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IMPROVEMENT OF CONCRETE AND BUILDING MORTAR TECHNOLOGY USING SECONDARY MINERAL RESOURCES

Purpose. Improving the technology of concretes on the basis of secondary mineral resources (waste foundry sand of metallurgical and machine-building industry, ash-and-slag mixes of thermal power plants).

Methodology. Generally accepted standard methods in the study of the basic properties of raw materials, concrete mixes and concretes are used in the work. The samples were moulded using specially made laboratory vacuum equipment.

Findings. The study results on the main properties of concretes on the basis of secondary mineral resources confirmed the effectiveness of vibrovacuum technology. For example, the strength of ash-and-slag vacuum concrete is on average higher than the strength of vibrocompacted concrete from a mobile concrete mix by 6–10 MPa or by 60–100 % (depending on the cement consumption). Also, high-quality concretes with moderate cement consumption for various types of construction are obtained on the basis of waste foundry sand.

Originality. Scientific and technical bases of the technology of vibrovacuum concrete on the basis of waste foundry sand and ash-and-slag mixes were developed.

Practical value. Through the development of the technology of vibrovacuum products based on secondary mineral resources concrete, high-quality concretes (increased strength, frost resistance, etc.) were obtained for road and other types of construction. This technology allows applying the existing technological equipment without fundamental design changes, carrying out immediate dismantling of moulded products, which significantly reduces the metal consumption of the technology.

Keywords: *secondary mineral resources, waste foundry sand (WFS), ash-and-slag mixes, vibrovacuumizing, moulding, concrete*

Introduction. Tens of millions of tons of various secondary mineral resources have accumulated in landfills, dumps and storage facilities of the Dnipro region (waste foundry sand (WFS) of metallurgical and machine-building enterprises, ash-and-slag mixes of thermal power plants (TPPs), and others).

Theoretical and experimental studies showed that vibrovacuumizing is a more effective method of compaction of ash-and-slag concrete and concrete on the basis of WFS compared to the traditional vibration method. Compaction of concrete mixes using a vibrating vacuum makes it possible to increase substantially density, strength, frost resistance and other properties of such concretes. For concretes having the equal strength, it is possible to reduce cement consumption. At the same time, immediate dismantling, as well as significant reducing of the duration of heat treatment, is also possible. The proposed moulding method does not require large capital expenditures for implementation, since it uses standard equipment that is widely used in the construction industry and reinforced concrete technology. The relevance of the work is the development and research of the technology of vibrovacuum processing of concrete mixes on the basis of secondary mineral resources, which makes it possible to obtain high-quality concretes with increased density, strength and other properties. A method for improving the quality of ash-and-slag vacuum concrete by adding a small amount of electrolyte to the concrete mix during its preparation is proposed. The main properties of vibrated and vibrovacuumized concretes on the basis of secondary mineral resources are studied, a comparative assessment of these properties is carried out, and the advantages of vacuum concrete are proved.

The most objective assessment of the strength characteristics and other physical and mechanical properties of concrete on the basis of secondary mineral resources compacted by a

vibrating vacuum is possible to get it in production conditions, for example, in reinforced concrete plants.

Literature review. The assessment of the most widely used WFS and their harm to the environment is presented in [1]. However, this paper provides only measurements of emissions of gases, harmful and dangerous substances (for example, benzene). The method for using WFS in concrete and mortar technology is not considered.

A vacuum technology of concrete on the basis of WFS is offered in [2]. However, light concrete was used in the study. This type of concrete tends to crack under high vacuum pressure. Therefore, heavy concrete on the basis of WFS was used in our further research.

The first complete generalization of the results of scientific research, as well as production experience in the use of ash-and-slag waste from TPPs, was given in the 30s of the last century. High efficiency of using ash-and-slag waste from TPPs in production of pozzolan cements, wall stones, light aggregates, and light (warm) concretes was proved.

A classification of TTP waste from coal burning was introduced, which indicates their separation into slags (partially melted and sintered particles) and ash (small unburned particles). In turn, slags, depending on the type of fuel burned, were divided into: anthracite, coal, brown coal, peat, oil shale [3]. This determines the need for comprehensive studies on the composition and properties of the mineral part of various coals that are burned at power plants, since the main reason for the insufficient use of ash and slag in the national economy is the fact that they are poorly studied as raw materials. Besides, without a thorough study on such waste and its impact on hydration, hardening, and operational properties of ash concrete, their production is impossible [4].

A classification of this waste, which is based on such characteristics as the type of fuel burned, the method of combustion, chemical and mineralogical composition of the mineral

part of the fuel, structure and external characteristics of slags was also proposed. It was noted that its external morphological features, such as structure, degree of clinkering, granulometry and color, are much more important for characterizing the technical properties of fuel slags, than the initial type of fuel. The main attention was paid to fuel slags. Composition and properties of fly ash were hardly considered [5]. At a higher level of replacement of natural sand with slag in concretes and mortars, the concretes showed lower strength than ordinary concretes compacted by vibration [6].

Small volumes and low efficiency of ash use at construction industry enterprises, insufficient energy waste disposal does not allow designing low-waste and waste-free technologies at large TPPs. The disadvantages of ash-and-slag mixes are less pronounced when used in hydraulic engineering construction, where concrete class is determined at the age of 180 days. At most enterprises of the construction industry that direction was ineffective in the preparation of concrete for public, industrial and agricultural construction, and fly ash had no practical application [7]. The heterogeneous composition of TPP ash is one of the main disadvantages that reduce its use. With a high content of large fly ash particles (more than 0.045 mm), as well as with an increase in the content of unburned coal particles, the water demand of concrete mix increases. This leads to segregation of concrete mix during compaction, reducing physical and mechanical properties of concrete, and durability of the product or structure [8].

Since ash-and-slag mixes make up the bulk of the dumps of most TPPs that burn pulverized fuel, they are of particular interest to construction industry enterprises as a component of concrete. Constantly growing stocks of this raw material could significantly reduce the existing shortage of concrete aggregates [9].

Purpose. The aim of the study is to improve the technology of concretes on the basis of secondary mineral resources. In practice, optimization of concrete composition is made by application of WFS and ash as traditional aggregates for concrete. Besides, vibration vacuum treatment of concrete mixes is used.

The following tasks were set to achieve the goal:

- designing rational compositions of concrete mixes for vacuum treatment;
- investigating basic physical and mechanical properties of vibrovacuum concretes on the basis of secondary mineral resources of the Dnipro region;
- developing a technology for vibrovacuumized concrete products on the basis of secondary mineral resources of the Dnieper region.

Results. Waste foundry sand (WFS). Hundreds of thousands of tons of WFS have accumulated in the landfills of metallurgical and machine-building enterprises of the Dnipro region. These mixes contain more than 90 % of quartz sand. This allows us to make assumptions about the possibility of using WFS as a fine aggregate for concrete [10]. The chemical composition of WFS is shown in Table 1.

The use of secondary resources in the production of building materials is associated with the mandatory complete and

thorough chemical analysis of this waste in order to prevent the application of harmful substances in building materials [11]. Increasing the requirements for the reliability of building materials, products and structures manufactured using recycled materials requires them to be completely safe for human health. The content of harmful impurities (heavy metals) in WFS is shown in Table 2 [12].

According to Table 2, WFS are classified as low-hazard (toxicity Class IV) [13, 14]. It makes it possible to use them in road and transport construction.

The granulometry composition of WFS is determined. According to the classification of sands by size (ДСТУ Б В. 2.7-32-95), the WFS under consideration belongs to the group of very fine sands.

Based on studies [12, 14], as well as taking into account toxicity level (Class IV), it was proposed to produce paving stones for road construction on the basis of WFS: average height – 130 mm, cross-section 150 × 150 mm).

The main equipment of the technology: a pallet vacuum shield with removable on-board equipment, a vibration platform, a vacuum pump with a receiver and a catcher, a bridge or gantry crane.

The technology is the following. A filter made of perforated polymer film is placed on the pallet vacuum shield, after which the on-board equipment is installed. It allows us to form simultaneously 80 products. Then the plastic concrete mix is laid with a short-term vibration (5–10 s), the vacuum shield is connected to the vacuum pump (through the catcher and receiver), the products are vacuumed and the side equipment is opened. Freshly formed products are delivered on a vacuum pallet to the hardening station under normal conditions. In a day, the vacuumed products have transportable strength and arrive at the finished product warehouse for further hardening, where in 7 days they gain a handling strength.

The technology was tested in the laboratory. At the same time, the paving stones were formed from fine concrete of the composition 1 : 3 (Cement : WFS) and from ordinary concrete of the composition 1 : 6 (Table 3), in which WFS was used as a fine aggregate. The research used:

- portland blast-furnace cement M400 (Kryvyi Rih) (ДСТУ Б В. 2.7-46-96);
- crushed stone of the Rybalsky quarry (Dnipro), fraction 20–40 mm (ДСТУ Б В. 2.7.-75-98);
- tempering water (ДСТУ Б В. 2.7-273:2011).

Mobility of the initial concrete mix was S1 (slump 30–50 mm). Paving stones were moulded both by vibration (30 s) and by vibrovacuumizing (6 min).

The moulded samples (paving stones 150 × 150 mm, height 130 mm) hardened under normal conditions. The samples were tested at the age of 1 day and 28 days. The results are shown in Tables 4 and 5.

A significant increase in density and strength of vibrovacuum paving stones, made on both fine and ordinary concrete, was proved.

Table 1

Chemical composition of waste foundry sand

Waste foundry sand of	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	SO ₃	N ₂ O	Residue
Steelmaking shop	91.32	0.83	2.12	1.79	1.23	–	1.09	0.89
Cast iron shop	79.3	1.50	5.64	1.07	0.98	0.74	1.93	9.34

Table 2

Heavy metal content in waste foundry sand

Average amount of heavy metals in the waste	Concentration, mg/kg						
	Pb	Cd	Zn	Mn	Cu	Cr	Ni
	<0.001	<0.004	5.7	0.017	<0.001	<0.001	<0.001

Table 3

Composition of fine and ordinary concrete

Materials	Units	Fine concrete	Ordinary concrete
Cement	kg	413	320
Waste foundry sand	kg	1,267	663
Crushed stone (10–20 mm)	kg	–	1,280
Water	l	290	210

Table 4

Density and strength of vibrated and vibrovacuumized fine concrete on the basis of waste foundry sand

Age of the tested samples	Vibrated concrete		Vibrovacuumized concrete	
	Density, kg/m ³	Strength, MPa	density, kg/m ³	Strength, MPa
1 day	1993.0	1.6	2218.0	4.8
28 days	1980.0	18.6	2210.0	32.4

Table 5

Density and strength of vibrated and vibrovacuumized ordinary concrete on the basis of waste foundry sand

Age of the tested samples	Vibrated concrete		Vibrovacuumized concrete	
	Density, kg/m ³	Strength, MPa	Density, kg/m ³	Strength, MPa
1 day	2373.0	2.3	2428.0	8.4
28 days	2362.0	23.9	2423.0	30.8

When using fine concrete, the strength increase was achieved from 18.6 to 32.4 MPa, or 73 %, and for ordinary concrete – from 23.9 to 30.8 MPa, or 29 %. In both cases the calculated strength of paving stones (30 MPa) was provided by vibrovacuumizing with moderate cement consumption.

According to the above data, the use of vibrovacuum technology for the manufacture of paving stones makes it possible to:

- exclude heat treatment from the production technology;
- reduce the metal consumption of equipment by 1.5–2 times;
- increase labor productivity by 40–60 % (due to the exclusion from the technological process of cleaning, lubrication and assembly of moulds, product stripping, heat treatment);
- provide savings of metal by 30–60 %, cement by 20–30 %, energy resources by 25–50 %.

The low strength of concretes on the basis of WFS is explained by the fact that there is a large amount of dust on the sand grains. The grains are covered with films of binders, and additives of mineral and organic origin. This is a modification due to thermal exposure.

The main component of WFS is quartz sand. Such sand practically does not change its chemical and mineralogical composition. Therefore, the mix can be used as ordinary quartz sand. But only if the grain surface is cleaned of impurities by activation.

In practice, various methods of WFS activation are used. A simple and cheap method of WFS activation with vibration is suggested. For this purpose, vibration equipment, which almost all enterprises of the construction industry have, is recommended for use [1].

The film on the sand grains is destroyed, the protrusions on their surface break off, the surface layer is exposed and new clean surfaces are formed with such treatment of WFS. As a result, the cleaned surface will have better adhesion to the binder, ensuring high-quality concrete with moderate binder consumption.

Ash-and-slag mixes of TPPs. TPP, one of the largest in Europe, throws thousands of tons of ash-and-slag mixes into landfills every day, causing significant damage to the environment.

Fly ash grains are tiny particles ranging in size from a few microns to 0.14 mm. Most of the grains are slagged and rounded. Some of the grains are sanded only from the outside. Under the vitreous shell there are minerals that did not have time to melt at combustion of pulverized coal in the furnace. The structure of the grain itself is due to its very short stay in the high temperature zone. As a result of a rapid increase in temperature, organic substances contained in coal burn out almost simultaneously and the mineral part sinters. The gas released during this process inflates the melt. Sharp cooling of the grains stabilizes the vitreous phase. As a result, fly ash particles are molten grains, many of which have tiny, mostly closed pores.

Slags are glassy grains with a size of 0.3–20 mm and irregular shape with sharp edges. A significant part of the grains has pores of various sizes, which have been formed under the influence of steam when fiery liquid slag enters the water. Sometimes there are larger slag inclusions in this mix – up to 40 mm in size. The chemical composition of ash-and-slag mixes is given in Table 6.

The following materials were used to prepare concrete mixes:

- portland blast-furnace cement M400 (Kryvyi Rih) (ДСТУ Б В. 2.7-46-96);
- fly ash of Prydniprovsk TPP (ДСТУ Б В. 2.7-205:2009);
- tempering water (ДСТУ Б В. 2.7-273:2011);
- electrolyte CaCl₂ (ДСТУ Б В. 2.7-175:2008. ДСТУ Б В. 2.7-69-98).

Concrete mixes with the same mobility S2 (slump 50–60 mm) were prepared.

The results of the authors' research [15] indicate high water demand for ash concrete mixes. In our opinion this is the main reason for the low strength of ash concrete with moderate cement consumption.

First, the efficiency of vibrovacuum treatment of ash concrete mixes without electrolyte was determined. In these studies, a concrete mix with a cement consumption of 280 kg/m³ was used. Samples of 150 × 150 × 70 mm (in order to reduce the influence of the scale factor) were moulded by vibrovacuumizing. These samples were pre-vibrated for 7–10 s, then vacuumized until the removal of excess tempering water

Table 6

Chemical composition of ash-and-slag mixes of thermal power plants

Waste type	Composition of oxides, %							
	SiO ₂	Al ₂ O ₃	FeO + Fe ₂ O ₃	TiO ₂	CaO	MgO	SO ₃	LOI
Ash	41–53	15–22	5–9	0.5	3–4	1–1.6	0.4–0.8	10–14
Slag	48–56	20–28	9–13	0.5	4.5–5	1–1.6	0.5–0.6	0–1

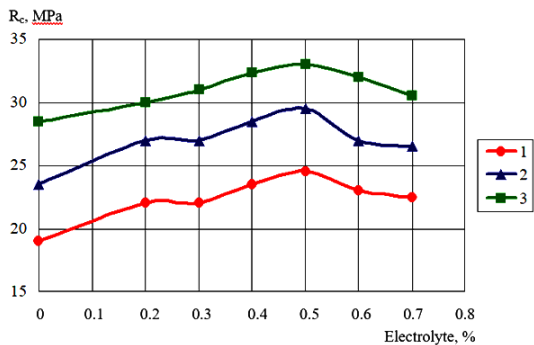


Fig. Ultimate strength of ash-and-slag vacuum concrete depending on the electrolyte consumption:

1 – at cement consumption of 280 kg/m³; 2 – the same, at 350 kg/m³; 3 – the same, at 400 kg/m³

stopped. The vacuum value was 0.7 (perfect vacuum was equal to 1). Periodic vibration (8–10 s) every 1.5–2 min was performed twice during vacuumizing [16].

Adding an electrolyte in the amount of 0.2–0.7 % of the cement consumption can significantly increase the amount of excess water removed, while reducing the duration of vacuumizing. For all accepted cement consumption, the rational electrolyte addition was 0.4–0.5 %. Due to the addition, the largest amount of excess tempering water was obtained (110 l/m³ or 37 %). And the duration of vacuum treatment was reduced from 6 min. to 4–4.5 min that is very important in production conditions [16].

These regularities are also confirmed by the results of strength analysis of vacuum concretes on the basis of ash-and-slag mixes of TPPs (Figure).

Vacuum concrete obtained from concrete mixes with the addition of electrolyte have a higher strength compared to the strength of vacuum concrete from concrete mixes without such an additive. With a rational consumption of electrolyte, the greatest increase in strength was 17–22 % (compared to the strength of vacuum concrete made of concrete mixes without electrolyte). The obtained results can be convincingly explained with the theory of electrolyte coagulation.

The widespread use of concretes on the basis of WFS and waste from TPPs in construction makes it possible to solve the problem of local aggregates, as well as contributes to environmental protection [17].

Conclusions.

1. The optimal mobility of the initial concrete mix, which ensures the most compact placement of components in the vacuumizing process (the highest density), was determined when designing rational compositions of concrete mixes for vacuum treatment. The mobility increases as the cement consumption decreases (with slump 1–2 to 5–7 cm).

2. The results of studies on the main properties of vibro-vacuumized ash-and-slag concrete confirmed that the strength of ash-and-slag vacuum concrete is on average higher than the strength of vibrated concrete from mobile mixes by 6–10 MPa or 60–100 % (depending on the cement consumption).

3. High-quality (high-strength) concretes for various types of construction on the basis of waste foundry sand (WFS) of metallurgical and machine-building enterprises were obtained.

4. The developed technology of vibrovacuum concrete products on the basis of secondary mineral resources of the Dnipro region makes it possible to use the existing technological equipment without fundamental design changes, to carry out immediate dismantling of moulded products, which reduces significantly the metal consumption of the technology.

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Удосконалення технології бетону та будівельних розчинів із використанням вторинних мінеральних ресурсів

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Мета. Удосконалення технології бетонів на основі вторинних мінеральних ресурсів (відпрацьованих формувальних сумішей металургійних і машинобудівних підприємств (ВФС), золошлакових сумішей теплових електростанцій (ЗШС)).

Методика. У роботі застосовані загальноприйняті стандартні методи при дослідженні основних властивостей сировинних матеріалів, бетонних сумішей і бетонів. Формування зразків здійснювалося за допомогою спеціально виготовленого лабораторного вакуумного обладнання.

Результати. Результати досліджень основних властивостей бетонів на основі вторинних мінеральних ресурсів підтвердили ефективність використання вібровакуумної технології при їх виробництві. Так міцність золошлакового вакуумбетону в середньому вище міцності віброу-

щільненого бетону з рухомих сумішей на 6–10 МПа або на 60–100 % (у залежності від витрати цементу). Також отримані бетони високої якості за помірних витрат цементу для різних видів будівництва на основі ОФС.

Наукова новизна. Розроблені науково-технічні основи технології вібровакуумування бетонів на основі ВФС і ЗШС.

Практична значимість. Завдяки розробці технології вібровакуумованих виробів на основі бетонів на вторинних мінеральних ресурсах отримані бетони високої якості (підвищених міцності, морозостійкості та ін.) для дорожнього та інших видів будівництва. Дана технологія дозволяє використовувати існуюче технологічне обладнання без принципових конструктивних змін, здійснювати негайне розпалублення відформованих виробів, що суттєво зменшує металоємність технології.

Ключові слова: *вторинні мінеральні ресурси, відпрацьовані формувальні суміші, золошлакові суміші, вібровакуумування, бетонні суміші*

The manuscript was submitted 30.06.21.