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Soil concrete based on waste of heat power engineering and siftings of rock grinding

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Abstract. The possibility of recycling large-tonnage waste of heat power engineering and mining industry in road construction is shown. The introduction of industrial waste into road soil concrete allows one to reduce consumption of expensive stone materials and solve a number of environmental problems. The complex of modern methods was used to study the characteristics, composition and structural features of rock grinding siftings and fly ash, formed during combustion of brown coal, with a purpose of their further utilization in road construction. To ensure the optimum strength characteristics of soil concrete, the content of the main structure-forming minerals of Portland cement and its chemical composition are of importance. It was revealed that the initial mineral raw materials belong to multiphase polymineral systems; therefore, when modifying them with stabilizing additives, binding of finely divided particles should be taken into account. Soil concrete compositions based on industrial waste modified with *StabOL* polymer stabilizing additive have been developed. The physical and mechanical characteristics of soil concrete were studied. It was revealed that the optimal content of Portland cement and fly ash in samples is 8 and 10 wt.%. It was found that an increase in the mass fraction of fly ash in the composition of soil-concrete up to 30 wt.% leads to softening of the samples and a decrease in their strength characteristics.

1. Introduction

The most important environmental problem nowadays is the safe handling of industrial waste, which is the main source of environmental pollution [1, 2]. In this regard, there is a tendency towards decreasing the number of waste and introduction of technologies for their safe disposal throughout the world [3-5].

The mining industries account for the largest amount of large-tonnage waste [1, 6]. The extraction of mineral raw materials is accompanied by extraction of a sufficiently large number of overburden and containing rocks, which are stored in dumps, causing irreparable damage to the environment. These rocks are not suitable for agricultural purposes, occupy significant areas, lead to environmental degradation in the adjacent territories [7]. Extraction, transportation, as well as primary processing of mineral raw materials leads to violation of the structure and integrity of ecosystems, change in topography, formation of dips and subsidence of the earth's surface, dust formation, pollution of surface and soil waters, and erosion of soil [8-11]. Therefore, the issues on introduction of large-tonnage waste into technological chains as non-traditional raw material in order to obtain new

types of various products [12] are of high priority. Drawing of production waste into economic circulation will contribute to the rational and cost-effective use of natural mineral raw materials, since this process will not entail an increase in the costs of its extraction and processing.

Accumulated waste from mining industry and fuel and energy complex can be used in large quantities in the construction industry, which is the main material-intensive sector of the national economy [13, 14]. However, manufacturers of building materials prefer primary natural materials, therefore, the resource potential of waste is not fully utilized due to a number of technological, economic, and social reasons. At the same time, large-tonnage waste has a resource potential, the involvement of which in the production of road-building materials can significantly reduce the use of primary mineral raw materials, solve the problems of rational nature management, and reduce the cost of production [1, 15].

The deficit of standard road-building materials is the main reason for the rise in the cost of road construction. The use of local mineral raw materials, improved by stabilizing additives of various nature, can be an effective way to reduce material and technical costs. Quick utilization of waste from the mining industry and the fuel and energy complex is promising when they are introduced into the soil concrete used when forming structural layers of road pavement, basements, foundations of buildings and structures, sites of various purposes [16-20].

The use of soil concrete in the construction of road pavements has been mastered for over 50 years and has scientific, methodological and regulatory support. However, structural layers of mineral raw materials reinforced only with cement are characterized by low crack resistance, due to the peculiarities of the material structure, as well as the applied dynamic and climatic loads. To ensure the durability of soil concrete, it is advisable to use various stabilizing additives. Utilization of mining waste is constrained by the heterogeneity of their properties and composition. There is no sufficient research data on this theme in scientific and technical literature.

The purpose of this work was to study the characteristics, composition, and structural features of mining waste (siftings of rock) and ash and slag waste for their disposal in road construction.

2. Methods

X-ray phase analysis of siftings of rock grinding was performed by powder diffraction using the D8 Advance X-ray diffractometer (Bruker AXS, Germany) with the following characteristics: $\text{CuK}\alpha$ radiation, $U=40$ kV, $I=40$ mA, Goebel mirror, Soller slots of 2.5 mm, scintillation counter, $2\theta=3 - 60^\circ$, scan step of 0.02° , exposure was 1 s/step. The fly ash, grinded in an agate mortar with alcohol, was examined using the DRON - 3.0 X-ray diffractometer with the following characteristics: $\text{CuK}\alpha$ radiation, Ni filter,

V=25 kV, I=20 mA, 2θ in the range of 3 - 65 °, scanning step of 0.05°. The phase composition of samples was identified using the EVA phase search program (Diffrac^{plus} PDF-2, 2007). The RIR method [21] was used to carry out a semiquantitative analysis of certain phases in samples using corundum numbers of mineral phases from the PDF-2 crystallographic database (2007). The samples' microstructure was studied using the JSM-6510LV JEOL scanning electron microscope (Japan) with a microanalysis system, namely the INCA Energy 350 energy dispersive X-ray spectrometer (Oxford Instruments, Great Britain). A thin layer of platinum was deposited onto a non-conducting sample using the JFC-1600 setup (United Kingdom). Ferrett diameter was measured from microphotographs as the maximum particle size. IR spectra were recorded using the SHIMADZU FTIR-8400S infrared Fourier spectrometer on tablets prepared according to standard procedures from well-calcined KBr powder containing 0.1-5.0 wt.% of the test sample with thorough grinding in an agate mortar. The chemical composition of fly ash and Portland cement was determined by inductively coupled plasma atomic emission spectrometry using the Optima 5300DV emission spectrometer for 167-403 nm (PerkinElmer, USA). Samples were pre-dissolved in a mixture of HCl, HNO₃, HClO₄ and HF acids.

3. Results and Discussion

The fly ash under investigation is a light gray powder and has the following aluminosilicate composition (ω , wt.%): 36.1 of SiO₂; 10.2 of Al₂O₃; 7.80 of Fe₂O₃; 1.42 of MgO; 0.56 of Na₂O; 1.21 of K₂O; 0.41 of TiO₂; 0.61 of SO₃; 9.37 of CaO; 0.4 of CaO_{sv}. Wastes from the heat power industry in terms of CaO content are classified as hidden-active. The specific surface area of the particles was 276 m²/kg. The specific activity of natural radionuclides (²²⁶Ra, ²³²Th, ⁴⁰K) was 248 Bq/kg, which enables this waste usage in construction without restrictions.

According to infrared spectroscopy, the ash contains calcite, as evidenced by absorption bands with maxima at 1454; 1435 and 876 cm⁻¹, associated with valence and deformation vibrations of the CO₃²⁻ group (Fig. 1a). The presence of quartz and cristobalite in ash is evidenced by characteristic bands with maxima at 797; 779 cm⁻¹ and 692; 671 cm⁻¹, respectively. Hematite has absorption bands with maxima at 563 and 461 cm⁻¹ (Fe-O), and bands at 3458 and 1092 cm⁻¹ correspond to valence vibrations of OH- and Si-O-Si (Al) groups.

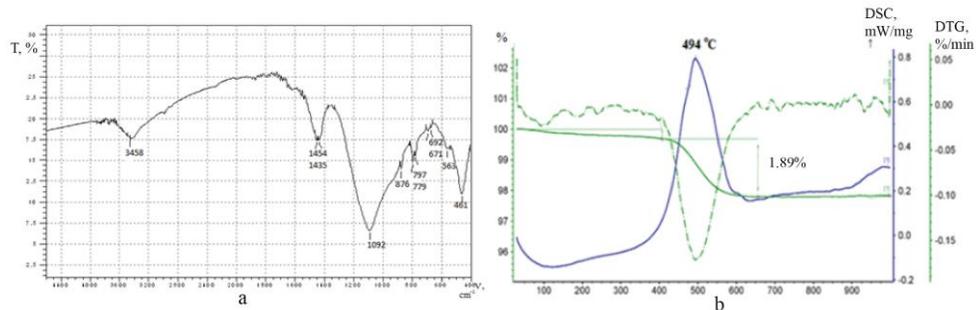


Fig. 1 Infrared spectrum (a) and thermogram (b) of fly ash

The ash investigation by differential scanning calorimetry (DSC) and thermogravimetry (TG) revealed thermal activity of the sample (Fig. 1b). The mass loss accompanying the exoeffect with a maximum at 493.5 °C was 1.89%. No steps associated with decomposition of carbonates are observed; small jumps in the mass loss rate increase at 680 and 715 °C are observed. When heated from 25 to 400 °C, the sample loses 0.3% of adsorbed moisture.

X-ray phase analysis showed that the ash has the following phase composition: quartz, calcite, feldspar, goethite and X-ray amorphous phase.

The siftings of rock grinding of 0-5 mm fraction has a bulk density of 1397 kg/m³, the content of dust and clay particles is 7.3%. The specific effective activity of natural radio nuclides (²²⁶Ra, ²³²Th, ⁴⁰K) was 110 Bq/kg; therefore, grinding siftings can be used in the construction industry without restrictions. The data obtained by scanning electron microscopy show that the considered siftings are heterogeneous in its dispersed composition and contains irregular granular particles less than 1 mm in size.

Infrared spectroscopy (Fig. 2 a) showed that the siftings contain calcite, as evidenced by absorption bands with maxima at 1431; 880 and 721 cm⁻¹, associated with valence and deformation vibrations of the CO₃²⁻ group. Absorption bands with maxima at 3621 and 3422 cm⁻¹ correspond to valence vibrations of hydroxyl groups bound by hydrogen bonds, and with maxima at 1628 cm⁻¹ correspond to deformation vibrations of H–O–H crystallization water. Absorption bands are observed at 1030 and 1009, as well as at 463 and 436 cm⁻¹, which belong to valence and deformation vibrations of Si–O bonds of silicates.

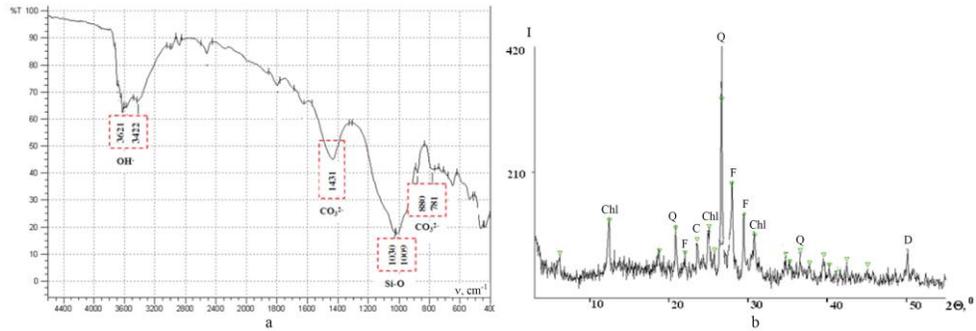


Figure 2. Infrared spectrum (a) and diffraction pattern (b) of grinding siftings: Q - quartz; C - calcite; F - feldspars; Chl - chlorite; D - dolomite

The X-ray phase analysis of grinding siftings (Fig. 2 b) showed that it contains quartz SiO_2 (4.26; 3.35; 2.45 Å), feldspars $\text{NaAlSi}_3\text{O}_8$ (4.04; 3.19; 2.99 Å), chlorite $(\text{Mg, Al})_6(\text{Si, Al})_4\text{O}_{10}(\text{OH})_8$ (7.14; 3.56; 2.85 Å) calcite CaCO_3 (3.77; 3.03; 2.45 Å), dolomite $\text{CaMg}(\text{CO}_3)_2$ (2.90; 1.79 Å).

To ensure optimal strength characteristics of soil concrete, the content of the main structure-forming minerals of Portland cement is important, as well as its chemical composition. Figure 3 shows diffractogram and thermogram of the binder.

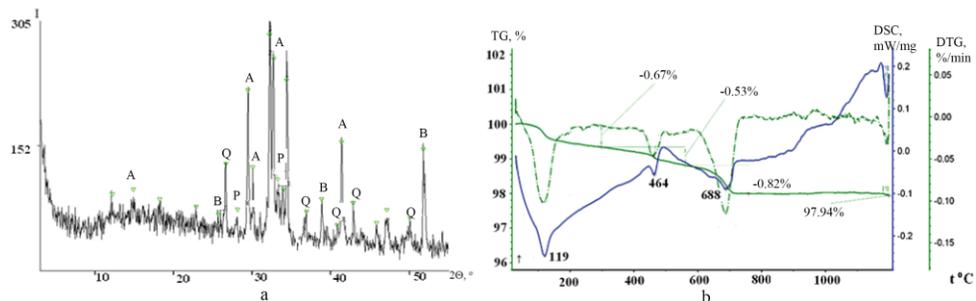


Fig. 3. The diffractogram (a) and thermogram (b) of Portland cement
A - alite; B - belite; P - Portlandite; Q - quartz

X-ray phase analysis of Portland cement (Fig. 3a) showed that it includes alite Ca_3SiO_5 (5.95; 3.03; 2.97; 2.74; 2.18 Å), belite Ca_2SiO_4 (3.43; 2.88; 2.81; 2.28; 1.76 Å), Portlandite $\text{Ca}(\text{OH})_2$ (3.19; 2.65 Å) and silica SiO_2 (3.35; 2.44; 2.32; 2.21 ; 2.11; 1.82 Å). The phase composition of Portland cement is confirmed by the data obtained by differential scanning calorimetry and thermogravimetry (Fig. 3 b). The basic chemical composition of Portland cement (ω , wt.%) is the following: 6.75 of Al_2O_3 ; 36.55 of CaO ; 4.41 of Fe_2O_3 ; 4.04 of MgO ; 27.90 of SiO_2 ; 2.80 of SO_3 .

Thus, the initial mineral raw material is a multi-phase polymineral system, therefore, when modifying them with stabilizing additives, attention should be paid to the binding of finely divided particles. Establishing the relationship between physic-mechanical characteristics of samples and the content of Portland cement and ash will make it possible to control the strength of soil concrete.

The optimal dosages of raw materials are determined based on experience. The mass fractions of Portland cement (6, 8, 10 wt.%) and fly ash (10, 20, 30 wt.%) were varied in the composition of soil concrete. It was experimentally established that the optimal content of the stabilizing additive was 1 wt.%. The relationship between physico-mechanical characteristics of samples and the mass fraction of raw materials is given in table 1.

Table 1 Physico-mechanical characteristics of samples.

Samples	ω , wt.%		Compression strength, MPa	Bending strength, MPa
	Ash	Portland cement		
I _a	10	6	4.2	0.8
I _b	20		3.1	0.5
I _c	30		2.9	0.4
II_a	10	8	6.3	1.2
II _b	20		4.1	0.8
II _c	30		3.5	0.5
III _a	10	10	7.3	1.2
III _b	20		4.3	0.8
III _c	30		3.3	0.5

Analysis of data (Table 1) showed that the optimal content of Portland cement and ash is 8 and 10 wt.% (II_a). It has been established that the physico-mechanical characteristics of samples containing 8 and 10 wt.% of binder (II_{a-c}, III_{a-c}) differ slightly from each other, so the introduction of 10 wt.% of Portland cement is economically inefficient. It was found that an increase in ash content up to 30 wt.% contributes to the process of gradual decompression of samples and, consequently, a decrease in their strength characteristics, including frost resistance.

4. Conclusions

1. The conducted studies have shown the fundamental possibility of using mining waste and ash and slag waste as components of road soil-concrete.

2. A set of modern methods (atomic-emission spectrometry with inductively coupled plasma, differential scanning calorimetry and thermogravimetry, scanning electron microscopy, X-ray phase analysis, infrared spectroscopy) were used to study the chemical and phase composition, physico-chemical, physical properties of rock grinding siftings and fly ash. The studied wastes are multiphase polymineral systems and their important component is grouting of finely divided particles. It was revealed that the specific effective activity index of natural radionuclides (^{226}Ra , ^{232}Th , ^{40}K) of the studied wastes is less than 370 Bq/kg, which allows them to be used in the construction industry without restrictions. The hydraulic properties of ash are classified as hidden-active and can be disposed in soil concrete compositions modified by stabilizing additives.
3. The relationship between strength characteristics of the soil-concrete modified with a stabilizing additive and the mass fraction of binder and ash is shown. It was found that to obtain road soil concrete with maximum strength, the optimal ash and Portland cement content was 10 and 8 wt.%

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