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VIBROVACUUMIZED SLAG-AND-ASH CONCRETE AND ASH CONCRETE

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Problem formulation. The modern thermal power plants during the coal firing produce two types of solid waste:

- fuel slag (granular material with grain size from 0.25 mm to 20 mm; occasionally there are larger pieces);
- fly ash (a dispersed material).

When burning fuel the larger particles are not captured by the flow of the gases of combustion and the particles settle down into a slag receptacle. Carbon particles completely burn out there. The mineral part passes into the flaming state (melt) and it is poured out into a special bath filled with water. As a result of rapid cooling and high pressure of generated water vapor large pieces of slag crack and disintegrate into relatively small grains (granules). The remaining large pieces are fed into a crusher. The crushed slag is removed by the hydraulic method in the dumps.

The smallest particles are carried out with the flow of gas from the combustion zone. The particles are rapidly cooled due to their small size. They are extracted from the gas flow with a system of ash collectors. This way fly ash that is one of the main types of waste of thermal power plants is formed.

Slag of thermal power plants is quite successfully used in road construction.

Ash of thermal power plants is studied well enough and recommended the builders for application as active mineral additive in the production of binders or in the preparation of concrete and mortar; as mineral powder for asphalt concrete. It is also used in production of silicate and ceramic products. In all these cases ash is used as an additive in a relatively small volume. Therewith as a rule such application of ash causes complication of technology, supplementary technological equipment, increase of production areas.

Hence, at the moment the actual problem is the development of technologies contributing to a significant increase of application of slag and ash in the construction industry [1, 2].

Analysis of the publications. The chemical composition of ash of Prydniprovs'ka thermal power plant that runs on Donets-Basin coal is shown in the table 1 [3]. It should be noted that the analysis of the given data shows that ash of the largest thermal power plants of Ukraine are similar in their chemical composition. The content of SiO_2 is mainly in the range of 41...54%. Deviation from these limits is just in some samples. The content of oxides of aluminum, iron, calcium and magnesium are also similar. Variations of the chemical composition of ash in the specified range do not cause significant changes in their properties.

Lime factor of ash, calculated according to the table 1, is generally in the range of 0.04...0.08. Thus ash from the burning of Donets-Basin coal is ultra-acid.

Table 1

The chemical composition of ash of Prydniprovs'ka thermal power plant

Chemical composition, %							Unburned carbon particles, %
SiO_2	Al_2O_3	FeO+ +Fe_2O_3	CaO	MgO	K_2O + + Na_2O	SO_3	
47...56	18...25	14...20	2...4	1...1.6	3.2...4.5	0.1...0.8	14...26

Research by the instrumentality of the light microscope showed that the mineral part of the ash of thermal power plants consists of glass (glass phase) to 90...92% [3]. The main component of this phase is silica that substantially forms physical and chemical properties of ash. It is included into the mineral part of coal and the residues from its burning (ash, slag). Silica is the main component in the processes of hydration hardening and in the processes of synthesis that forms different hydrosilicates [4].

Real density of fly ash of Prydniprovs'ka thermal power plant and other main power plants of Ukraine is as a rule within the limits of 2.26...2.50 g/cm^3. The bulk density of this ash is in the range of 0.75...1.05 g/cm^3. It depends on the grain size, the content of unburned carbon particles and reduced iron.

The average results of sieve analysis of fly ash are characterized by the following data: mass fraction of residue on a sieve with grid 016 – 3...9%, 008 – 8...16%. The dispersity of the ash depends on the stage of ash collectors, where a sample is taken. At the initial stage of collecting relatively large fractions are taken. They are characterized by a specific surface of 1500...2000 cm^2/g. At the last stage the smallest fractions are collected (5000...6000 cm^2/g). The average dispersity of dumped ash is 2600...3800 cm^2/g. In general, as a result of natural delamination of the material in various areas of the ash dumps generated by the hydraulic system of the waste disposal from thermal power plants, the ashes of various particle size (1800...7000 cm^2/g) settle and accumulate.

Chemical composition of fuel slag and fly ash of the same thermal power plants differs insignificantly. The difference lies in the fact that as a result of afterburning of the fuel in the slag collectors slags practically do not contain unburned carbon particles. Mass fraction of these particles, irrespective of the type of burned coal, is usually 0.4...0.8% and rarely exceeds 1%. When afterburning of high-temperature residues contained in ash, reduction processes intensify. As a result the content of FeO in the total mass of iron oxides increases in slag up to 60...90% against 20...30% in fly ash. Gases exuding in this period form micro- and macropores in slag [5].

Physic-mechanical characteristics of fuel slag from the burning of Donets-Basin coal in boilers with slag-tap removal have the following values [6]. Average density of grains is 2.27...2.47 g/cm^3. Fluctuation of density is caused by different value of porosity of certain grains. Real density of slag is close to 2.60 g/cm^3. Porosity of slag grains is in the range of 6...13%. Bulk density depends on density of grains, grain size and makes 1250...1450 kg/m^3. Strength characteristics of fuel slag, determined by testing in a cylinder, are given in the table 2.

Table 2

Strength characteristics of slag of thermal power plants

Size of fraction, mm	Crushability, %	Compression strength in the cylinder, MPa
3...10	19...26	4.8...5.1
10...20	31...34	3.6...3.8

From the data we can see, that slag of small fraction is stronger than that one of large fraction as large grains of slag have more defects such as large pores, cavities and microcracks.

The results of frost resistance test of slag (fraction 5...10 mm): weight loss after 50 cycles of alternate freezing and thawing – 1.85%, after 100 cycles – 3.8%, after 200 cycles 4.9% [3].

The main material. Concretes on coarse aggregate (slag and granite crushed stone) with quartz sand and ash used as fine aggregate are investigated. The following assumption is assumed as a basis of our research.

Optimum composition of a concrete mix that is compacted by vacuumizing considerably differs from that one of vibrated. A distinctive feature of vacuum concrete, having optimum composition, is its non-contact structure, caused by the excess content of the mortar component due to the increase of fine aggregate content. The correct selection of ratio between fine and coarse aggregate (F/C) is an important factor of quality and affectivity of vacuum concrete.

Concrete mixes of the same workability (S1 according to EN 206-1) with ratio 1 : 6 (cement : fine aggregate + coarse aggregate), cement consumption 316...330 kg/m^3, that differ in ratio of fine and coarse aggregate and also consumption of water were prepared to identify the dependence of the main properties of vacuum concrete from the F/C and its influence on the process of vacuumizing.

Samples 15x15x7 cm were moulded by vibrovacuumizing and vibrating method of compaction. Before vibrovacuumizing concrete mix was compacted by vibration for 15 sec. During vacuumizing (6 min) with suction in the vacuum hollow of the vacuum baffle 0.7...0.75 (perfect vacuum is equal to 1) were periodic vibration (15 sec) with an interval 1...1.5 min [7]. Strength results of the samples determined in 28 days of normal hardening are shown in fig. 1 and 2. The data show a significant increase of strength of all types and compositions of vacuum concrete in comparison with compacted by vibration. The optimal F/C ensuring the greatest strength of vacuum concrete on quartz sand (0.5...0.6) on 25...30% more than that of vibrated concrete (0.4). Vacuumizing (when comparing the optimum compositions) give the increase of concrete strength at 30...40%. After vacuumizing of concrete mix, having optimal composition for compacting by vibration, this increase is about 20%. Therefore, the optimal composition of concrete mix for vibration is not optimal for vacuum concrete.

Similar regularities were obtained for concrete, with ash used as a fine aggregate. Only in this case, the optimal F/C ratio for vacuum concrete is 0.4, and for vibrated concrete F/C=0.3. It should be noted that concrete made of slag and ash, both vibrovacuumized and vibrated, has greater strength than the same concrete made of crushed stone and quartz sand. It gives the facility of use of slag and ash for production of building products and structures, significantly reducing the cost of construction.

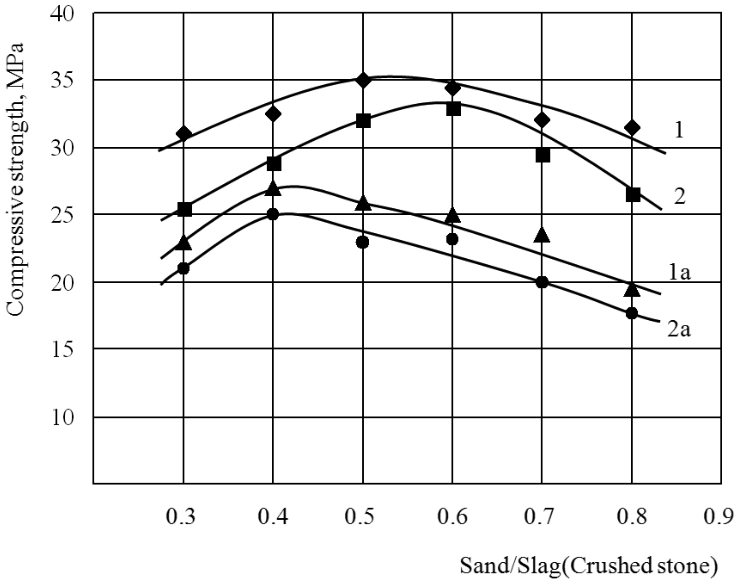

Fig. 1. Compressive strength of concrete (coarse aggregate – slag or crushed stone, fine aggregate – quartz sand): 1 – vibrovacuumized concrete (slag); 1a – vibrated concrete (slag); 2 – vibrovacuumized concrete (granite crushed stone); 2a – vibrated concrete (granite crushed stone)

Especially it is necessary to note the relevance of the mass application of fly ash as a fine aggregate for concrete. It is caused not only by the necessity of recycling of large volumes of the material in the dumps, but also by the current deficit of traditional fine aggregate.

Studying density and strength of ash concrete the samples were moulded:

- vibrated made from the initial (mobile) concrete mix;
- vibrovacuumized;
- vibrated made from stiff concrete mix (has the same consumption of water as vibrovacuumized).

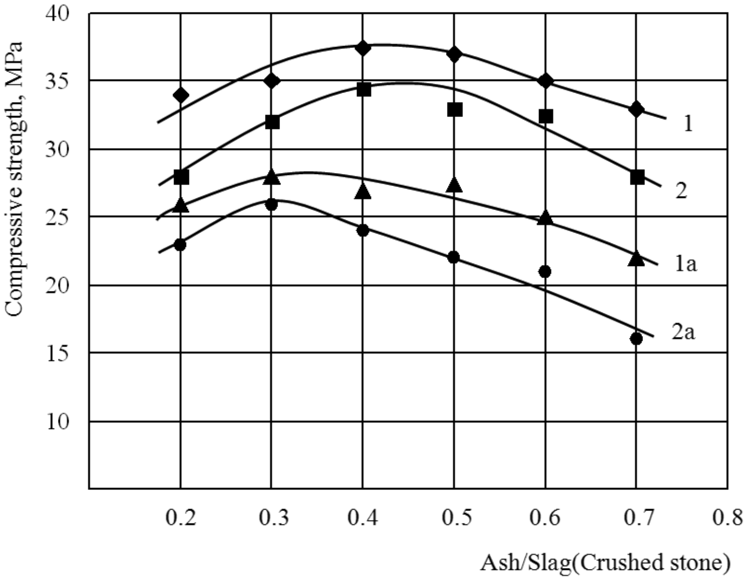

Fig. 2. Compressive strength of concrete (coarse aggregate – slag or crushed stone, fine aggregate – ash): 1 – vibrovacuumized concrete (slag); 1a – vibrated concrete (slag); 2 – vibrovacuumized concrete (granite crushed stone); 2a – vibrated concrete (granite crushed stone)

Portland cement (activity 40 MPa) and local cement (activity 20 MPa) were used in the experiments. Mobility of the initial ash concrete mix – S1 (slump is 30...40 mm). The same samples as in previous experiments were made from each type of concrete mix to determine density and strength at the age of 28 days under the following modes and methods of compacting (on the basis of previous studies) [8]. Samples made from concrete mix of the initial composition were moulded by vibration for 25...30 sec. When moulding samples from stiff concrete mix the duration of vibration was 60...65 sec. Vibrovacuumized samples were pre-vibrated during 15...20 sec, and then vacuumized under vacuum 0.7...0.8. In the process of vacuumizing applied periodic vibration was applied (in the beginning of the process two times for 10...12 sec in 2 min). The total duration of vibrovacuumizing was 9 min with removing 88...110 liters of water per 1 m^3 of vacuum concrete. All samples hardened in normal conditions.

Compositions of concrete and test results are given in the table 3.

Vibrovacuumizing provides the opportunity to increase strength of ash concrete practically in 2 times, using cements with activity both 40 and 20 MPa. Strength of concrete made of stiff ash concrete mix is only 25...30% greater than that of concrete made of mobile mix. It can be explained by insufficient compacting of such mixes by vibration [7].

Table 3

Composition, density and compressive strength of ash concrete

Type of ash concrete	Consumption of materials, kg/m^3			Volume of removed water, l/m^3	Density of concrete, kg/m^3	Compressive strength, MPa
	Cement	Ash	Water			
Portland cement (activity 40 MPa)						
Vibrated (mobile mix)	278	1114	368	-	1760 / 1492	5.8
Vibrovacuumized	295	1180	276	110	1751 / 1520	11.7
Vibrated (stiff mix)	285	1158	274	-	1717 / 1486	8.4
Local cement (activity 20 MPa)						
Vibrated (mobile mix)	291	1107	356	-	1754 / 1460	2.5
Vibrovacuumized	318	1172	261	88	1751 / 1532	4.9
Vibrated (stiff mix)	312	1166	258	-	1736 / 1517	3.2

Note: *the numerator – density of concrete after moulding, the denominator – density of dry concrete.*

The results of extensive research of the authors are summarized in table 4. Dependence of strength of different types of ash concrete on cement consumption is shown.

As can be seen from the given data, denoted earlier regularities on strength characteristics of the concrete under study are kept at all accepted in the research consumptions of cement. These research results once again confirm high efficiency of vacuumizing of ash concrete mixes.

Table 4

Strength of ash concrete depending on cement consumption and method of compacting of concrete mix

Type of ash concrete	Compressive strength (MPa) at cement consumption (kg/m^3)		
	250	280	360
Vibrated (mobile mix)	8.6	11.8	15.3
Vibrovacuumized	4.2	5.7	10.1
Vibrated (stiff mix)	6.3	8.4	12.0

Conclusions

Rational concrete mixes for vacuumizing, both with slag or crushed stone used as coarse aggregate, differ from vibrated by increased fine aggregate consumption (25...30% or 200 kg/m^3 and more) and therefore increased F/C ratio (20...40%). Vacuumizing of such concretes gives increase of strength (30...50%). And when producing concretes with the same strength it provides significant reduce of cement consumption.

High efficiency of vacuumizing of ash concrete is shown, both with ordinary cement (activity 40 MPa) and local cement (activity 20 MPa). It gives the opportunity to increase strength of such concretes in almost 2 times.

General application of slag concrete and ash concrete in construction industry helps to solve the problem of deficit of aggregates for concrete; facilitates utilization of wastes of thermal power plants and accordingly environmental protection.

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