in heavy concrete is presented in [14], where the calculation equations for determining the sand content in a mixture of concrete aggregates are substantiated. This ensures the lowest viscosity of the concrete mix and prevents water separation. The properties of concrete with various types of aggregates are studied in [15–19]. The mechanism of the effect of the particle size distribution of aggregate on the strength of concrete is analyzed in [20].

2. Materials and methods
One of the production wastes associated with the machining of metal products is ceramic dust or abrasive powder having a dusty state of aggregation. The starting material for it is a ceramic fraction.
Ceramic dust has a fourth class of environmental hazard and does not have hazardous properties. The waste is black and irregularly shaped particles. Its component composition is presented in table 1.

| Component name          | % by weight |
|-------------------------|-------------|
| Silica                  | 44.06       |
| Calcium oxide           | 19.57       |
| Iron oxide              | 18.98       |
| Aluminium oxide         | 8.66        |
| Magnesium oxide         | 7.40        |
| Titanium oxide          | 0.60        |
| Nickel                  | 0.1773      |
| Manganese               | 0.4524      |
| Zinc                    | 0.0837      |
| Copper                  | 0.0102      |
| Lead                    | 0.0064      |

From the analysis of the table it follows that ceramic dust has a significant similarity with sand since it consists of 44% silicon oxide.

The question arises about the possibility of using ceramic dust waste as a filler in the manufacture of road slabs, which are used not only in road construction, but also in the arrangement of any construction site.

A study of the physical and technical properties of the waste was carried out in the laboratory of Building Materials SibADI. A comparison was also made of the indicators with the requirements of GOST 8735-88 "Sand for construction work. Test methods" to sand class 2. The grain composition of ceramic dust is presented in table 2.

| Name the residues | Residues, % by weight, on sieves | Pass through a sieve with a mesh No. 0.16, % by weight |
|-------------------|---------------------------------|----------------------------------------------------------|
|                   | 2.5  | 1.25 | 0.63 | 0.315 | 0.16 | 12.8 |
| Private           | 0.5  | 7.7  | 24.9 | 34.3  | 19.8 |  |
| Full              | 0.5  | 8.2  | 33.1 | 67.4  | 87.2 | 100 |

From table 2 it is seen that the largest percentage of the content of particles of ceramic dust accounts for 0.315 sieve and is 34%. Ceramic dust modulus is \( M_k = 1.96 \).

Comparative characteristics of ceramic dust and building sand are presented in table 3.

| Indicator                                      | Ceramic dust value | GOST 8735-88 requirements for sand of the II class (small) |
|------------------------------------------------|--------------------|----------------------------------------------------------|
| True density, \( \text{kg} / \text{m}^3 \)    | 3100               | not standardized                                         |
| Bulk density, \( \text{kg} / \text{m}^3 \)    | 1655               | not standardized                                         |
| Intergranular voidness                        | 46.7               | not standardized                                         |
| Fineness modulus                              | 1.96               | 1.5-2.0                                                 |
| Grain content (total residue on sieve No. 063 is finer than 0.16 mm) | 33.1              | 10-30                                                   |
| The content of clay and dust particles         | 0.5                | no more than 5                                           |

From the analysis of the comparative characteristics presented in table 3, it follows that sand of class 2 (fine) and ceramic dust have similar physical and mechanical properties and satisfy the
For testing, three concrete mixes were selected, from which samples were made of cubes of the reference (clean) concrete mix and samples containing 10 and 50 % ceramic dust instead of sand. The compositions of concrete mixtures are presented in table 4.

**Table 4. The composition of concrete mixtures**

| Compositions          | Pure mixture, kg | Mix with 10 % ceramic dust, kg | Mix with 50 % ceramic dust, kg |
|-----------------------|------------------|--------------------------------|--------------------------------|
| Cement                | 4.8              | 4.8                            | 4.8                            |
| Sand                  | 8.4              | 7.56                           | 4.2                            |
| Ceramic dust          | –                | 0.84                           | 4.2                            |
| Crushed stone         | 21.24            | 21.24                          | 21.24                          |
| Water                 | 2.2              | 2.2                            | 2.3                            |

Testing of the samples was carried out in accordance with GOST 10181 - 2014 “Concrete mixtures. Test Methods”. At the same time, the requirements of the following standards were taken into account: GOST 26633-2015 “Concrete heavy and fine-grained. Specifications”, GOST 13015-2012 "Concrete and reinforced concrete products for construction. General technical requirements. Rules for acceptance, marking, transportation and storage”, GOST 10060 – 2012 “Concretes. Methods for determining frost resistance”.

3. The discussion of the results

The test results of samples of concrete mix are presented in table 5.

**Table 5. Test results of samples made from concrete mix**

| Name indicator                  | Clean mixture | Mixture with 10 % ceramic dust | Mixture with 50 % ceramic dust | GOST 13015-2012 requirements |
|--------------------------------|---------------|--------------------------------|--------------------------------|-------------------------------|
| Cone draft, cm                 | 4             | 4.3                            | 4.1                            | not standardized             |
| The average density of the     | 2500          | 2520                           | 2530                           | not standardized             |
| concrete mixture, kg/m³        |               |                                |                                |                               |
| The average strength of concrete after steaming, MPa | 26.6          | 31.9                           | 28.8                           | Not less than 70 % of concrete class |
| The average strength of concrete at the age of 28 days, MPa | 29.5          | 40.7                           | 42.5                           | Not lower than 26.19±4.5     |
| Average abrasion of concrete   | 0.17          | 0.125                          | 0.1                            | No more than 0.7 g/cm²       |
| mix, g/cm²                     |               |                                |                                |                               |
| Concrete frost resistance      | 0.20          | 0.25                           | 0.21                           | 0.18–0.25 (F 200)            |

From the analysis of table 5 it follows that the sediment cone and the average density of the concrete mixture containing ceramic dust, slightly differ from similar parameters of the clean mixture, not exceeding the values of 7.5 and 3.6 %, respectively. The average strength of concrete increases with an increase in the percentage of ceramic dust in its composition. So the average concrete strength at the age of 28 days increases to 44 % when replacing 50 % of sand with ceramic dust. The rate of abrasion of a concrete mixture containing ceramic dust is reduced compared to the rate of a clean mixture, but still corresponds to the grade of abrasion G1 – (0.7 g/cm), established by the standard for structures operating in conditions of increased traffic intensity ( road plates, sidewalk plates, etc.). The frost resistance of a concrete mixture with ceramic dust slightly exceeds the frost resistance of a clean mixture.

All the indicators shown comply with the requirements of GOST 13015-2012; therefore, all the mixtures presented are suitable for the manufacture of products for structures operating in conditions of increased traffic.
In accordance with GOST 33148-2014 “General automobile roads. intensity: sidewalk plates and road plates”.

For the production of road slabs with non-tensioning reinforcement, the strength class of concrete must be at least B30 “Reinforced concrete road plates. Technical requirements”. Concrete mixtures where part of the sand is replaced with ceramic dust, have just such a strength class, therefore they are suitable for the production of road plates.

4. Conclusions
1. The study of the physical and technical properties of ceramic dust showed that it can be used as a fine aggregate for cement concrete mixtures.
2. The developed composition of cement concrete with 50 % ceramic dust content as a fine aggregate has a strength class of B30, abrasion resistance of 0.1 g/cm² and in accordance with GOST 33148-2014 can be used for the manufacture of road plates.
3. The frost resistance indicator makes it possible to use road plates for arranging construction sites and laying roads in winter.

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