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An Artificial Lightweight Aggregate Based on Non-ferrous Metallurgy Slags

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Abstract— *This paper relates to the obtaining of an artificial porous aggregate from slag waste of non-ferrous metallurgy. The developed technology permits to widen raw stuff basis of producing artificial porous aggregates for lightweight concretes.*

The investigations have demonstrated that granulated slags which are a by-product and are obtained through making non-ferrous metals, can be utilized as a basic starting raw material for manufacturing an artificial porous aggregate.

From the results of the investigations expansion intervals of a mass based on the studied slags of metallurgical plants are determined. The technology of obtaining an artificial porous aggregate with the prescribedphysico-mechanical characteristics has been worked out.

The main physico-mechanical characteristics of the produced aggregate have been studied. It has been revealed that the obtained artificial porous aggregate meets the requirements of the acting standard GOST 9757-90 "Gravel, Crushed Stone and Sand, Artificial Porous" by its physico-mechanical characteristics.

It is found that the strength of the obtained aggregate 1.5-2.0 times exceeds that of the well-known aggregate- keramzit gravel.

Using porous sand lightweight concrete of B7.5-B40 strength class with density of 1100-1600kg/cu.m has been produced on the base of the obtained gravel and high-strength lightweight concrete of strength class B25-B50 with density of 1500-1800 kg/cu.m has been manufactured with the use of dense sand and plasticizing additives.

Keywords— ***artificial porous aggregate, density, strength, expansion temperature, high-strength lightweight concrete.***

I. INTRODUCTION

Economy of fuel and energy resources, reduction in consumption of materials of building structures, improvement of their quality, increase in heat-shielding characteristics, lessening of mass of buildings and structures are the most important problems of construction.

One of the most efficient ways of solving these problems is the manufacture and use of products and structures from lightweight concretes made with artificial porous aggregates.

The reduction in proper weight of reinforced concrete structures at the expense of using lightweight concrete instead of heavy-weight one brings about considerable economy of building materials and improvement of thermal technological features of buildings and structures.

One of effective ways of solving this problem is the production of lightweight concretesmade with artificial porous aggregates [1, 2, 3, 4, 5].

The broadening of raw stuff basis of making an artificial lightweight aggregate by means of utilizing waste of industrial enterprises leads to improvement of ecological situation. In this case a method of obtaining a lightweight aggregate with the use of metallurgical slags as the basic raw staff is of practical significance and presents a topical problem [6,7, 8].

The use of slags in the manufacture of artificial porous aggregates makes it possible to save material, labour and natural resources, to solve the problem involving secondary resources in the production of building materials to some extent and to protect environment from pollution [9, 10].

The aim of the research is to reveal a possibility of obtaining and determining the main regularities of

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guided control of porous structure and phase composition of aggregates based on slag waste of non-ferrous metallurgy and to develop a technology of producing porous aggregates with the prescribed physico-mechanical characteristics.

The basis of research is the working hypothesis about the possibility of obtaining porous aggregates with uniform porous structure, regulated phase composition and prescribed physico-mechanical properties in transition from pore formation of fire-liquid slags to the expanding of granules originated from granulated slags. These aggregates were planned to be obtained from metallurgical slags.

Investigations aimed at broadening raw stuff basis and utilizing industrial waste to produce high-effective aggregates were performed at the Research and Design Institute of Building Materials named after S.A.Dadashev (Baku) and a new technology of obtaining artificial porous aggregates for lightweight concretes from glass-containing waste-slags of non-ferrous metals – was elaborated using the results of the above-mentioned investigations [11, 12].

II. EXPERIMENTAL PROCEDURE

The experimental investigations were conducted using various granulated slag of non-ferrous metallurgy and correction additives as the main raw stuff.

In developing batch composition plastic clays were taken as binding additives for the purpose of raw granule hardening and mineral, organic or organ mineral additives were employed as gas-generating agents.

The experimental investigations were conducted in three stages: preparation of the batch and raw granules making at the first stage, studying into mass expansion kinetics and aggregate structure formation at the second stage, studying into petrography and physico-mechanical properties of the artificial porous aggregate being obtained at the third stage. When performing the experimental investigations X-ray (diffraction), differential thermal and petrographic analyses were employed.

The performance of industrial tests and specification of technological parameters of porous gravel fabrication were carried out on a production line of the Research and Design Institute of Building Materials named after S.A.Dadashev.

III. MATERIALS

In conducting the experimental investigations slags of Karabash integrated copper smeltery and slags of Ufaley integrated nickel plant were used as the basic raw stuff materials.

The bulk density of non-ferrous metallurgy granulated slags varies between 1670 and 1920kg/cu.m. The density of such slags is 2.78-2.92 g/cu.cm. Basicity modulus of the granulated slags of Karabash integrated copper smeltery is 0.17 which relates to a group of acid slags and basicity modulus of the granulated slags of Ufaley integrated nickel plant is 1.28 which relates to a group of basic slags. Chemical compositions of the granulated slags from nickel and copper production are given in Table 1.

Table.1: Chemical composition of non-ferrous metallurgy slags after magnetic separation

No	Kind of slag	Oxide content, %							
		SiO_2	Al_2O_3	$FeO + Fe_2O_3$	MgO	CaO	S	SO_3	∑
1.	The slag of Karabash integrated copper smeltery	37,41 / 52,75	6,28 / 12,3	47,0 / 16,2	0,89 / 1,4	6,59 / 12,84	0,61 / 0,85	1,22 / 2,80	100,0 / 99,2
2.	The slag of Ufaley integrated nickel plant	44,50 / 45,54	9,78 / 12,8	21,5 / 14,8	11,0 / 13,6	12,3 / 12,9	- / -	0,12 / 0,16	100,0 / 99,8

Note: above the line – oxide content before magnetic separation
under the line – oxide content after magnetic separation

With the use of a gas-generating and a binding additive a batch was being prepared which was ground till the specific surface of 2500-3500sq/cm/g and specimens in the shape of cylinder with diameter and height of 16 mm as well as granules of 5-10 mm fraction were made from the obtained powder on a plate granulator.

The specimens prepared from the non-ferrous metallurgy slags of Ufaley integrated nickel plant with basicity modulus of $M_0>1$ and from the slags of Karabash integrated copper smeltery with basicity modulus of $M_0<1$were expanded under various conditions.

IV. ANALYTICAL INVESTIGATIONS

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One of the main requirements for pore formation of the masses under study made on the base of metallurgical slags is primary crystallization of phases contained in the slags. X-ray (diffraction) analyses show that in the process of rapid cooling granulation in both kinds of slags occurs in normal enough conditions, degree of crystallization is nearly absent. The main constituent on the X-ray photograph of the granulated slags is vitreous phase.

FeO content is 21.5% in chemical composition of the slag of Ufaley integrated nickel plant while $FeO + Fe_2O_3$ content in the slag of Karabash integrated copper smeltery reaches 45-47%.

That is why for pore formation of the mass prepared from such slags having high content of iron oxide or monoxide in its composition it was intended to subject the dispersed powder obtained from the slags to magnetic separation with the purpose of lowering iron content in the mass composition.

To achieve this aim, after the slag grinding the powder was passed through a magnetic separator and then its chemical composition was determined. The investigation results given in Table 1 demonstrate that after magnetic separation iron content in the slag composition falls considerably. A decrease in Fe_2O_3content in the mass composition causes a rise in $SiO_2$and Al_2O_3content in the mass composition which is positive for the nature of mass bloating. Due to this fact it is recommended to pass the batch through magnetic separator after grinding for further studies and also when organizing production of a porous aggregate on the base of non-ferrous metallurgy slags.

The specimens prepared using gas-generating and binding additives were subjected to expansion.

The results of investigations into expansion of the mass based on the studied slags as well as a change in density of the expanded specimens can be seen in Fig.1.

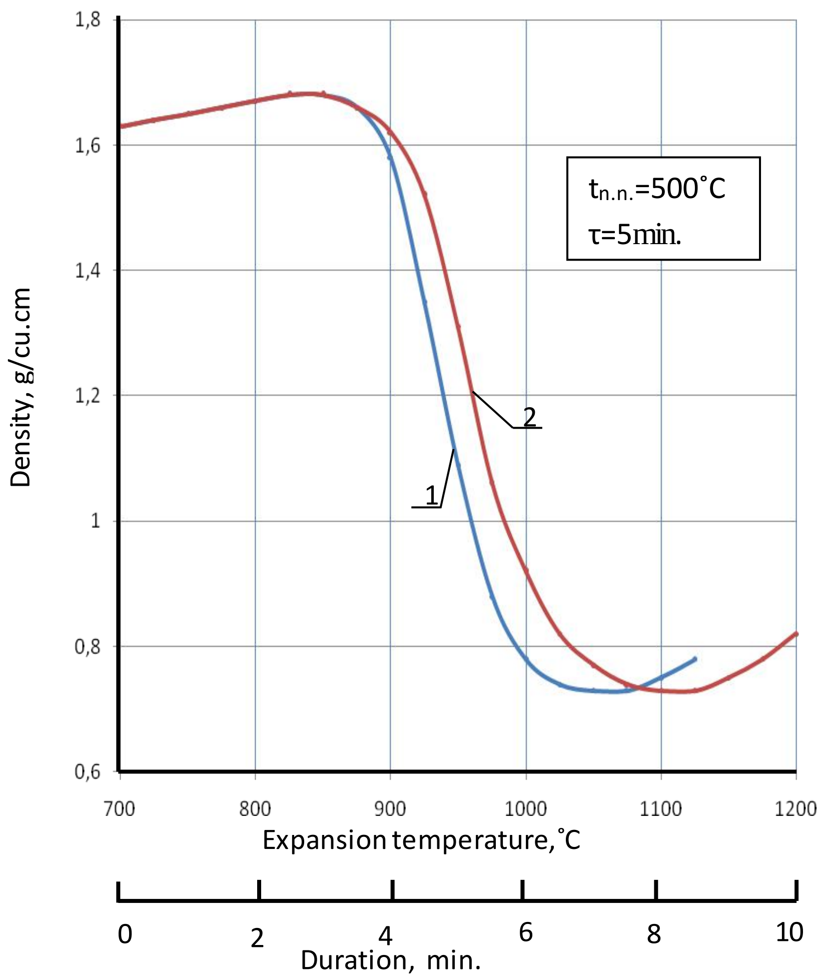

Fig.1: The influence of expansion conditions on pore formation process and density of the expanded specimens based on the mass from non-ferrous metallurgy slags.

1- slags of nickel production;
2- slags of copper production.

It is seen from Fig.1 that the process of pore formation of the mass and of appearance of porous

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structure of the aggregate is substantially influenced by their expansion conditions.

The primary porous structure arises during formation of raw specimens in the shape of cylinders and granules. The density of raw granules in dried state is 1.60-1.62g/cu.cm. A major part of pores formed in this period is observed in the course of their thermal treatment.

The investigation results have demonstrated that under the action of high temperatures the softening of individual particles, sintering, compaction and deformation of the specimens develop within a temperature range from 750^0C to 850^0C. The density in this case goes up to 1.66-1.68 g/cu.cm. The evolution of gaseous phase starts at a temperature of $850\text{-}880^0$C and these gases which cannot escape through the shell create excessive pressure in the inner cavity under the action of which bloating – expansion of granules begins.

Intensive expansion and formation of porous structure continue before a temperature of $1050\text{-}1150^0$C. Optimal porous structure develops at a temperature of $1000\text{-}1150^0$C. The density of the expanded specimens goes down to 0.72-0.73 g/cu.cm. The expansion process ends when the gas evolution process is completed. A further rise in expansion temperature up to $1120\text{-}1200^0$C brings about an increase in the density of the expanded specimens to 0.80g/cu.cm. Optimal expansion temperature lies in the range between 1050 and 1150^0C^{0}C.

From Fig.1 it is seen that during high-temperature treatment transition of the material to pyroplastic state, deformation and maximum shrinkage take place within 3 or 4 minutes.

The start of gas evolution and a decrease in density are observed after the fourth minute. Intensive expansion and porous structure formation occur for 4-7minutes. The completion of the expansion process is detected at the seventh or ninth minute. A further increase in expansion duration to 10 minutes results in fusion of the surface of granules and a gain in the aggregate density.

The investigation results show that the process of expansion and obtaining of the aggregate from non-ferrous metallurgy slags consists of three main stages: dispersion and development of primary structure during granulation, sintering with the formation of closed pores and expansion itself under pressure of gases evolving inside closed pores.

The obtained aggregate expanded at a temperature of $1050\text{-}1150^0$C is characterized by dark grey color, fine pore structure. The pores are of various shapes, they are chiefly regularly spherical, of 5-8 mcm to 0.5mm in diameter. The pores are uniformly distributed over the whole volume of granules, beginning from the granule surface to its centre. Structure elements are represented by vitrified substance interspersed by amorphized material of dark grey color.

The pore content attains 68-70%. Fig. 2 demonstrates microstructure of the aggregate manufactured on the base of non-ferrous metallurgy slags.

So, the investigation results have shown that when non-ferrous metallurgy slags are used as basic raw stuff for producing the artificial porous aggregate they must be ground together with gas-generating and binding additives, the mass must be granulated, raw granules should be made and expanded under optimal conditions. If gas-generating additives are utilized it is necessary to use mineral and organic additives in combination.

The results of laboratory investigations have undergone tentative industrial tests on the production line of the Research and Design Institute of Building Materials named after S.A.Dadashev. A tentative production batch of porous gravel based on slags of Karabash integrated copper smeltery was manufactured. Physico-mechanical characteristics of a pilot batch of slag gravel were tested according to GOST 9757-2012 “Inorganic Aggregates for Concrete. Testing Methods” [13].

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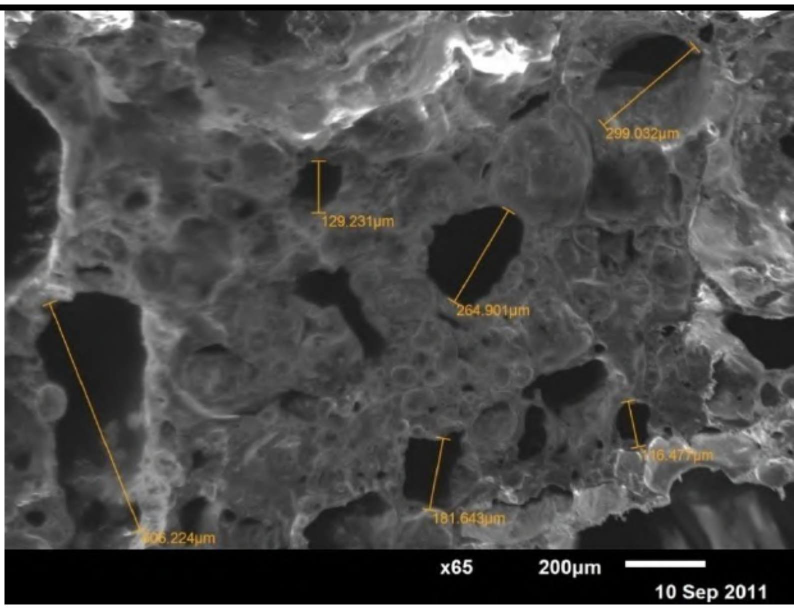

Fig.2: Microstructure of porous gravel based on granulated slags of non-ferrous metallurgy (magnification x 65).

Batch compositions, burning conditions and physico-mechanical properties of slag gravel fabricated on the pilot production line are given in Table 2.

Table.2: Batch compositions, burning conditions and physico-mechanical characteristics of slag gravel manufactured on the base of slags of Karabash integrated copper smeltery(semi-production tests)

Batch composition, % by mass			Burning conditions		Physico-mechanical characteristics of the aggregate	
slag	clay	additive	expansion temperature, ^0C	expansion duration, min.	bulk density, kg/cu.m	compression strength in cylinder, MPa
73,5	15	mineral 10%	1050-1070	6-8	420	3,0
					480	3,8
					520	4,8
		organic 1,5%		8-10	580	6,2
					650	7,8
					760	9,6

The obtained aggregate is of rounded shape, its surface is slightly rough, by shape and nature of the surface of granules it is classified as a gravel-like artificial porous aggregate. The main physico-mechanical properties of the manufactured aggregate are studied.

It has been revealed that by its physico-mechanical properties the obtained porous aggregate meets the requirements of the acting standard [14]. It has been found that the obtained aggregate is 1.5-2.0 times stronger than the well - known keramzit gravel.

The results of the conducted investigations and semiproduction tests demonstrate that it is possible to obtain a lightweight aggregate with highly favourablephysico-mechanical properties on the base of slag waste of non-ferrous metallurgy. Such aggregates can be effectively used as basic raw stuff when manufacturing an artificial porous aggregate for the production of lightweight heat-insulating, heat-insulating structural and structural concretes.

The obtained porous gravel is tested in concrete and optimal compositions of concrete mixes are worked out. It has been revealed that using porous gravel and sand lightweight concrete of B7.5-B40 strength class and density of 1000-1700kg/cu.m has been obtained and with the use of natural dense sand and plasticizing additives lightweight concrete of B25-B250 strength class and density of 1600-1800kg/cu.m has been made. The consumption of cement for 1cu.m of concrete is 210-550kg.

V. CONCLUSIONS

1. The possibility of utilizing non-ferrous metallurgy slags as basic raw staff for manufacturing an artificial porous aggregate is proved.

2. Expansion kinetics of the mass based on non-ferrous metallurgy slags is studied, mechanism of expansion process and regularities of porous structure formation are revealed, dependencies of the main physico-mechanical properties of the obtained aggregates on temperature-and-time parameters are determined.
3. The technology of producing artificial porous aggregates on the base of non-ferrous metallurgy slags is developed and a qualitatively new light weight aggregate with bulk density of 420-760kg/cu.m and compression strength in cylinder of 3.0-9.6MPa is obtained under production conditions.
4. The obtained porous gravel is tested in concrete. It has been found that using porous gravel and sand lightweight concrete of class B7.5-B40 by strength and density of 1100-1700kg/cu.mis produced and with the use of natural dense sand lightweight concrete of B25-B50 strength class and density of 1600-1800kg/cu.mis made. The consumption of cement for 1cu.m. of concrete is 210-550kg.

REFERENCES

[1] Rogovoy M.I. Technology of Artificial Porous Aggregates and Ceramics // Ekolit, 2011, -320pp.
[2] Korolev E.V., Inozemtsev A.S. High-strength Lightweight Concretes: Structure and Properties / / Concrete and Reinforced Concrete - a Look into the Future. III All-Russian (II International) Conference on Concrete and Reinforced Concrete, Vol. V, M., 2014, pp.277-285.
[3] Davidyuk A.N. Lightweight Concretes Made with Glass Granulates - Future of Space Enclosing Structures, Concrete and Reinforced Concrete, 2016, No. 1, pp.2-4.
[4] Bazhenov Yu.M., Korolev E.A. and others. Space Enclosing Structures with the Use of Low Heat-Conduction Concretes. Fundamentals of the Theory, Methods of Calculations in Technological Design.M., ASV, 2008, -320s.
[5] Yermakovskiy V.N., Semchenkov A.S. Structural Lightweight Concrete of New Modifications - in Resource-saving Structural Systems of Buildings // Academia. Architecture and Construction, 2010, No 3, pp.31-39.
[6] Antonenko L.V., Bigildeeva G.M. etc. The Use of Thermal Power Station Slags for Keramzit Production.Science techn.abstr. inf., series "Ceramic Wall Materials and Porous Aggregate Industry". M., VNIISMM, 1980, No 1, pp.1-6.
[7] Babenishev V.I. Reducing Volume Density of Expanded Clay by Adding Waste of Coke and Benzene Production Waste. Journal "Building Materials", 1977, №10, 12 pp.
[8] Zavadsky V.F., Onitsenko A.I., OznobukhinYu.I., Okun F.I. Obtaining Claydite Gravel Using an Oil Sludge Additive. Ref. inf., Ser. Ceramic Wall Materials and Porous Aggregate Industry. M., VNIISMM, 1981, issue 2.
[9] The Use of Steel-melting Slags in Building Materials. Review .inform., Ser. II. Use of Waste, By products in the Fabrication of Building Materials and Products. Environmental Protection, Moscow, VNIISMM, 1983, 40 pp.
[10] Belik G. Ya., Dumcheva V.V., Mishurin Yu. N. Use of Shale Ash of Thermal Power Station Dumps Abstr. Inform. Series 4, Ceramic Wall Materials and Porous Aggregate Industry, M., VNIISMM, 1980, issue 6, pp.6-7.
[11] Mamedov G.N. High-strength Artificial Porous Aggregates, Baku, 2000, -222pp.
[12] Mamedov G.N., Mirzoyev M.M. Porous Gravel Based on Various Slags and Low Expansion Stone-like Clays, High-strength Lightweight Concretes on Their Base// M., Concrete Technology, No 11, 2014, pp.16-18.
[13] GOST 9758-12 "Inorganic Aggregates for Concretes. Testing Methods".
[14] GOST 9757-90 "Gravel, Crushed Stone and Sand. Artificial Porous. Specifications".