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Quick Setting Composition Based on Steelmaking Metallurgical Slag

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Abstract. The article deals with the problem of utilizing steelmaking slag from the production of rapid hardening composition in Izhstal, CJSC (Izhevsk, Russia), determining its physical and mechanical characteristics, and applying its properties for renovation and reconstruction.

The physical and mechanical characteristics of the developed mortar exceed the existing analogues in many parameters (setting speed, strength). Dry mortar has a short setting time (the end of setting occurs 3,5 minutes after mixing with water at W/S = 0,3), its strength being 66,8 MPa after 28 days of normal hardening. The results show this mortar can be used for emergency renovation work to stop leaks in concrete, stone and brick structures. The studies were conducted using the methods of physical and chemical study of the structure and properties of the produced composition. The developed composition helps reduce the environmental pressure in places of electric steelmaking slag dump.

Keywords: slag utilizing, technogenic waste processing, electric steelmaking slag, rapid hardening mortars, structuring of cement compositions.

Conference topic: Environmental protection.

Introduction

Chemical composition and properties of many types of industrial waste are similar to those of natural raw materials used in the construction industry. An example of such large-tonnage waste is electric steelmaking slag (ESS).

Blast-furnace slags have long been used in the production of building materials as blast-furnace cement component. However, steelmaking slag is much less applied, which is primarily associated with the heterogeneity of the composition, the variability of its physical and mechanical properties and a tendency for silicate decomposition (Ping *et al*. 2013; Sato *et al*. 1986).

The chemical and mineral composition of slag varies greatly according to gangue composition, fuel, type of smelted metal and characteristics of smelting process, combustion conditions and, finally, cooling conditions (Khamatova, Khohryakov 2016). The chemical composition of many kinds of metallurgical slag issimilar to Portland cement and aluminate cement. Efficient use of these technogenic materials in producing binders has been in the focus of researchers and practicians (Dvorkin, L. I., Dvorkin, O. L. 2007; Pugin 2012).

Izhstal, CJSC (Izhevsk Metallurgical Plant) dumps about 2,000 tons of electric steelmaking slag monthly. Slag is produced in the process of steelmaking in electric furnaces.

Currently, steelmaking slag is subjected to coarse crushing in order to extract steel scrap. The metal extracted from scrap by means of magnetic separation is brought back to the main production cycle. The remaining waste is crushed into graded gravelused in road filling (Khamatova, Khohryakov 2015).

High activity of the studied slag makes it excellent raw material for producing cement binders. Due to its ability to expand and self-tighten, slag can be used as a component of non-shrink renovation and waterproof mortars. Therefore, our research offers an alternative way of ESS processing.

Materials and results

The object of this study is dry mortar produced by means of short mixed grinding (2 min) up to the specific surface of 6770 cm^2/g of the following components:

- Portland cement CEMI 42.5 B produced by Ulyanovskcement, CSC, Novoulyanovsk, Russia (60% from the mass of dry mortar);
- gypsum plaster G-4BII produced by Prikamskaya Gipsovaya Kompanya, LTD, Perm, Russia (12% from the mass of dry mortar);
- slag (28% from the mass of dry mortar).

The components were ground in a vibrating ball mill SVM-3with the engine capacity of 3 kW and the grinding chamber capacity of 10 produced by Opytny Zavod so Specialnym Buro, LTD (Moscow, Russia).

The principles of mechanical activation also enhance other construction and performance characteristics of the composition due to the combined fine grinding of cement grains and steelmaking slag, as well as increasing the mortar homogeneity (Boldyrev 2006; Trautvain *et al*. 2011; Takada 2004).

The studied slag is typically characterized with silicate and ferric decompositions. Such decomposition exposure makes its immediate use after cooling impossible. Therefore, the study used stabilized slag stored for 6–8 months in normal conditions to produce a stable structure. The decomposition was also accelerated with the crushing and subsequent grinding of slag right before being added to cement systems. Due to the low grindability of slag before being added to the dry mortar, it was subjected to further grinding up to the specific surface of 5200 cm^2/g. The slag characteristics are shown in Table 1.

Table 1. Characteristics of electric steelmaking stag produced by Izhstal, CJSC

№	Characteristic	Unit	Value
1	True density	kg/m^3	3500
2	Tap density – before grinding – after grinding	kg/m^3	1460 1510
3	Voidage	%	57
4	Specific surface – before grinding – after grinding (during 10 min)	cm^2/g	1448 5200
5	Grindability index	m^2/sec	1.74
6	pH of 10 % solution	–	11.8
7	Strength hydraulic activity (28 days), MPa	MPa	2.9

The hydraulic activity of stabilized ground slag was determined, and at the age of 28 days its strength was found not to exceed 3 MPa (see Table 1). The mineralogical composition of ESS was studied by means of X-ray diffraction (Fig. 1). The findings suggest that crystalline phases prevail in the structure of set slag with the minimum content of glassy formations. The predominant minerals are mayenite, periclase, belite, and portlandite. Some minerals can react with water forming such hydrated compounds as CSH, $Ca(OH)_2$, etc. This capability is likely to have a positive impact on the hydraulic activity of ESS, and also the strength development, Portland cement and slag working together in the rapid hardening composition.

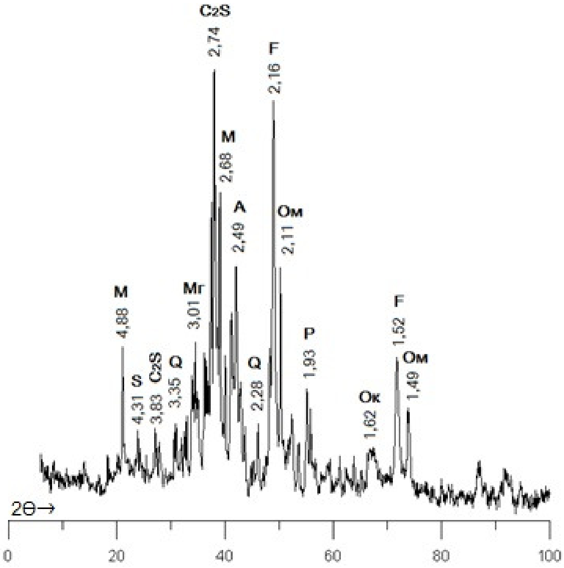

Fig. 1. X-ray of ESS:
M – mayenite ($12CaO\cdot 7Al_2O_3$); S – calcium metasilicate – wollastonite ($CaO\cdot SiO_2$); C_2S – belite ($2CaO\cdot SiO_2$); Q – silicon dioxide (SiO_2); Мг – magnetite (Fe_3O_4); A – monocalcium aluminate ($CaO\cdot Al_2O_3$); F – wustite (FeO); Ом – periclase (MgO); P – Portlandite ($Ca(OH)_2$); Ок – calcium oxide (CaO)

The physical and mechanical characteristics of rapid hardening mortar were determined using cube samples with 2 cm edge. The performance characteristics of the produced mortar (see Table 2) are presented in comparison with the existing industrial analogues of GIDROPAKOL-stop (Gidrointekh-plus, LTD, Russia) and Peneplag (Penetron-Russia GC). The slag in the content of the studied composition is characterized with significant acceleration of cement setting (Sari, Lexcellent 2008).

Table 2. Performance characteristics of dry cement with slug

№	Characteristic	Unit	Value		
			Studied composition	Peneplag (W/S = 0.30)	GIDROPAKOL-stop (W/S = 0.20)
1	Tap density	kg/m^3	947	1140±70	950±20
2	Specific surface	cm^2/g	6770	–	–
3	Density	kg/m^3	2.030	–	1.950±20
4	Setting time, min: – beginning – end	min	 1 3.5	 1 4	 1 3
5	Compressive strength at the age of 1 day of normal hardening	MPa	22.5	–	20.0
6	Compressive strength at the age of 7 days of normal hardening	MPa	66.4	–	–
7	Compressive strength at the age of 28 days of normal hardening	MPa	66.8	16.0	43.0
8	Water absorption of solution ppb mass, not exceeding	%	3.2	–	2.5

Table 2 clearly shows that the physical and mechanical characteristics of the produced mortar surpass the industrial analogues in many aspects. For example, the strength after 28 days of normal hardening exceed the ones of Peneplag mortar (Penetron-Russia) more than 4 times. It should be noted that the intensive strength development occurs in the first 7 days, and by the 28th day the hydration processes slows down significantly due to the fine grinding od the mortar components (Volzhenskiy *et al.* 1979).

To understand the processes in the structure of set cement, we conducted the microscopic studies of the samples selected after testing the slag-based composition. The results are presented in the images of microstructure of fresh chip surface of the samples.

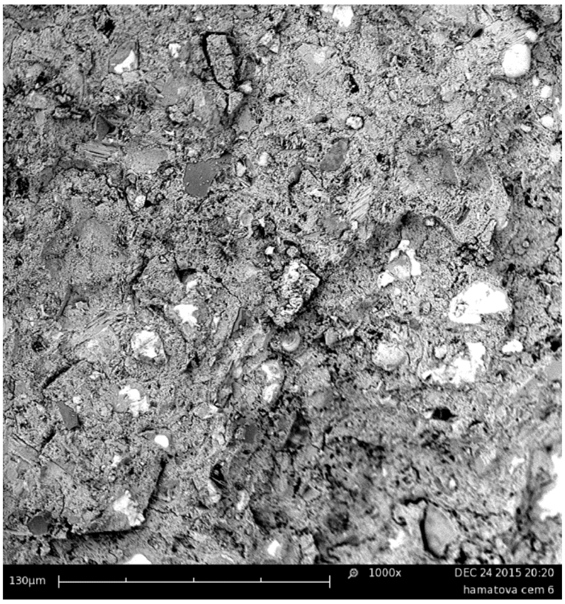

Fig. 2. Microstructure of cement sample produced from Portland cement CEMI 42,5 Б (Ulyanovskcement, CJSC) under the magnification of 1000 times

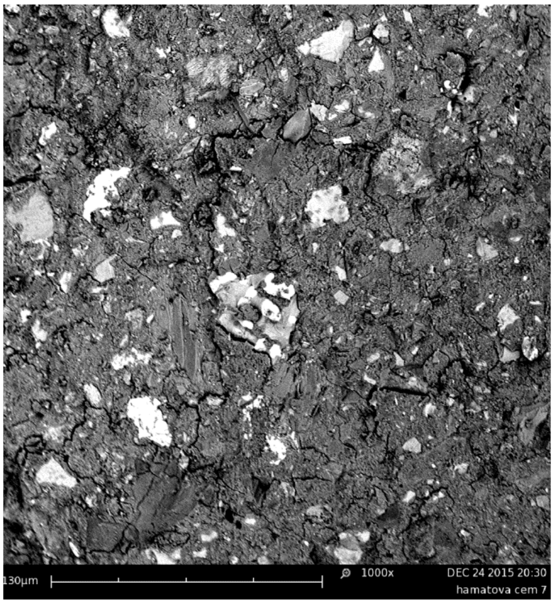

Fig. 3. Microstructure of composition sample including electric steelmaking slag (28% from the dry mortar mass) and gypsum plaster (12%) under the magnification of 1000 times

The comparing of the microstructure of the sample produced from usual Portland cement (Fig. 2) and the composition with electric steelmaking slag (Fig. 3) shows the latter as having a more homogenous structure of the set cement. The cement sample is characterized with a discrete loose structure consisting mainly of plate- and flake-like new formations, which is typical for such mineral as portlandite ($Ca(OH)_2$), as well as forcalcium silicate hydrates (Hafez, Abd. Elmoaty 2014).

The mineralogical composition of the unhydrated cement can be clearly seen in the IR spectra (Fig. 4): the main mineral – alit C_3S: valence vibrations of Si-O bonds – intense absorption bands of 981.77 cm^{-1}; 875.68 cm^{-1} and fluctuations of CaO – 472.56 cm^{-1}; tricalcium aluminate C_3A (valence vibrations of Al-O-Si bonds) – absorption bands in the range of 1112–1114 cm^{-1}.

Comparing the spectra of the set cement based on CEM I 42.5 B (Fig. 4, 6) and the slag-based composition (Fig. 5, 7) after 1-and 28-day hardening clearly shows visible traces of the hydration process with the formation of its main products. In the area of the valence vibrations of OH-groups the intensity of the portlandite absorption bands increases 3640 cm^{-1}; the vibrations of adsorption water increase at 1654.92 cm^{-1} and $Ca(OH)_2$ at 1473.62 cm^{-1}; 1458.18 cm^{-1}. At 3421.72 cm^{-1}, the absorption bands appear that are typical for the vibrations of OH groups involved in the formation of hydrogen bonds. The increasing of the intensity of absorption bands in the area of 1116.78 cm^{-1} is considered as indirect evidence of the formation of calcium hydroaluminates.

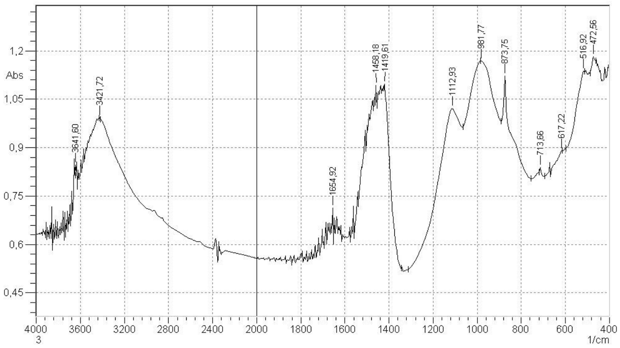

Fig. 4. IR-spectrum of cement sample produced from Portland cement CEMI 42,5 B (Ulyanovskcement, CJSC) at the age of 1 day

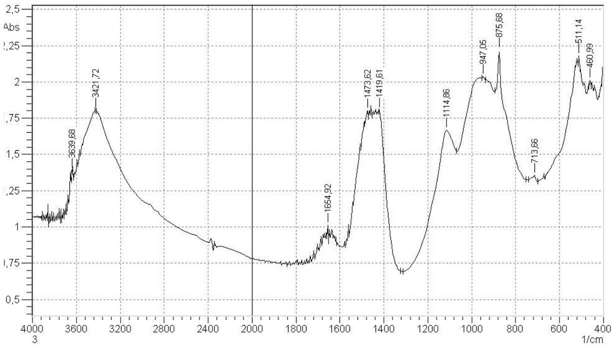

Fig. 5. IR-spectrum of cement composition sample including electric steelmaking slag (28% from the mass of dry mortar) and gypsum plaster (12%) at the age of 1 day

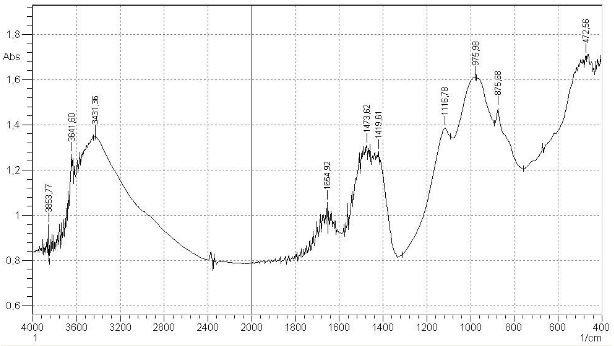

Fig. 6. IR-spectrum of cement sample produced from Portland cement CEMI 42,5 B (Ulyanovskcement, CJSC) at the age of 28 days

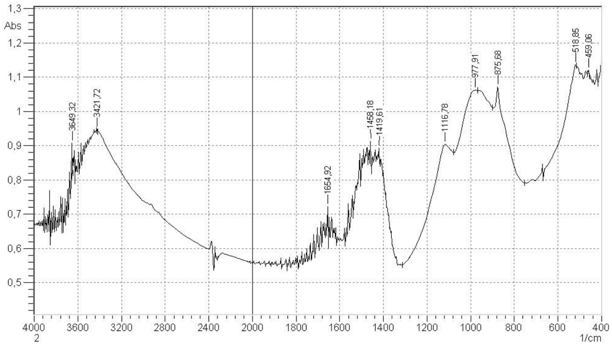

Fig. 7. IR-spectrum of cement composition sample including electric steelmaking slag (28% from the mass of dry mortar) and gypsum plaster (12%) at the age of 28 days

Comparing the IR spectra after 1-day hardening (Fig. 4, 5) shows the significant increase of the intensity of the absorption bands typical for the vibrations of OH-groups in the slag-based cement composition sample. We consider it as evidence of active hydration reactions surpassing the reactions in the check sample composition and, as a consequence, rapid hardening of the solution. However, by the 28th day the situation changes, and the intensity of hydrogen bonding prevails in the check composition (Fig. 6, 7). This shows that the hydration process in the slag-based cement composition is more intensive during the first day of hardening and significantly slower by the 28th day, because the binder particles have fully reacted with water.

Conclusion

The study of the rapid hardening composition has shown that:

1. The studied electric steelmaking slag has its own hydraulic activity, and its mineralogical composition is similar to that of Portland cement. This allows their successful combining as the components of rapid hardening compositions.
2. Adding slag produced by Izhstal, CJSC to the cement system in the amount of 28% (from the mass of dry mortar) in combination with gypsum plaster leads to faster setting of rapid hardening composition, reducing it to 3,5 min.
3. The microstructure of the set mortar based on the developed composition is more homogenous and denser in comparison with set Portland cement.
4. The properties of the composition to expand and self-tighten provide the successful use of steelmaking slag as a component of non-shrink renovation and waterproof mortars.

The results of the study allow us to say that electrical steelmaking slag can be anactive mineral component in producing rapid hardening compositions. Thus, utilizing and recycling ESS becomes possible right in the place of its production, which will improve the environmental situation in the area of slag dumping.

Funding

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