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UTILIZING OF THE METALLURGICAL SLAG FOR PRODUCTION OF CEMENTLESS CONCRETE MIXTURES

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Preliminary Note – Prethodno priopćenje

In process of pig iron, steel and cast iron production besides main product, also secondary products are formed, that have character of secondary raw materials and industrial wastes. The most abundant secondary product originating in the metallurgical process is furnace slag. Total amount of accured slag, also its chemical, mineralogical, physical – chemical properties and similarity with natural stones predestinate its utilisation in different fields of industry.

The contribution deals with production of cementless concrete mixtures, where the main parts were formed by blast furnace granulated slag grinded and different gravel slag from blast furnace, oxygen converter and electric arc furnace. As activators of solidification different kinds of water glass were tested.

Key words: metallurgical slag, cementless concrete, building industry, water glass

INTRODUCTION

Production of metallurgical slag is a huge load for environment from a viewpoint of their quantity. Development of new technologies in the area of preparing of the charge results into reducing quantity of slag, and also amount of emissions per one tone of pig iron or steel [1-2]. It is impossible to reduce the slag quantity on that level which affords us to stop concerning with the problem of the by-product treatment.

Chemical similarity of metallurgical slag with some natural gravels enables its utilization mainly in highway engineering and in production of expanded building materials [3-4]. Next possibilities of utilization of the slag from production of iron and steel are given in [5-7].

The goal of this contribution was to refer possibilities of cementless concrete mixtures preparation that have high values of mechanical properties and that consist only from a slag grave. In a part of experiments a ground granulated blast furnace slag was used as a substitution of a part of different kinds slag in mixtures. As an activator of solidification a water glass was used.

USED EXPERIMENTAL MATERIALS

In previous years at the Department of Ferrous Metallurgy and Foundry (Faculty of Metallurgy, Technical University in Kosice) many different experiments were realized in an effort to find new ways how to use metallurgical slag [8-10].

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Chemical composition of metallurgical slag is variable and depends on chemical composition of the charging materials and a melting technology [11-13]. The following types of slags were used in the experiments: the slag from electric arc furnace (EAFs), the slag from oxygen converter (BOFs) and the blast furnace slag (BFs). The chemical composition of fraction 0-4 mm, 4-8 mm and 8-16 mm of all slag is shown in Table 1, where the chemical composition of the granulated blast furnace slag that was used in part of experiments is also given. As an activator a water glass 44-46 ° Be was used.

By preparing of cementless concretes the following slags fractions were used: 0-4 mm, 4-8 mm, 8-16 mm. The fraction 0-4 mm was analysed detailed, because it has probably the greatest impact on the amount of added water glass. The amount of dust particles under 0,5 mm (in fraction 0–4 mm) in slag from electric arc furnace (EAFs) was 10 %, in slag from oxygen convertor (BOFs) it was over 54 % and in blast furnace slag (BFs) it was 41 %. From these results we assumed that amount of water glass is higher by preparing of BOFs mixture then by another mixtures.

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Table 1 **Chemical composition of used slag / mass %**

Chemical composition	EAFs			BOFs			BFs			
	fractions			fractions			fractions			
	0-4/ mm	4-8/ mm	8-16/ mm	0-4/ mm	4-8/ mm	8-16/ mm	0-4/ mm	4-8/ mm	8-16/ mm	granulate
Fe tot.	31,44	31,67	39,6	18,82	21,78	21,78	-	-	-	-
FeO	27,73	33,62	42,82	15,09	17,53	17,53	0,86	3,59	0,72	0,22
Fe_2O_3	14,22	8,02	9,16	10,18	11,71	11,71	0	0	0	0
SiO_2	12,36	12,41	10,64	9,36	13,49	13,49	40,02	32,48	38	38,71
CaO	24,44	24,66	22,08	39,42	38,13	38,13	37,12	39,26	39,94	39,15
MgO	6,93	6,66	4,07	8,61	10,35	10,35	9,68	10,65	10,57	9,8
Al_2O_3	5,25	5,32	3,11	1,96	2,88	2,88	8,3	6,69	7,59	8,42
MnO	5,59	5,64	5,37	2,99	3,97	3,97	0,65	1,3	0,62	0,65
P_2O_5	0,54	0,63	0,64	0,65	0,76	0,76	-	-	-	-
C	0,46	0,07	0,38	2,19	0,22	0,22	-	-	-	-
S	0,041	0,092	0,1	0,06	0,041	0,041	-	-	-	-

THE EXPERIMENT DESCRIPTION

Nine mixtures for the production of concrete were prepared. Mixtures EAFs1 and 2 consisted of slag from electric arc furnace in fractions 0-4 mm, 4-8 mm and 8-16 mm, mixtures BOFs1 and 2 of the fractions of oxygen converter slag and BFs1 and 2 of the fractions of blast furnace slag (from blast gravel). The content of fraction 0-4 mm in all mixtures was constant, consequently 50%, because it is a fraction that affects the properties of concrete very much, fraction 4-8 mm in the samples EAFs1, BOFs1 and BFs1 was 26,5% and in samples EAFs2, BOFs2 and BFs2 was its amount 36,5%. Fraction 8-16 was calculated to 100%. The addition of water glass was 16,9% of the total weight of the mixture (based on calculations and on the results of previous experiments) [10-11]. The slag fractions has been placed to the paddle mixer, and they were mixed for 1 minute, then water glass 44 – 46 °Be was added to the homogenized mixture as an activator and the mixture was mixed for a further 2 minutes. Molds of a cube shapes were filled up with the prepared mixtures and rammed with pneumatic plugging bar. After solidification the samples were removed from the molds and left on air for 7 days. During this period the samples were hardened. Subsequently, the samples were tested for compression strength. The composition of used mixtures is shown in Table 2.

Mixtures EAFs1 and EAFs2 (from slag from electric arc furnace) were mixed and formed very well. It could be caused of low content of dust particles in the fraction 0-4 mm. Samples EAFs1 and EAFs2 should be kept in the molds for 24 hours. During this time they should harden and then they should be taken out of the mold. After 24 hours the samples were not harden and they were therefore left in the molds for next 4 days. As seen on Figure 1a, after the taking out of the samples from the molds the cementless concrete mixture samples of slag from electric arc furnaces were practically broken, only a thin layer on the surface of samples was hardened. By the preparation of samples BOFs1 and BOFs2 was observed that the addition of water glass (16,9% of the weight of the mixture) was insufficient, because the mixture was mixed very difficult and it was rammed very difficult too.

From this reason 22% of water glass into the sample BOFs2 was added. The samples were completely hardened after 24 hours they were left in molds for 4 days, Figure 1b. Mixtures from blast furnace slag (BFs1, BFs2) were relatively moist during the molding and they were rammed very well in to the molds. They were hardened after 48 hours but after removal they were disintegrated, Figure 1c.

In the next part of the experiments the fraction 8-16 mm in all samples (EAFs, BOFs and BFs) was replaced by blast furnace ground granulated slag. It had a role of

Table 2 **Composition of cementless concrete mixtures and their compression strengths**

Mixture	Composition of mixture					Compression strength on cube /MPa
	0-4 mm/ mas.%	4-8 mm/ mas.%	8-16 mm/ mas.%	BFs ground granulated/ mas.%	Addition of Water glass 44-46 °Bé/ mas.%	
EAFs1	50	26,5	23,5	-	16,9	**Non-analyzed**
EAFs2	50	36,5	13,5	-	16,9	**Non-analyzed**
BOFs1	50	26,5	23,5	-	16,9	**9**
BOFs2	50	36,5	13,5	-	22,0	**7,1**
BFs1	50	26,5	23,5	-	16,9	**Non-analyzed**
BFs2	50	36,5	13,5	-	16,9	**Non-analyzed**
EAFsG	26,5	23,5	-	50	20,0	**1,6**
BOFsG	26,5	23,5	-	50	25,3	**30,0**
BFsG	26,5	23,5	-	50	23,3	**36,5**

a) EAFs1 b) BOFs1 c) BFs1

Figure 1 Samples of cementless concrete mixtures after removal from the molds

cement and it should to increase the strength properties of produced concrete.

The addition of water glass was individual for each type of slag with respect to its absorption and porosity and it ranged from 20 to 25,5%. The samples containing a granulated ground blast furnace slag (EAFsG, BOFsG and BFsG) were after removing from molds (Figure 2) intact, and they were left on the air for next 7 days.

ACHIEVED RESULTS AND THEIR DISCUSSION

Mixtures composition and their compression strengths are given in Table 2. It follows from the table that mixtures containing only slag from EAF and from blast furnace slag (in the composition given in Table 1) are inapplicable by concrete production because they were disintegrated. It could be caused their chemical composition, above all low content of CaO and SiO_2 and granulometry too, because the fraction 0-4 mm contained more then 60% of grains bigger then 2 mm, hence it followed that this kind of slag grave had by the same volume markedly smaller reactive surface. The compression strength of mixtures containing only slag from oxygen converter moved in the range from 7,1 to 9 MPa. This strength is a sufficient criterion of the strength for a lower class of concrete C8/10 by STN EN 206-1:2002, but in spite of this the mixture can not be used in praxis because of their low strength properties. In samples EAFsG, BOFsG and BFsG the slag fraction 8-16 mm was replacing by ground granulated slag, that behaved as the cement and it should improve the strength properties of prepared concretes.

The addition of ground granulated BF slag in the mixture of EAF slag (sample EAFsG) has caused its solidification but the final strength was very low (1,6 MPa) and the mixture was not sufficiently for the lower class of concrete. By the mixtures from oxygen converter slag the addition of granulated BF slag followed to arise of the strength – up to 30 MPa. It is a minimum value for the class of concrete C25/30. In the fall of mixture from BF slag the addition of ground granulated BF slag caused the improving of the strength on the level of 36,5 MPa – class of concrete C30/37, and it accords with the high quality concretes. All mixtures with addition of ground granulated slag were sufficiently hard and suitable for practical applications.

It results from the experiments that the addition of ground granulated slag has a significant influence on the strength of cementless mixtures. Behaviour of individual slags in the mixtures was influenced of their porosity and fine dust particles in the fraction 0-4 mm.

With increasing of dusts particles amount in the fraction 0-4 mm the compression strength of concrete was increased too.

RESULTS

The main goal of this contribution was to proposal and prepare cementless concrete mixtures and testing of their properties for above of compression strength. The

a) EAFsG b) BOFsG c) BFsG

Figure 2 Samples of cementless concrete mixtures with addition of blast furnace ground granulated slag after removal from the molds mixtures contained slag from electric arc furnace, oxygen convertor and from blast furnace slag in fraction 0-4 mm, 4-8 mm, 8-16 mm.

In a part of experiments the fraction 8-16 mm was replaced with ground granulated blast furnace slag. As an activator of solidification the water glass 44-46 °Be was used.

It was find by experiments:

- The best strength properties were achieved by mixtures in that the fraction 8-16 mm was replaced by ground granulated blast furnace slag in the amount of 50 %.
- All mixtures with addition of ground granulated slag had a sufficiently compression strength suitable for practical application.
- By mixtures with oxygen convertor slag the addition of ground granulated slag caused the high rise of compression strength on the level of 30 MPa, what is a minimal value for the class of concrete C 25/30.
- In the case of mixtures from blast furnace slag the addition of ground granulated blast furnace slag followed to increase of compression strength up to 36,5 MPa (class of concrete C30/37). It corresponded with high quality concrete.
- All mixtures with addition of ground granulated slag were sufficiently hard and suitable for practical application.

It is clear that not only compression strength determines using of concrete. It is necessary to exam some properties of concrete during the long lasting application directly in the ground. Production of concrete mixtures from the slag can make effectively utilization of slag graves created by production of pig iron and steel.

Generally the cementless concrete mixtures are still in the phase of research because it is necessary to find the most suitable rate of fraction and activator of solidification. The next very important factor which can influence very markedly the next possibilities of slags utilization is an economical point of view.

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