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Use of the burnt rock of coal deposits slag heaps in the concrete products manufacturing

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HIGHLIGHTS

- Studies of coal deposits mine dumps demonstrated homogeneity of burnt rocks.
- Burnt rock structure and properties allowed to use it as active mineral additive.
- It was shown the extent of burnt rock activity.
- Burnt rock activity is caused by the presence of needle-shaped formations.
- It is possible to replace up to 35% of cement without reducing its strength properties.

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ABSTRACT

The paper presents the results of the comprehensive study of the composition, properties and structure of the burnt rock found at the mining dumps of Cheremkhovo coal deposit (Irkutsk region, Russia). In the course of laboratory research, which included optical crystallography, there have been established the reasons accounting for the extent of burnt rock activity when in contact with cement during the cement stone formation. The benefit of the burnt rock as an active mineral additive, compared to the fly ash used by the cement plants, was confirmed as well. The optimal ratio of cement and burnt rock in concrete mixtures was determined experimentally. Likewise, the most effective method of using burnt rock as an active mineral additive was developed as the result of semi-industrial tests when the sample was subjected to the pressing and steam treatment. Finally, the impact such an additive can have on the production cost have been calculated.

1. Introduction

Since the last century and up to now, concrete on Portland cement binding is the most common building material All the emerging alternatives in this area have a narrow application. Hence, improving the quality of the concrete products while reducing the cost of their manufacturing is a task of the utmost importance. An extensive number of theoretical research as well as applied studies are dedicated to this issue [1–4].

The prime cost of the concrete (up to 70%) depends on the price of its main component – the cement, as it is the qualities of the cement that account for the strength and durability of the concrete constructions [5].

Therefore, the reduction of the proportion of cement in concrete, with unconditional preservation of its quality indicators, is the most effective way to reduce the cost of concrete products. This problem is solved by replacing cement (in certain proportions) with active mineral additives [6]. When cement is mixed with water, active mineral additives (AMA) react with calcium hydroxide, which is released as the result of hydration of tricalcium silicate, and form water-insoluble calcium hydrosilicates. Thus, together with conservation of the clinker part, mineral additives provide the cement with a number of special properties such as increased impact strength, reduced water permeability and efflorescence, and so on [7].

It is known a number of active mineral additives of various properties and effectiveness of interaction with cements.

It is also worth noting that as technogenic AMA are inherently wastes and by-products of various mining and processing

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industries, they are of considerable interest in terms of accessibility, cost and environmental safety [8,9].

Based on the extent of AMA activity, special attention should be paid to the burnt rock of the coal deposits, as that is one of the most widespread types of technogenic waste. During the mine exploitation of the coal deposits, dead rock containing traces of coal is stored in the artificial mounds called the slag heaps [10] (Fig. 1).

Spontaneous coal combustion in slag heaps with temperatures ranging from 600 °C to 850 °C results in the formation of ash rich in active ingredients [6,11,12]. Such combustion processes inside the slag heap tend to last for 35–40 years. During that time, the entire internal massif reaches a homogeneous state (i.e. the chemical composition of the samples is identical to those collected at all sampling points of the slag heap).

Nine slag heaps of a total volume of about three million cubic meters are located in the Cheremkhovo area of Irkutsk region, Russia. Multiple slag heaps of similar appearance and chemical composition are located in the regions where coal was extracted via deep mining technique (Russia, Ukraine, China, Czech Republic, Spain, Morocco etc.) [13–16]. In these countries, a number of studies have been carried out to study the possibility of using burned rock of coal deposits for the production of such materials as: hot asphalt mixtures (as a filler) [17], ceramic and refractories [18], lightweight aggregates [19], dye for paint and enameling [20] and other applications.

In [21] it was shown the possibility of recovering coal from burt rock and production of two value added products on its basis. The first product consists of fine anthracite coal with a high calorific value (sulfur content less than 1%; ash content less than 10%). The second product is high quality fired bricks containing up to 100% of coal wastes.

The burnt rock can also be used in cement production. Thus in the paper [22] it was shown the possibility of partial replacement of the cement by the heated coal gangue in quantities between 10 and 40 (wt%). Moreover, it should be noted that burnt rock recycling in cement production can provide ingression of useful impurities inside the mixture [23]. For example, impurities such as phosphorus can stabilize highly reactive varieties of dicalcium silicate [24] and other impurities such as manganese and chromium contribute to allotropic form of tricalcium silicate with larger hydraulic reactivity [14]. Other studies have focused on the pozzolanic properties of coal gangue activated when annealing at high temperature (700–1000 °C) [7,25]. Another study was interested in pozzolanic behaviour of compound activated red mud-coal gangue mixture [26].

In China there is a raw of technologies that allow to use coal deposits not only for construction and building materials but also for rare metals (Ge, Ga, Se, Li, Y) extraction, which play a key role in energy-efficient technologies and alternative power development [9].

The presented paper shows the results of the profound study of the burnt rock of the Cheremkhovo coal deposit. It also sets to propose technologies for the use of the burnt rock of the aforementioned mine dumps as an acidic active mineral additive to the cement and the concrete products based on it.

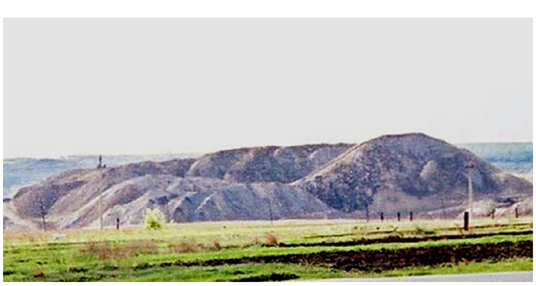

Fig. 1. Slag Heap.

The study is intended to provide a comprehensive explanation of the increased extent of the burnt rock activity, develop a technology for its use as an active mineral additive in the concrete production, and determine the optimum quantity of the cement to be replaced with the burnt rock without reducing the strength parameters of the end product.

To achieve this goal, accomplished tasks include the following:

– research of the physical properties and chemical composition, and the structure of the burnt rock;
– measurement of the extent of the burnt rock activity as well as its place in the range of active mineral additions;
– determination of the effect the burnt rock has on the formation of the cement stone as well as its subsequent qualitative characteristics; establishing of the optimum degree of replacement of cement by burnt rock under normal conditions of hardening;
– conducting crystal optical studies of the structure of the cement stone formed with the addition of the burnt rock to identify the possibility of new formations, namely, the forms and the types of replacement as well as interaction of the formed phases in the general structure;
– conducting semi-industrial tests with a view to replace the cement with the burnt rock at the operating plant; determination of the optimum degree of cement substitution under the conditions of vibrocompression and stream treatment.

2. Materials and methods of research

Crystal-optical studies of the burnt rock as well as the cement stone with the burnt rock additive were performed with a digital polarizing microscope Altami Polar 1. X-ray diffraction analysis was conducted to study the phase composition of the burnt rock, with the help of the Shimadzu X-ray diffractometer XRD-7000. Qualitative and quantitative analyses of the chemical composition of the samples was carried out by the Bruker AXS S4 PIONEER X-ray fluorescence spectrometer.

To conduct laboratory tests of the burnt rock activity as well as its mechanical properties in the cement composition, the following regulatory documents were referred to:

– GOST 310.1–76* "Cements. Test methods. General" (EN 197–1);
– GOST 310.2–76* "Cements. Methods of grinding fineness determination" (EN 196–6);
– GOST 25094–94 "Active mineral additions for cements. Methods of testing" (EN 934–2);
– GOST 310.4–81 "Cements. Methods of bending and compression strength determination" (EN196–1).

All samples were dried to achieve stationary weight. Burnt rock drying was carried out at the temperature of 105 ± 5 °C; gypsum stone drying (as to prevent its dehydration) was completed at the temperature of 68 ± 2 °C. Further, the materials were pebbled together. To study their grindability, the grinding time in the mill was altered (30, 60 and 100 min). The grinding quality was evaluated based on the specific surface and screen sizing (sieve No. 0071 was used). The surface area of the grains was 5500–6500 cm^2/g (to compare, the surface area of the cement grains subjected to the same grinding technique lies in the range of 3000–4000 cm^2/g).

The materials milled to the desired fineness were dried again for one-hour period and then placed in hermetically sealed vessels. The vessels with the powdered substance, prior to their use in the compositions, were stored in a chamber where calcium chloride was layered on the oven-tray to maintain the low level of relative air humidity.

Water-to-cement ratio was determined in accordance with GOST 30744 "Cements. Methods of testing with using polyfraction standard sand". The samples were prepared from the mortar mixtures based on GOST 310.4–81 (EN 196–1). Until the testing, the samples were stored in the chamber with a relative air humidity of 95–98%.

3. Results and discussion

3.1. Research into the composition, properties and the structure of the burnt rock

The burnt rock is comprised of a loose granular material; the color varies from crimson to light orange. The grains of the rock