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Properties of Cement Mortars Made With Local Steel Slag

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Abstract — **As a way to reduce the impact of the cement industry and reduce its production cost, researchers have studied to use by product materials such as fly ash, silica fume and slag as a partial replacement for Portland cement in the making of concrete. In this study, the effect of partial cement replacement with Libyan electric arc furnace steel slag in different substitution levels (0, 10, 20 and 30% by weight) were investigated using cement mortars. Slag of 350 m^2/kg Blaine fineness was used in this study. The mortar specimens were tested for compressive, flexural and direct tensile strengths at the ages of 3, 7, 28, 56 and 90 days. The effect of slag content on mortar workability was studied. Setting times and soundness of cement paste were also investigated.**

The experimental results showed that replacement of cement by slag causes delay in cement setting times. Setting times increases as the slag content increases. The results also showed that compressive, direct tensile and flexural strength of mortar improves with time and the development in strengths is influenced by the slag content. The addition of 10% electrical arc furnace slag (EAFS) has positive effect on compressive, tensile and flexural strengths of mortar at late age.

Index Terms: **Cement mortar; Steel slag; Compressive strength; Direct tensile strength; Flexural strength.**

I. INTRODUCTION

From the economic, technological, and environmental viewpoint, the role of cement replacement materials and supplementary cementitious materials (SCM) has become significant in the cement industry. Extensive studies [1-6] have been conducted in order to utilize by-product materials such as fly ash, silica fume, slag as a partial replacement of Portland cement (PC) in producing concrete. According to its production process, slag can be classified into three different categories, Blast furnace slag (BFS), Basic oxygen furnace slag (BOFS), and Electric arc furnace slag (EAFS). Blast furnaces slag are generated from iron production, while EAFS and BOFS are generated from iron steel production [7]. The air-cooled slag (BFS) can be used as an aggregate, but is commonly used as (SCM) in the form of water-cooled (GGBFS). This type is found to improve the properties of concrete when used as cement binder [8].

Currently, steel slag (EAFS) is used mostly for low value applications, including asphalt concrete aggregates, fillers for foundation engineering [9,10]. Electric Arc Furnace slag (EAFS) to employ (SCM) considered low reactivity due to its low CaO/SiO_2 ratio and processing method of air-cooled [11]. Alsadig and Wagialla [12] investigated the effect of Electric Arc Furnace slag (EAFS) addition on the strength properties of mortars and found that the use of (EAFS) as a partial replacement of cement is a good pozzolan. Wang and Suraneni [13] argue that since SFS may have variable chemistry and mineralogy, it is perhaps not surprising that the hydraulic or pozzolanic reactivity is also variable, and found that compressive strength testing defines steel slag materials as SCM. Brand and Fanijo [8] states that because the various steelmaking processes are different from one another, the resultant SFS chemistry and mineralogy change. In general, the bulk oxide chemistry of most SFSs consists of CaO, MgO, SiO_2, and FeO, along with some Al_2O_3 and MnO. The mineralogy of the SFS is dependent on the steelmaking process and fluxing agents but is also dependent on the cooling process. The cooling process can influence SFS properties and composition, such as degree of crystallinity, particle size, and free CaO and MgO contents, the crystalline composition of SFS also varies.

At 90 days of testing, the compressive and flexural strengths of cement mortar were reported by Santamaría-Vicario, et al., [14] to increase as the slag content in the mix increases. Study by Pan, Z., et al., [15] found that 10% cement replacement by steel slag, causes a 6% increase in compressive and splitting tensile strength at the 28 days.

In this experimental study, the effect of Libyan electric arc furnace steel slag on compressive, flexural and direct tensile strengths as well as workability of cement mortars were investigated. Four different substitution levels (0, 10, 20 and 30% by weight of cement) of steel slag were used. Setting time and soundness of cement paste was also investigated.

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II. EXPERIMENTAL PROGRAM

A. Materials Used

A commercial CEMI 42.5N obtained from a local manufacturing plant, Al Fataiah cement factory - eastern Libya, conforming to the requirement of BS EN 197-1: 2011 was used. The physical and chemical properties of cement are given in Table 1.

A standard siliceous sand (Figure 1) with a maximum size of 2.36 mm was used in this study.

Air-cooled electrical arc furnace steel slag (EAFS) was collected in aggregate form (Figure 2) with average particle size between 20 mm and 50 mm. The slag produced as a by-product of the steel industry in Benghazi/Libya. To turn it into a fine powder of 350 m^2/kg Blaine surface area, it was subjected to a grinding process. For this purpose, two types of mills were used in the grinding process, ball mill (Figures 3) and ring mill (Figures 4). The Slag was included in the mortar mixtures as a cement replacement with different levels (10, 20, and 30% by weight). XRF test was conducted in order to determine oxides content in slag and cement samples. Tap water available at laboratory of civil engineering was used to make all mortar mixtures.

Table 1 Physical and chemical characteristics of cement and slag

Chemical composition (%)	**Cement**	**Steel Slag (EAFS)**
SiO_2	20.86	35.8
$A_{l2}O_3$	5.6	13.5
Fe_2O_3	4	10.4
CaO	62.39	25.2
MgO	1	1.52
SO_3	2.93	-
Na_2O	-	-
K_2O	-	-
Loss on ignition	2.52	-
Specific gravity	3.13	3.19
Fineness (m^2/kg) (Blaine)	320	350

Figure 1 Siliceous sand used

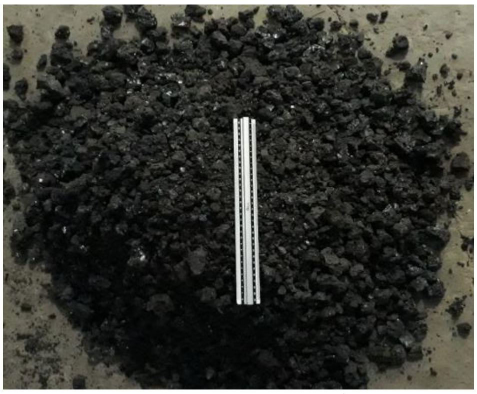

Figure 2 Slag in aggregate form

Figure 3 Ball mill used to grind slag aggregates

Figure 4 Ring mill used to grind slag to required fineness

B. Proportions and Mixing Procedure

The mortar mixtures shown in Table 2 were used to prepare mortar specimens. A fixed water to binder ratio of 0.485, binder to sand ratio of 1:2.75 and siliceous sand were used to prepare the specimens. Mixing were performed using the Hobart mixer following the method specified by ASTM C305 [16]. After mixing, the molds were filled with mortar and properly compacted by means of a vibrating table.

Table 2. Mortar Mixtures

Mix	**Slag (%)**	**Per weight of binder**				
		Cement	**Slag**	**Water**		**Sand**
C-0	0	1	0	0.485		2.75
C-10	10	0.9	0.1	0.485		2.75
C-20	20	0.8	0.2	0.485		2.75
C-30	30	0.7	0.3	0.485		2.75

C. Curing of Test Specimens

After casting, the mortar specimens were left for 24 hours in the mould at laboratory conditions (20±2°C). Then, specimens were removed from the mould and kept at 20°C in curing water (Figure 5) until test dates.

Figure 5 Mortar Specimens in Curing Water

D. Experiments

The flow of freshly mixed mortars was measured according to ASTM C1437 [17]. The flexural strength of 40X40X160 mm prisms were conducted according to ASTM C348 [18]. Direct tensile strength was done according to ASTM C190 [19] and compressive strength was performed on 50 mm cube according to ASTM C 109 [20]. Figure 6 shows mortar specimens in moulds. Setting times and soundness tests were performed according to BS EN 196-3 [21].

Figure 6 Mortar Specimens in Moulds

III. RESULTS AND DISCUSION

A. Setting Times and Soundness of Cement Paste

The results of the setting times and soundness of cement pastes presents in Table 3. It is obvious from the results that the increase in slag content resulted in further delay in the setting times of cement pastes. This may be attributed to the dilution effect and the latent properties of the slag. The 30% slag content resulted in retarding the initial and final setting times of about 36 min and 23 min, respectively. The result of soundness of cement pastes is given in Table 3. It can be seen from the results that the presence of steel slag causes reduction in the soundness of cement paste.

Table 3 Setting times and Soundness of cement paste

Mix	**Setting time (min)**		**Soundness (mm)**
	Initial	**Final**	
C-0	95	129	1.3
C-10	116	133	0.7
C-20	124	136	0.8
C-30	131	152	1.0

B. Workability

Figure 7 shows the flow test of cement mortar. The results of mortar flow is given in Figure 8. As the Figure shows, the flow shows a slight increase with the addition of steel slag, and thus the workability increases with increasing the slag content. The flow for C-30 mix is 88 mm compared to 84 mm for control mix (C-0).

Figure 7 Flow Test of Mortar

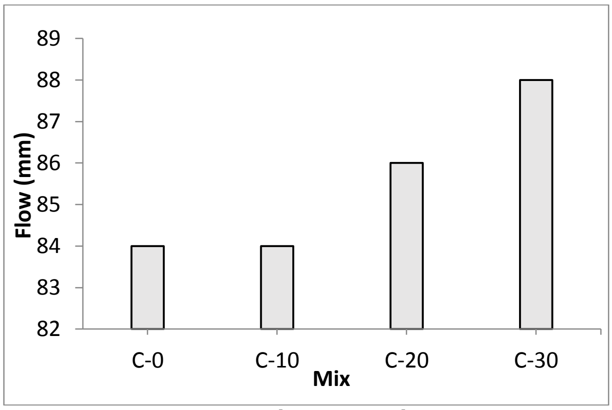

Figure 8 Flow Test Results

C. Compressive Strength

The results presented in Figure 9 show that for all mortar specimens, the compressive strength increases as curing time increases. It can also be seen from the graph that at curing age up to 28 days, the rate of compressive strength development of slag cement mortars is greater than that for control mortar (C-0). At early age, all slag cement mortars have lower compressive strengths in comparison to control mix (C-0). This is in a agreement with results reported by Bougara et al. [11], which show that slag cement has lower initial compressive strength in comparison to the OPC control. However, at 56 and 90 days of curing, the strength of mortar containing 10% slag (C-10) shows an increase by about 5 and 11.5% respectively compared to control mix (C-0), as Figure 9 illustrates. This confirms previous results reported by Pan et al. [15], which show enhancement in mechanical properties of concrete with 10% steel slag.

For all ages, the compressive strength of mortars containing 20% and 30% slag show clear reduction, as Figure 9 illustrates. It can be seen from the graph that at 90 days, the presence of 30% steel slag (C-30) causes reduction by about 12% in the compressive strength compared to control mortar (C-0). This behaviour is similar to that observed by others [15]

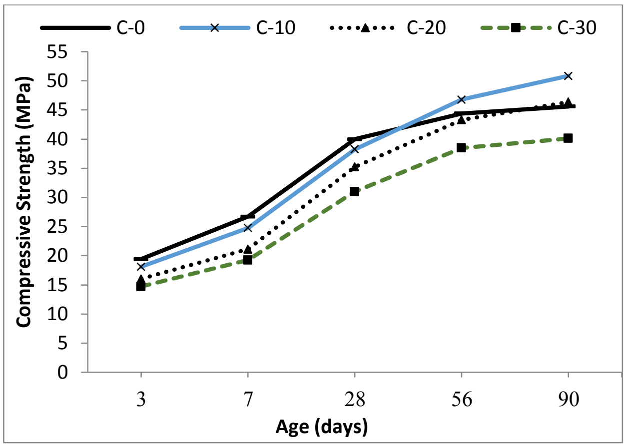

Figure 9 Compressive Strength Results

D. *Direct Tensile Strength*

Figure 10 shows mortar specimen under direct tensile test. The results of direct tensile strength of cement mortars are shown in Figure 11. For all mortar specimens, the direct tensile strength increases with curing age, as shown in Figure 11. From the graph, it can also be seen that increasing slag content in cement mortar causes reduction in the tensile strength compared to control mortar (C-0), except mortar containing 10% steel slag which shows improvement in tensile strength at 56 and 90 days of curing. At 90 days of curing, the increase in mortar tensile strength is about 2.65% for mix with 10% steel slag (C-10) compared to control mortar (C-0). At 90 days, however, mortar with 30% slag content show reduction in the tensile strength by about 10.6% (C-30) compared to control mortar (C-0).

Figure 10 Mortar Specimens under Direct Tensile Test

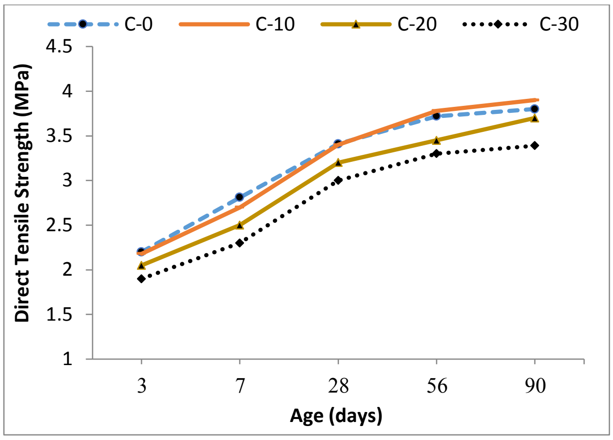

Figure 11 Direct Tensile Strength Results

E. *Flexural Strength*

Figure 12 shows the results of flexural strength of mortar specimens. It can be seen from Figure 12 that the flexural strength of all mortar specimens increases with time. It can also be seen (Figure12) that increasing slag content in cement mortar causes reduction in the flexural strength compared to control mortar (C-0). Mortar containing 10% steel slag shows some improvement in flexural strength at 90 days of curing, as Figure 12 demonstrates. At 90 days, however, 30% slag replacement causes about 12.3 % reduction in the flexural strength of cement mortar (C-0) compared to control mortar (C-0).

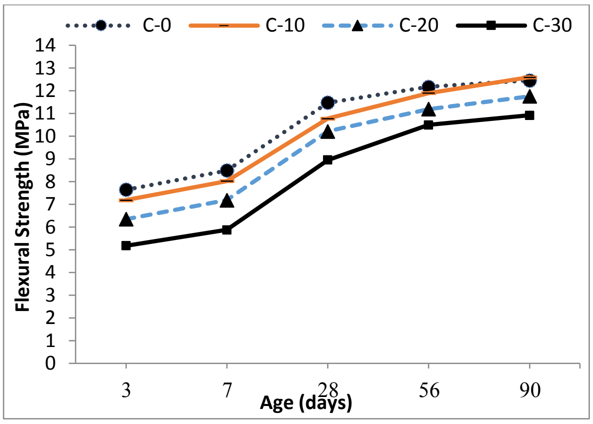

Figure 12 Flexural Strength Results

III. CONCLUSION AND RECOMMENDATIONS

The following findings can be drawn from the obtained results:

- The workability of mortar enhances with the addition of electrical arc furnace steel slag (EAFS).
- The replacement of cement by electrical arc furnace steel slag (EAFS) results in retarding setting times and reduction the soundness of cement mortar.
- Compressive, flexural and tensile strengths of concrete with steel slag develops with time.
- The addition of 10% electrical arc furnace slag (EAFS) has positive effect on compressive, tensile and flexural strengths of concrete at late age.

- The addition of electrical arc furnace slag (EAFS) by more than 20% causes reduction in the compressive, tensile and flexural strengths of concrete.

It is recommended to conduct more experiments regarding durability issues of concrete. Analysis using techniques such as scanning electron microscopy (SEM), Infra-red and X-Ray diffraction (XRD) should be involved to investigate the microstructure of mortar specimens with various levels of steel slag. Different methods of activation for steel slag should also be studied to examine the performance of mortar/concrete.

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