Use of metallurgical slags in mortar production

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Abstract. The possibility of using the metallurgical slags of metallurgical enterprises of the Novokuznetsk city as a filler in the manufacture of mortars is shown in this work. The methodology of the research is based on the previously developed technological schemes for recycling metallurgical slags in the form of a system of work stages, which is associated with the need for a consistent transformation of the properties of slags, and what is achieved through a series of mechanical and physicochemical effects. The use of the express method of selecting the composition of aggregate fractions from open-hearth slag made it possible to obtain the densest packing of filler grains in compliance with the strength requirements for mortars. On a set of basic physical and mechanical quality indicators, experimental mortars meet the current regulatory requirements, which allows us to recommend their compositions for testing in industrial conditions.

1. Introduction
The basic postulates of the strategy of innovative development of the building materials industry for the period until 2030 in the Russian Federation determine the urgent need to increase the share of alternative products of processing of metallurgical enterprises involved in the construction industry, and, moreover, to reduce the share of mineral raw materials and replace it with industrial waste [1], which emphasizes the relevance of this work. Widespread steel waste is steel-smelting and blast-furnace slags, whose chemical composition is comparable to the Portland cement clinker, which determines the possibility of their use in the construction industry in various directions [2-20].

2. Relevance
Analysis of the metallurgical wastes recycling practice shows the positive results of using them as raw materials for the production of various mortars [7-10,14]. However, the known technologies for industrial waste processing are unprofitable [9,10], the bulk of them are returned to the dumps [5]. Based on the review of technical literature and the results of patent searches, it has been established that to date, some experience has been gained in the use of steelmaking waste in various sectors of the country's economy. Up to now, slag producers have not given due attention to the utilization and slags processing, since the slags are classified as the 4th hazard class and the degree of their harmful impact on the environment is low.

To date, the use of steelmaking wastes is extremely limited not only in our country but abroad primarily due to insufficient knowledge of the chemical and mineralogical composition, the slags behavior in various application conditions, as well as inappropriate storage and lack of primary
processing (separation of metals, averaging and fractionation). One of the main ways to improve the efficiency of building materials is fractionation of the filler and the aggregate, high-density packaging creation and rational selection of the mixture composition. A method for manufacturing a building material in which a mixture of initial components with a moisture content of 10-15% is homogenized in a selectable weight percentage is known: a natural soil of 48-75%, an industrial waste with astringent properties of 50-20% and an alkaline activator - 2-5%, produce a weight or volume dosage of the mixture, compact the resulting mixture at a load of 3 to 10 MPa, depending on the chemical, mineral and granulometric compositions of the initial components, the storage mode of the compacted materials and the required mechanical characteristic. The invention relates to the field of construction and is intended, for example, for the manufacture of bases for roads and railways, airfields, industrial and municipal landfills, sites for various purposes, dams, foundations for buildings and structures, and building materials such as non-burnt bricks and blocks.

The problems of compressive strength enhancement, as well as the strength after freeze-thaw cycles, simplification of the technology of preparation of asphalt mix for road construction, using electric steel-smelting slags have been solving by scientists from Voronezh State Architectural Construction University. The composition of the asphalt-concrete mixture for road construction, including bitumen, electric-steel smelting slag and aggregate, sand-gravel mixture, is developed at the following ratio of components in mass%: Bitumen 7.4-8.3, slag of electric steelmaking production of fraction 0-15 mm 39, 0-44,0, sand and crash stoned mix from quartzite sandstone fraction 0-15 mm 47.7-53.6.

A team of authors of the Kazan State Academy of Architecture and Construction proposed a method for manufacturing an astringent on the basis of a slag. The binder contains a annealed mixture of magnesium-containing carbonate rocks with clay at a ratio of (3-9): 1, a mineral additive - a waste of the metallurgical plant's production - blast-furnace granulated slag of 0.01-0.08 mm fractions and additional sulfate of magnesia with the following ratio of mixture, %: the indicated mixture of magnesium-containing carbonate rocks with clay - 60-85, blast-furnace granulated slag - 10-30, sulfate of magnesia - 5-10

3. Research objective
The purpose of this work is the development of technological methods for steelmaking slags recycling of metallurgical enterprises of the Kemerovo region (Novokuznetsk city) for the production of building mixtures using the express method of selecting the composition of aggregate fractions.

The object of the study was metallurgical slag (open-hearth furnace, fraction 0-40 mm, converter, fraction 0-40 mm), which are stored in dumps under conditions of varying effects of temperature and humidity.

The physical and mechanical properties of metallurgical slags were studied on the basis of the testing laboratory of the Department of Building Materials, Standardization and Certification of the Federal State Educational Institution of Higher Professional Education in the NSSA (Sibstrin).

4. Theoretical part
Steel smelting slag is an artificial crushed stone with grains of various sizes (from 0 to 80 cm) and various mineral compositions. The phase composition of the steel-smelting slag is unstable, but changed in a limited range: it contains up to 15-20% of metallic iron in the form of various kinds of inclusions of metallic shot and scrap (about 7% in the form of scrap and about 8% - frozen droplets); and is quite complex (contains oxides of many elements). This is due to a wide variety of raw materials, including alloying additives, deoxidizers, etc. Depending on the characteristics of the feedstock and the technological parameters of the smelting process, the chemical composition of steelmaking slags is characterized by a significant fluctuation in the content of the main components. Thus, by mass, the content of CaO can vary from 12 to 50%; SiO2 - from 10 to 35%; MgO - from 4 to 22%; FeO - from 3 to 28%; MnO - from 1,5 to 15%; A12O3 - from 2 to 10%; Fe2O3 - from 1 to 27%.
It is known from literature sources that, due to slow cooling, the minerals making up the steelmaking slag have high crystallization and low hydraulic activity. The preliminary activation of the slag makes it possible to largely regulate the strength and performance properties of the material based on it. As activators for hardening slag compositions, building lime, gypsum, alkali solutions, and cement are used. The usage of fine-dispersion fillers in the form of cement dust, limestone, loam, burnt rocks, etc. is known. The following methods are used for activation: mechanical (grinding, vibroactivation), chemical (addition of additives), thermal (autoclave treatment, temperature-humidity treatment, abrupt cooling). The quality of astringent materials based on slag depends on the following factors:
1) selection of the composition, so that it more closely corresponds to the composition of Portland cement;
2) mixing of components so that a chemical effect is possible between them.

Experimental research. The research methodology is based on the technological schemes of recycling metallurgical slags developed by us in the form of a system of work stages [2-5,9]. These schemes justify the need for a consistent transformation of the properties of slags, which is achieved through a series of mechanical and physicochemical effects. They are systemic in nature, which determines the possibility of their practical application with the aim of maximizing the full utilization of metallurgical waste, and also fully applicable to various types of metallurgical slags.

After appropriate technological processing, the main physical and mechanical properties of metallurgical slags [2] were studied with the development of experimental compositions of concrete, plaster and masonry mortars. The technological scheme for the composition selection of the concrete mix using the express method [6] provided the dosage of open-hearth slag (coarse and fine fractions, respectively), sand, cement, water and plasticizer with thorough mixing at each stage. The composition of the experimental concrete mixture based on open-hearth metallurgical slag (calculation for 1 m$^3$ of concrete mix): slag, fraction 20-40 mm - 783 kg; slag, fraction 5-10 mm - 638 kg; sand - 657kg; Portland cement ЦЕМ II / A-Ш 32,5B - 382 kg; water - 191 l; plasticizer Master Glenium SKY 591 - 2,2 kg.

The workability (mobility) of the concrete mix was determined in accordance with GOST 10181-2014 "Concrete mixtures. Testing methods." The sediment of the cone was 20 cm, which corresponds to grade P4 (GOST 7473-2010 "Concrete mixtures: technical conditions"); the density of the concrete mixture was 2654 kg / m$^3$. At the age of 7 days, samples-cubes of concrete with an edge of 10 cm were tested. The average compressive strength ($R_c$) was 34.18 MPa, which corresponds to class B25.

In addition, as per GOST 310.4-81 "Cement. Methods for determining the ultimate strength in bending and compression ", samples of masonry and plaster solutions with four different compositions and subsequent determination of mobility and density of the mortar mixture were prepared and tested (GOST 5802-86 "Mortars. Test methods"). In the course of the experiment, the mortar formulae that corresponded to GOST 31357-2007 "Dry mortars on a binding cement. General technical specifications", including: a cement mortar Pк2, M100; a cement mortar Pк2, M150; a cement mortar Pк2, M25; a cement mortar Pк2, M10 were obtained.

The results of physical and mechanical tests have shown that according to the basic quality parameters (table 1), the samples corresponded to the requirements of GOST 31357-2007 "Dry mortars on a binding cement. General technical specifications"

5. Conclusion
Thus as a result of the conducted research, conceptual approaches to the utilization of metallurgical slag (blast furnace, steel-smelting) of Novokuzeznetsk metallurgical manufacturing plants as a filler in the concretes manufacture, as well as plaster and masonry mortars, have been developed. Using the express method of selecting the composition of aggregate fractions from blast-furnace slag made it possible to obtain the densest packing of aggregate in compliance with the strength requirements for mortars. On a set of basic physical and mechanical quality parameters experimental construction
mortar meet the current regulatory requirements, which allows us to recommend their compositions for implementation in industrial conditions.

**Table 1.** The basic quality parameters of dry mortars for floor, facing and plaster mixtures and mortars as per GOST 31357-2007.

| Parameter Name                        | Parameter Value for Mortars | Test Results of Mortars | GOST 31357-2007 |
|---------------------------------------|-----------------------------|-------------------------|-----------------|
|                                       |                             | facing                  | plaster         |
| 1. Quality of dry mortars             |                             |                         |                 |
| 1.1 Moisture, %                       | 0.2                         | 0.2                     | 0.3             |
| 1.2 Maximum aggregate size, mm        | 3.5                         | 3.5                     | not exceeding 5 |
| 1.3 Maximum size of aggregate, %      | up to 5                     | up to 5                 | not exceeding 5 |
| 2. Quality of ready-to-use mortar     |                             |                         |                 |
| 2.1 Fluidity, immersion of a cone, cm | 6                           | 6                       | 4.8             |
| 2.3 Persistence of initial fluidity, min | 45                         | 45                      | 45              |
| 2.4 Water holding capacity, %         | 98                          | 98                      | not less than 90|
| 3. Quality of hardened mortar         |                             |                         |                 |
| 3.1 Water absorption, %               | 13                          | 12                      | not exceeding 15|
| 3.3 Adhesion strength with base, MPa  | 0.69*                       | 0.5 *                   | not less than 0.5*|
|                                       |                             |                         | not less than 0.25**|

6. References

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