The effect of Elbasan GGBFS addition on different properties of cement mortars

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ABSTRACT

The purpose of this research is to study the effect of local ground granulated blast furnace slag as a partial replacing material in Portland cement mortars. The GGBFS used in this investigation is delivered as an industrial waste from the Steel Production Factory in Elbasan, Albania. For this reason, six different series of (0/100, 5/95, 10/90, 15/85, 20/80 and 25/75) GGBFS to cement ratios were produced. Normal consistency, initial and final setting time of the pastes as well as flexural strength and compressive strength of the hardened mortars were investigated. The test results showed that the use of the ground granulated blast furnace slag under investigation as a cement replacing material has different advantages and drawbacks.

Keywords: GGBFS, cement mortar, flexural strength, compressive strength

INTRODUCTION

Using mineral admixtures in the production of Portland cement concrete may improve several properties of concrete such as resistance to thermal cracking, ultimate strength, impermeability etc. [1]. If their quality is rigorously controlled, high amounts of different industrial by-products can be used in concrete production, in the form of blended Portland cement or as mineral admixtures. The use of pozzolanic materials as a partial replacement for Portland cement in concrete, reduces significantly the energy consumption and cost [2]. The pozzolanic reaction in Portland cement takes place due to the reaction of silica found in high amounts in the pozzolan combining with the free lime released during the hydration of Portland cement. This reaction can happen only in the presence of water, so the moisture level must be kept at a certain level for a long time for it to complete. During this reaction the finely ground glassy silica and hydrated lime react, resulting with the production of extra calcium silicate hydrate gel, similar to that produced from the hydration of Portland cement. The extra calcium silicate hydrate gel contributes in the impermeability, durability and increase of strength of concrete. The amount of pozzolan used as a replacement for cement, may vary between 10-30 % and it can be as low as 4-6% for natural pozzolans [3]. Slag is known as a non-metallic waste material disposed from the iron and steel production. When immediately cooled and ground to fine powder it has some good cementitious properties that can be used in many engineering fields. The first usage of slag starts back in the early 20th century, when the modern processes of iron and steel production began to be developed. The need to use all industrial by-products was strong and storage space was missing. Iron ores consist of compounds of iron, usually iron oxides such as hematite (Fe_2O_3), magnetite (Fe_2O_4), limonite ($Fe_3O_4.nH_2O$) and siderite ($FeCO_3$); these ores contain some silica, clay, etc., called gangue. For the removal of oxygen of iron oxides and the removal of the gangue, the ore is heated in a furnace with a high temperature under strongly reducing conditions in the presence of a flux. The flux combines with the gangue of the ore and ash of the fuel and produces a melt called slag.

"Blast-furnace slag it is known as the non-metallic product which consists of calcium silicates and other bases and is developed in a molten condition simultaneously with iron in a blast-furnace" [2]. The main composition of Blast-furnace slag is mainly silica (SiO_2), alumina (Al2O3) and lime (CaO). Slag also contains small percentages of iron (Fe_2O_3), magnesia (MgO), manganese oxide (MnO) and sulfur (S). The temperature of liquid slag taken out from blast furnace is approximately 1500 'C. The process of cooling of the liquid slag into a solid form is a crucial factor in forming the structure and characteristics of the solid slag [4]. The rate and cooling method of liquid BFS results in the production of three types of slag in solid form: air-cooled, expanded and granulated BFS. The granulated blast-furnace slag is the only product suitable for use as cementitious material when finely ground This is due to the high content of silica and alumina in non-crystalline form. GGBFS show pozzolanic properties similar to those of finely ground natural pozzolans and fly ash. The high content of CaO makes GGBFS somewhat self-cementitious besides the pozzolanic characteristics. The use of GGBFS may affect several properties of concrete such as: higher ultimate strength with lower early strength, improves sulfate and seawater resistance, improves resistance to alkali-silica reaction, decreases heat evolution, better finish and color, better durability to freezing and thawing, decreases porosity and chloride penetration [5]. During the communist period Albania developed as an intensive mining country consisting of a large number of mines and processing units of metals such as chrome, copper, coal, ferro-nickel, bitumen, tar sands etc. The foundations of steel production industry in Albania are settled since 1975. The slag, as a by-product of the process of production of steel, is in high amounts deposited in special fields in Elbasan where the production of steel is concentrated.

Figure 1 Slag deposits in Elbasan.

KURUM Holding produces an average of 600 tons of steel per year. Therefore, in Elbasan there are large amounts of slag dislocated in special areas. In Albania slag finds small usage by the construction companies, while worldwide slag is being used as a very useful and cheap building material. It is well good material for road construction because of its positive characteristics like durability and high skid resistance. It can be used in porous asphalts or as other construction materials. The only usage of GGBFS of Elbasan is in the road construction where it is proven to be a good stabilizing material. In its positive one year it is used 180 ton of slag in road construction. The usage of slag in this direction is growing while the companies are learning the benefits of slag as a stabilizing material. The exact amount of slag deposit it is not known but it has become a problem for the steel production companies. They are offering the material for free because of this. [6]. Since the slag is underused in Albanian construction projects and even though it is not a danger for the environment and is not harmful the large GGBFS stock is creating different problems to the region. The purpose of this research is to study the effect of local ground granulated blast furnace slag as a partial replacing material in Portland cement mortars.

MATERIALS AND EXPERIMENTAL PROGRAM

In this study different aspects of the use of GGBFS as a Portland cement replacing material were investigated through laboratory experiments, consisting in evaluating its effect on the normal consistency, initial and final setting time as well as flexural and compressive strength.

MATERIALS

The materials used in this experimental study are; sand (crushed limestone), water, cement CEM I 52.5 R, GGBFS.

Sand

The used sand is crushed limestone sand taken from Fushe-Kruja, Albania. This type of sand is very widely used in Albania in the production of concretes and mortars. It has a specific gravity of 2.56 and a maximum aggregate size of 4mm. Table 1 shows the grading of sand used in the production of the test mortars.

Table 1. Particle size distribution of limestone sand

Sieve Size	4	2	1	0.5	0.25	0.125	0.063	pan
Cumulative % retained	0	16.5	53.8	71.4	83.9	92.6	98.8	100

Table 2. Chemical characteristics of CEM I 52.2

Chemical Properties	As per Cement Declaration	Standard	Unit
SiO_2	20,09		%
Fe_2O_3	3,87		%
Al_2O_3	4,84		%
CaO	64,02		%
MgO	1,15	Max 5,0	%
SO_3	2,83	Max 4,0	%
Loss on Ignition	2,36	Max 5,0	%
Insoluble Residue	0,34	Max 5,0	%
Free Lime	0,80		%
Alkali Equivalent	0,65		%
Total Additive	3,85		%

Cement CEM I 52.5 R

The cement used in this experimental work is white Portland cement, CEM I 52.5 R produced by Heracles ™ Company in Greece. It complies with the requirements of EN 197-1 [7]. It can be used for plaster as well as for concrete applications. Table 2 shows the chemical composition of the cement used in this study.

Slag

The Ground Granulated Blast Furnace Slag (GGBFS) used in this study was provided form the Metallurgical factory in Elbasan, Albania. The results of the chemical analysis of the slag are given in the Table 3. The chemical analysis shows a high content of iron oxide. This brings a decrease in the amount of calcium oxide and silica, and therefore may affect the pozzolanic and cementitious properties of slag.

Table 3. Chemical composition of Elbasan GGBFS

Oxide type	CaO	SiO_2	Al_2O_3	Fe_2O_3	P	S	MgO
Amount in (%)	37.24	23.42	11.74	19.93	0.1	0.6	6.97

EXPERIMENTAL PROGRAM

Normal consistency, initial and final setting time

The Normal consistency is defined as the ratio of water to cement in order to obtain the required compaction. Normal consistency, initial and final setting time were assessed in accordance with EN 196-3 standard [8]. The same procedure was performed for all the six cement paste series.

Preparation of the specimen Mixtures

Six different series of mortars with 0.5 water to binder ratio and (0/100, 5/95,10/90,15/85.20/80 and 25/75) slag to cement ratios were prepared. The results were compared with those carried out with the control specimens produced with 0,5 w/c ratio and no other additives. All the materials used for the preparation of the specimens were weighed separately on a precision scale. The ingredient amounts used in the preparation of the mortar mixtures are given in Table 4. For all the mixtures, the sand weight is given in dry condition.

Table 4. Mortar mixture mix design

Specimen series	Cement replacement %	Sand (g)	Cement (g)	Water (g)	GGBFS (g)
C	0	1350	450.0	225	0.0
S1	5	1350	427.5	225	22.5
S2	10	1350	405.0	225	45.0
S3	15	1350	382.5	225	67.5
S4	20	1350	360.0	225	90.0
S5	25	1350	337.5	225	112.5

Casting of the mortar specimens

The mortars were mixed in the Hobart mixer according to EN 196-1 standard [9]. Firstly, the water and priorly prepared solid binder were mixed, then the sand is added slowly. After that the fresh mortar is mixed until obtaining a homogeneous mix. As the mixer stops, with an appropriate spoon the fresh mortar is casted into prismatic molds of 40 x 40 x 160 mm and covered with an impermeable cover. After 24 hours, the specimens are taken out of the molds and cured for 7 and 28 days in water at 21±1 ºC.

Flexural and compressive strength tests

The flexural test of the specimens was performed according to EN 1015–11 Standard [10] on mortars specimens of dimensions 40x40x160 mm were. The specimens were tested for 7 and 28-day strength under three-point loading with a 100 mm distance between the supports. Whereas the compressive strength test was carried out in accordance with relevant specification EN 196-1 [9]. The test is performed on a 40 x 40 mm area at a loading rate of 500 N/s. The average of value obtained from six test samples is reported as the compressive strength for each of the mortar series.

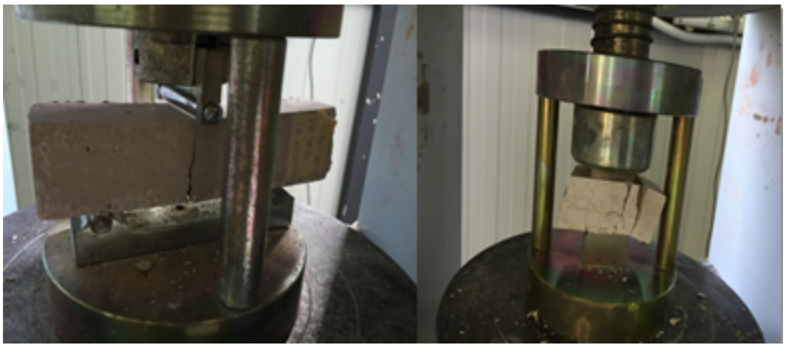

Figure 2 Flexural and compressive strength tests

RESULTS AND DISCUSSION

Normal consistency, initial and final setting time test results

Figure 3 shows the measurements of normal consistency, defined as water to binder ratio. From the results of the experiment shown in the graph, the water demand to reach normal consistency decreases as the percentage of slag increases. The comparison is made with the C sample which indicates the sample with Portland cement and no addition. As it is seen from the results the water demand decreases as the amount of slag increases.

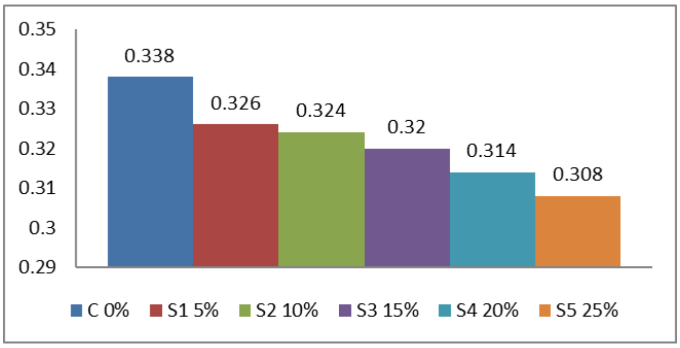

Figure 3. Normal consistency test results

On the other hand, Figure 4 shows the initial and final setting time test results. The results of the initial sett show that there is an increase in time up to 10% slag than as the slag ratio continues to increase the setting time decrease but it is still higher than that on Portland cement alone. Whereas final setting time results show an increase in time with the increase of slag percentage.

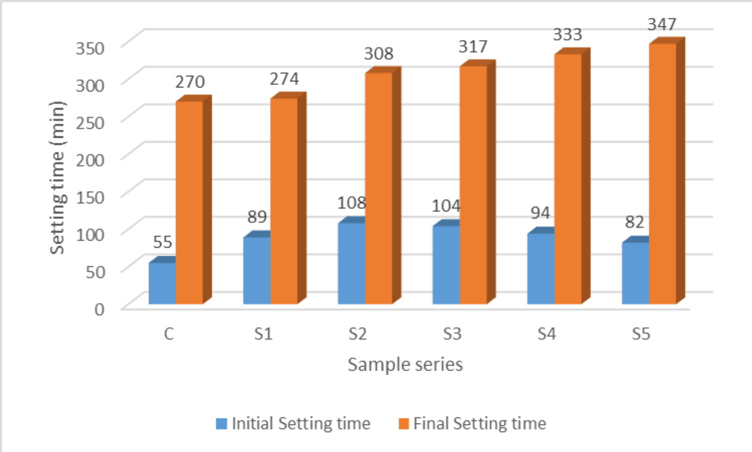

Figure 4. Initial and final setting time results

Flexural and compressive strength test results

In the Figure 5 are shown the flexural strength values of the samples after 7 and 28 days. It can be seen that the flexural strength values are very changeable and is difficult to define e certain trend.

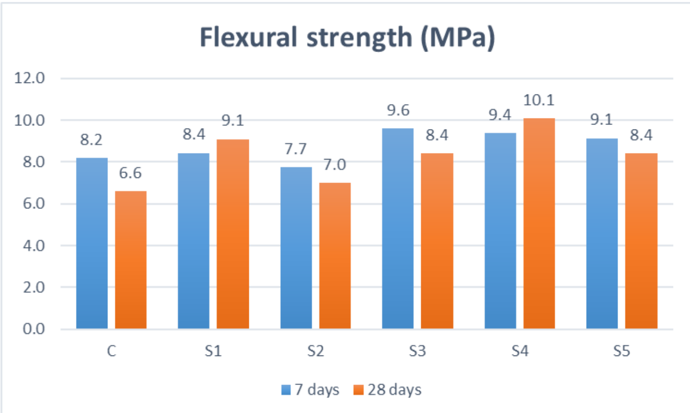

Figure 5. Flexural strength after 7 and 28 days

In the graph in Figure 6 are reflected the compressive strength test results of the mortar samples after 7 and 28 days.

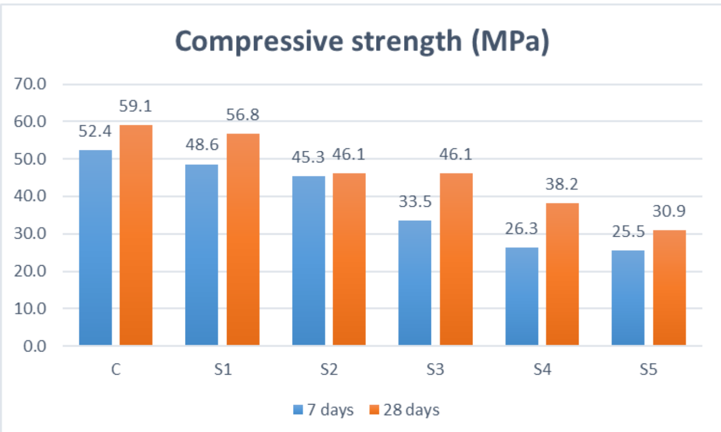

Figure 6. Compressive strength after 7 and 28 days

The results show a significant decrease in the compressive strength of the samples. The highest average value is obtained from the samples with 0% slag equal to 59 MPa and lowest from those with 25% slag equal to 30.9 MPa. In order to analyze the results, it must be taken in consideration the chemical composition of the Elbasan slag, which resulted with a high percentage of iron oxides. The high content of iron oxides decreases the percentage of CaO and SiO2 in the composition of the slag. This results in a decrease in the cementitious and pozzolanic properties of the slag.

CONCLUSION

In this study it is investigated the partial replacement of Elbasan slag in cement mortars and the results were compared with those carried out with the control specimens produced with 0,5 w/c ratio and no other additions. Based on the investigation is concluded that the GGBFS slag deposited in the Metallurgical factory of Elbasan, Albania is not very appropriate for its use as a mineral admixture because of its high amount of iron oxides in its composition. This also shows that a high amount of iron was lost during the production of steel, so by a better treatment of the raw materials higher amounts of pure iron or steel could be produced an at the same time the generated slag would have better properties and be more usable.

REFERENCES

[1] Hassan, K.E., Cabrera, J.G., & Maliehe, R.S. (2000) The effect of mineral admixtures on the properties of high-performance concrete, Cement and Concrete Composites, 22(4), 267-271
[2] P. K. Mehta and P. J. Monteiro, (2006) Concrete: Microstructure, Properties, and Materials, New York: McGraw-Hill Education, pp. 295-312.
[3] S. K. Duggal, (2008) Building Materials, 3rd ed., New Delhi: New Age International Publishers, pp. 234-242.
[4] J. Bijen, (1996) "Benefits of slag and fly ash," Construction and Building Materials, vol. 10, no. 5, pp. 309-314,
[5] J. R. Prusinski, (2006) "Slag as Cementitious Material," in Significance of Tests and Properties of Concrete and Concrete-Making Materials, J. F. &. P. J. H. Lamond, Ed., Massachusetts, ASTM International, pp. 512-528.
[6] H. Mueller, A. Vangjeli, R. Lurf and C. Redl, (2013) "Ferro Chrome Production in Albania," in INF ACON XIII: Efficient Technologies in Ferroalloy Industry, Almaty, Kazakhstan.
[7] EN 197-1, (2011) "Cement, Part 1: Composition, specifications and conformity criteria for common cements," European Committee for Standardization, Brussels.
[8] EN 196-3, (2008) "Methods of testing cement - Part 3: Determination of setting times and soundness," European Committee for Standardization, Brussels.
[9] EN 196-1, (2005) "Methods of testing cement - Part 1: Determination of strength," European Committee for Standardization, Brussels.
[10] EN 1015-11, (2006) "Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar," European Committee for Standardization, Brussels.