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Effect of Local Steel Slag on Compressive Strength of Cement Mortars

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Abstract

The main objective of this research was to determine the effectiveness of local Electric Arc Furnace Slag (EAFS) as a replacement material in cement mortar and to determine the degree of its pozzolanicity.

The properties of steel slag blended cement were studied at chemical and physical laboratories of Nile cement Industry in accordance to the international standards (ASTM and BS). Chemical analysis showed that locally produced steel slag contains a high amount of iron due to a purification process in steel manufacturing compared with the standard (ACI 233). According to test results, it found that the degree of pozzolanicity is 95.8 % for 28 days which indicates a good quality electric arc furnace slag and a promising pozzolanic supplementary material in concrete. Compressive strength test of mortar samples at 2, 7 and 28 days with different percentages of electric arc furnace slag (0%, 5%, 10%, 15%, and 20%) had been conducted. Finally, the study proved the efficiency of using one of the industrial wastes as a pozzolanic material in cement industry.

Keywords: Electric arc furnace slag; Pozzolanicity; Chemical analysis; Concrete; Compressive strength

Introduction

The use of such industrial by-product or a waste material having desirable qualities can result in saving of energy and resources. With the increase in population, the demand for construction of residential and public buildings is also increasing [1]. The iron and steel industry produce extremely large amounts of slag as by-product of the iron making and steel making processes [2]. In Sudan, many industrial plants consume scrap raw material to manufacture of reinforced concrete, steel beams and other structural steel sections [3]. These plants annually produce huge tones of electric arc furnace steel slag. This locally produced (EAFS) has been an environmental hazard and it could be investigated for the potential used as an artificial pozzolanic or aggregate material in the construction Industry.

The American Society for Testing and Materials (ASTM) defines Steel Slag as a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc, or open-hearth furnaces [4]. Steel slag can be produced by a variety of processes that include Open-Hearth Furnace (OHF), Basic Oxygen Furnace (BOF), and an Electric Arc Furnace (EAF). Due to the amount of time the OHF takes to produce the steel, most of them have been closed since the early 1990's and have been replaced by BOF and EAF processes [5].

Electric arc furnace slag is produced during the manufacture of crude steel by the electric arc furnace (EAF) process. In this process steel scrap with additions of fluxes (e.g., limestone and/or dolomite) are heated to a liquid state by means of an electric current. During the melting process, the fluxes combine with non-metallic scrap components and steel incompatible elements to form the liquid slag [6]. As the slag has a lower density than steel, it floats on top of the molten bath of steel. The liquid slag is tapped at temperatures around 1600°C and allowed to slowly air-cool forming crystalline slag [7].

Since the difference between electric arc furnace slag and blast furnace slag is in the technology of production rather than the chemical composition and behavior in mortar mixes, same international standards are used for both types. According to ASTM C989, Slag is classified into three grades according to its performance in the "slag activity test". The three grades are Grade 80, Grade 100 and Grade 120 [8].

The basic components of Slag comprise generally CaO (30-48%), MgO (28-45%), Al_2O_3 (5-18%), and SiO_2 (1-18%), which are in principle the same as that of Portland cement [9]. Other minor components including Fe_2O_3, MnO, and SO_3 are also present in slag. The compositions do not change very much so long as the sources of iron ore, coke and lux are consistent [10].

The high cost of slag disposal besides their negative impact on the environment and the lack of natural aggregate resources in many regions led the utilization of steel slag in various applications. There are also a few types of researches that have been performed regarding the utilization of steel slag in concrete [11-13].

Objectives of the Study

The main objective of this research was to determine the effectiveness of Electric Arc Furnace Slag (EAFS) as a replacement material in cement mortar and to determine the degree of its pozzolanicity. Besides the safe disposal of accumulated amounts of slag as a byproduct (waste) of the Steel Industry.

Experimental Work

Materials

Steel slag: Sudanese electric arc furnace slag produced from Giad industrial city was used in this investigation. Three samples were collected for the work of the tests required and took the average with a bulk density of 1.102 g/cm^3 and specific density of 1.65 g/cm^3.

Fresh clinker: Obtained from Nile cement factory, Clinker particles of size between 0.8 cm to 1.5 cm, having blackish gray color and intermediate hardness produced at Nile cement factory were used in conducting the experimental work, the density of clinker between 1.2 Kg/Liter to 1.4 Kg/Liter.

Raw gypsum: Obtained from Port Sudan city employed by the same factory to produce the cement, also used in performing the tests, the particle size in between 10 mm to 15 mm of density 1.2 g/cm^3.

Sand: The sand used for making test specimens is natural silica sand conforming to the requirements for graded standard sand in specification C 778 obtained from Um Kwika North Kordofan state. The sand was prepared according to ASTM C 778, Sieved and washed then it was dried at normal condition.

Water: Tap water suitable for drinking is usually good enough for concrete. The water should be free of all organic matter and certain chemicals such as alkaline and sulfate salts.

Testing of raw materials and mortar

Chemical analysis: Chemical analysis of clinker, steel slag, and blended cement was carried out according to the standard methods ASTM C114: 2003 technical methods of analysis. Chemical analysis is used to determine SiO_2, Fe_2O_3, Al_2O_3, CaO, MgO, Sulphate as percentage age by mass and loss on ignition at 1000C (Tables 1 and 2).

Compressive strength: The compressive strength of cement is determined by compressive strength test on mortar cubes compacted by means of a standard vibration machine. Local sand is used for the preparation of cement mortar. The specimen is in the form of cubes 70.6 mm × 70.6 mm × 70.6 mm [14].

Clinker was replaced by steel slag with the percentages of 5%, 10%, 15%, and 20%. The control sample (0% steel slag) was mixed for the purpose of compression and for the calculation requirements. The mortar samples were first mixed then they were molded into cubes. The molds were then cured and crushed at different ages. The water to cement ratio was taken (w/c=0.4).

Strength activity index test: According to (ASTM C989-99) Slag activity is evaluated by determining the compressive strength of both Portland- cement mortars and corresponding mortars made with the mass combinations of slag and Portland cement.

The activity index is expressed as a percentage of the strength of the control sample. It follows that the activity index at 28 days shall be not less than 70% for grade 80, 90 for grade 100 and 110 for grade 120. The compressive strength was determined for the test and control samples as specified in ASTM C109 [15].

Strength activity index was determined in as follows;

Strength activity index=(SP/P) × 100%

Where; SP: the average compressive strength of test mixture in cubes at 28 days,

P: the average compressive strength of control mix cubes at 28 days.

Sample No.	Code	Clinker%	Gypsum%	Steel Slag %
1	NOPC	96	4	0
2	NS5	91	4	5
3	NS10	86	4	10
4	NS15	81	4	15
5	NS20	76	4	20

Table 1: Proportion of blending OPC with Steel Slag.

Sample No.	Code	Clinker (g)	Gypsum (g)	Steel Slag (g)
1	NOPC	2880	120	0
2	NS5	2730	120	150
3	NS10	2580	120	300
4	NS15	2430	120	450
5	NS20	2280	120	600

Table 2: Quantities of components in steel slag blended cement. Note: The description of the blending code is: (i) NOPC indicates control cement prepared by Nile OPC without steel slag. (ii) NS5 indicates Nile OPC cement blended with 5% steel slag. (iii) NS10 indicates Nile OPC cement blended with 10% steel slag. (iv) NS15 indicates Nile OPC cement blended with 15% steel slag. (v) NS20 indicates Nile OPC cement blended with 20% steel slag.

Results and Discussion

Chemical analysis

Chemical analysis was carried out at the chemical laboratory of Nile cement industry at Rabak-Sudan. The chemical composition of steel slag was tested in accordance to (ASTM C 311 and ACI 233) and the results are shown in Table 3 (Figure 1).

Components	Percentage %
CaO	30.8
SiO_2	23.42
Al_2O_3	11.09
Fe_2O_3	18.55
MgO	7.26
SO_3	0.46
L.O.I	2.46
F.L	0.07

Table 3: Chemical compositions of steel slag used for the test.

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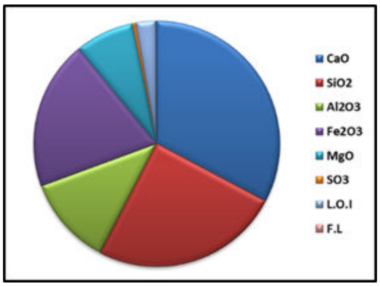

Figure 1: Chart of chemical compositions of steel slag.

The limiting values according to BS 6699: 1992 are the maximum insoluble residue of 1.5 percent, maximum magnesia content of 14 percent, maximum loss on ignition of 3 percent [16].

In addition, the maximum lime/silica ratio is 1.4 and minimum chemical modulus [(CaO)+(MgO)]/(SiO_2), is 1.0. According to BS 146:1991 and BS 4246:1991, at least two- thirds of the total mass of slag must consist of the sum of CaO, MgO, and SiO_2. Also, the ratio of the mass of CaO plus MgO to the mass of SiO_2 must exceed 1.0, this ratio assures a high alkalinity, without which the slag would be hydraulically inactive.

However, when taking into account the second and the third criterion (BS 146:1991, BS 4246:1991 and BS 6699:1992) we find that the sum of CaO, MgO, and SiO_2 is 61.48 less than the minimum, whereas the ratio of [(CaO)+(MgO)]/(SiO_2) is 1.6 which exceeds the minimum. In addition, the lime/ silica ratio is 1.32 close to the standard. Also, the value of LOI is 2.46<3% whereas SO3 00.46<4%, they clearly satisfy the requirements of BS 6699:1992.

Sample Code	NOPC	NS5	NS10	NS15	NS20
SiO_2%	20.83	20.98	21.06	21.22	21.62
Al_2O_3%	4.65	4.77	4.81	4.97	5.07
Fe_2O_3%	4.61	5.31	6.01	6.71	7.41
CaO%	63.17	61.49	59.81	58.13	56.45
MgO%	3.53	3.66	3.79	3.92	4.05
L.O.I%	0.76	0.84	0.93	1.01	1.09
SO_3%	2.2	2.15	2	0 1.98	1.77
F.L%	2.32	2.21	2.09	1.97	1.85

Table 4: Chemical compositions of steel slag blended cement compared with control OPC.

From the results, as shown in Table 4 above, it is seen that the addition of steel slag increases the percentage of SiO_2, Al_2O_3, Fe_2O_3, MgO, and the loss of ignition (L.O.I). Furthermore, the addition of steel slag reduces the percentage of CaO, SO_3 and free lime (F.L) to be less than the control OPC (Figure 2).

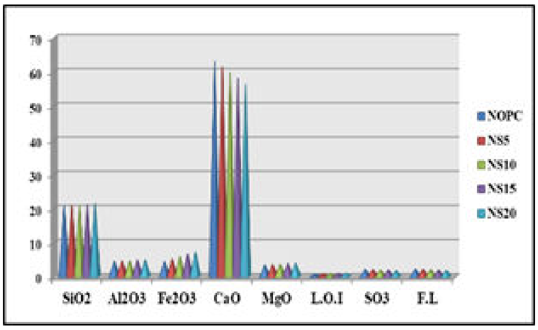

Figure 2: Histogram of chemical compositions of steel slag blended cement.

Compressive Strength of Mortars: Different standards had set minimum strength for different purpose cement as standard controlling parameters. In this research, mortars were prepared from Nile OPC cement and steel slag blended cement in accordance with EN 196-1 methods of testing cement, so as to examining the effects of the Steel Slag on the compressive strengths of mortars.

The compressive strength of the mortars was tested at 2, 7 and 28 days. The detail test results are given in the Appendices. Table 5 below shows the summary of average test results (Figures 3 and 4).

Sample No.	Code	Compressive strength (N/mm^2)		
		2 days	7 days	28 days
1	NOPC	19.6	33	48
2	NS5	16.8	31.4	46
3	NS10	13.6	29	45.8
4	NS15	18.4	32.2	44
5	NS20	20.2	32	43

Table 5: Summarized compressive strengths of test mortars for two, seven and twenty-eight days.

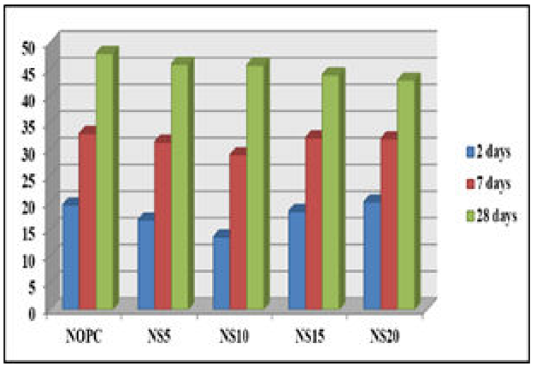

Figure 3: Histogram of compressive strength of test mortars for 2,7 and 28 days.

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As shown in Figure 3 above, the effects of steel slag addition to clinker on two days compressive strengths are different. The addition of 5%, 10% and 15% of steel slag decreases the compressive strength, however, the addition of 20% cause increase the compressive strength.

On the other hand, the test results on the seven days compressive strength showed the similar effect on different types of cement mortars, therefore, all additions of steel slag cause decrease the compressive strength compared with the control one.

The test results on the 28 days compressive strength test showed different effects degree. The addition of 5%, 10% of steel slag decreases the compressive strength compared to the control one and more addition of steel slag up to 20% led still more decreases in strength, however, all results are in the range of standard value 42.5.

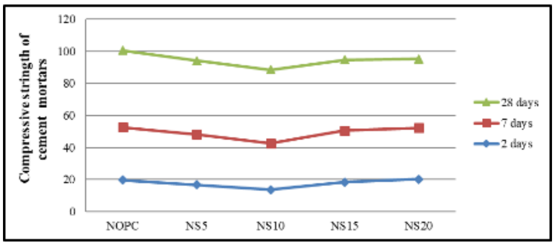

Figure 4: Compressive strength of blended cement mortars in the age of 2,7 and 28 days.

According to EN 197-1, all results of the compressive strengths of the blended cement at two, seven and 28 days satisfy EN 197-1 compressive strength limit for cement requirement of high early strength class 42.5 MPa [17].

Strength activity index test: Strength Activity Index is calculated as follows:

Strength Activity Index%= (Strength of 5% replacement at 28 Days/ Strength of control sample at 28 Days) × 100%,

(5%) Strength Activity Index of 28 Days=(46/48) × 100%=95.8%.

ASTM C989, 90% as the minimum of strength activity index, hence the locally produced electric arc furnace slag has higher strength activity index than the minimum required by ASTM C 989.

Conclusion

A summary of the main findings from this work are as follows:

- According to the physical and chemical analysis of locally produced electric arc furnace slag, it was found that it has acceptable chemical and physical qualities comparing with the standard steel slag.
- The locally produced steel slag contains a higher proportion of iron in comparison with the results with the standard method ACI 233, due to the iron purification process in Giad steel industry.
- From the results of compressive strength, it could be seen that the compressive strength increases remarkably with increasing curing time. Also, the compressive strength decreases with an increase of the slag content, as mentioned before this may be due to the chemical composition of slag.
- The strength test results showed that the locally produced steel slag from Giad steel industry is a good pozzolan and its strength activity index was 95.8% which is greater than the minimum target of 90% set by the American Society for Testing and Material.

According to the American Society of Testing and Material Standard (ASTM C 989 and ASTM C311), the steel slag product by Giad steel industry in Sudan was classified as a pozzolan of grade 100.

Recommendations

The following recommendations could be stated:

- This paper studied the chemical Analysis of local steel slag and the compressive strength in order to give conclusive evidence about the pozzolanicity of the materials concerned. However, further studies are recommended to the study the crystalline structure of slag by using X-Ray Diffraction Testing (XRD).
- For a better utilization of slag, there must be rapid cooling of slag by air or water to gain larger amount amorphous silica which enhances slag quality.
- The study also recommends to finely crush of steel slag that will make it better to use as cementitious material in concrete.
- Evaluation of environmental hazards of huge amount of steel slag in Giad industry and other steel industries in Sudan should be studied.
- In this study, the compressive strength was tested until the age of 28 days only, it is recommended that further studies for longer periods of time in order to get a better understanding of the long-term strength development.

References

1. Rojas MF, Rojas MS (2004) Chemical Assessment of the Electric Arc Furnace Slag as Construction Material: Expansive Compounds. Cement and Concrete Research 34: 1881-1888.
2. Nippon Slag Association (2006) The Slag Sector in the Steel Industry.
3. Leung PW, Wong HD (2010) Final Report on durability and strength development of ground granulated blast furnace slag concrete. Geotechnical Engineering office, Civil Engineering and Development Department The Government of The Hong Kong Special Administrative Region.
4. Nwaubani SO, Muntasser TZ (2012) Hydration characteristics of cement pastes incorporating electric arc-furnace slag. Journal of Civil Engineering and Construction Technology 3: 291-301.
5. Venkateswaran D, Sharma D, Muhmood L, Vitta S (2007) Treatment and characterization of electric arc furnace (EAF) slag for its effective utilization in cementitious products. Indorama Cement Ltd, Indian Institute of Technology.
6. Chidiac SE, Panesar DK (2008) Evolution of mechanical properties of concrete containing ground granulated blastfurnace slag and effects on the scaling resistance test at 28 days. Cem Concr Comp 30: 63-71.
7. Ansu J, Elson J (2013) Study on the partial replacement of fine aggregate using induction furnace slag. American Journal of Engineering Research 4: 1-5.
8. Netinger I, Milicevic I, Guljas I (2011) The effect of high temperatures on the mechanical properties of concrete made with different types of aggregates. Fire Safety J 46: 425-430.
9. Tsakiridis PE, Papadimitriou GD, Tsivilis S, Koroneos CJ (2008) Utilization of steel slag for Portland cement clinker production. J Hazard Mater 152: 805-811.
10. Iacobescua RI, Koumpouri D, Pontikesc Y, Sabana R, Angelopoulos GN (2011) Valorisation of electric arc furnace steel slag as raw material for low energy belite cements. J Hazard Mater 196: 287-294.

11. Wanga Q, Yan P, Feng J (2011) A discussion on improving hydration activity of steel slag by altering its mineral compositions. J Hazard Mater 186: 1070-1075.
12. Luo X, Liu JX, Wang B, Zhu GL, Lu ZF (2011) Effect of accelerators on the early strength of steel slag cementitious materials. J Beijing Univ Chem Technol 38: 73-75.
13. Ameri M, Shahabishahmiri H, Kazemzadehazad S (2012) Evaluation of the use of steel slag in concrete. Journal of BRR 20: 47.
14. Rafat S (2014) Utilization of industrial By-product in concrete. Procedia Engineering, p: 4.
15. Osama MA, Safa AA (2016) Characterization and evaluation of Giad Arc furnace slag as partial replacement for cement in mortar mixes. Journal of Building and Road Research 20: 29-47.
16. Asare S, Odoom A (2010) Comparing the compressive strength of concrete utilizing natural pozzolana as a partial replacement of Portland cement I cement production. Thesis HND, School of Engineering in Ghana.
17. Ducman V, Mladenovic A (2011) The potential use of steel slag in refractory concrete. Materials Characterization 62: 716-723.