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Utilizing Steel Slag Powder as a Sustainable Alternative to Cement Mortar Mixtures

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ABSTRACT

Researchers have investigated the use of byproduct materials such as fly ash, silica fume, and slag in place of Portland cement in the production of concrete in an effort to reduce the environmental impact of the cement industry and decrease its production costs. The objective of this research was to examine the impact of incorporating steel slag into cement mortars at varying substitution levels (0, 10, 20, and 30% by weight). The slag utilized in this investigation had a Blaine fineness of 350 m^2/kg. At 3, 7, 28, 56, and 90 days, the compressive strengths of the mortar specimens were evaluated. It was investigated how clinker content affected the workability of mortar. Additionally, the soundness and setting periods of cement paste were examined. Cement setting times are prolonged when slag is used in lieu of cement, according to the outcomes of the experiments. The setting time increases in direct proportion to the slag content. Additionally, the findings demonstrated that the compressive and direct tensile strengths of mortar increase as time passes, with the slag content exerting an influence on the progression of these strengths. As mortar ages, the incorporation of 10% Steel slag powder into the mixture results in enhanced compressive and tensile strengths.

Keywords: *steel slag, cement replacement, pozzolanic activity, mechanical properties, durability, environmental impact.*

INTRODUCTION

In the cement Industries, replacement and supplementary cementation materials (SCM) play an important role from an economic, technological, and environmental perspective .Byproduct elements like fly ash, silica fume, and slag have been studied to partially replace Portland Cement (PC) in concrete. Slag is classified by production process as blast furnace, basic oxygen furnace, or electric arc furnace. Iron manufacturing industries produces blast furnace slag, while iron steel production produces EAFS and BOFS [1]. As an aggregate, air-cooled slag (BFS) can be used, but water-cooled SCM is more popular. It improves concrete characteristics as a cement binder

[2]. Slag is typically used for low-value applications such asphalt concrete aggregates and foundation engineering fillers [3, 4]. Low CaO/SiO_2 ratio and air-cooled processing make electric arc furnace slag (EAFS) low-reactive [5]. Alsadig and Wagialla [6] observed that Electric Arc Furnace slag (EAFS) as a partial cement replacement is a suitable pozzolan for mortar strength. SFS may have varying chemistry and mineralogy, hence hydraulic or pozzolanic reactivity may also be variable, according to Wang and Suraneni [7]. Compressive strength testing identifies steel slag materials as SCM. Because steelmaking methods vary, SFS chemistry and mineralogy alter, according to Brand and Fanijo [2]. SFS bulk oxide chemistry often includes CaO, MgO, SiO_2, FeO, $Al2O_3$, and MnO. SFS mineralogy depends on steelmaking, fluxing agents, and cooling. The degree of crystallinity, particle size, free CaO and MgO concentrations, and crystalline composition of SFS can change during cooling. After 90 days of testing, Santamaría reported the compressive strengths of cement mortar.As mix slag content grows, Vicario et al. [8] increase. At 28 days, 10% cement replacement by steel slag increases compressive and splitting tensile strength by 6%, according to Pan, Z., et al. This experiment examined how Libyan electric arc furnace steel slag affected cement mortar compressive, flexural, direct tensile, and workability. Steel slag was substituted at 0, 10, 20, and 30% cement weight. We also examined cement paste setting time and soundness.

EXPERIMENTAL PROGRAM

A. Materials Used:

A standard sand (Fig. 1) with a maximum size of 2 mm and minimum size of 0.09 mm was used in this study. Steel slag was collected in aggregate form which is shown in (Fig. 2) with average particle size between 5 mm to 10 mm. The slag produced as a by-product of the Bhagwati steel industry in Sinnar, Nashik. To turn it into a fine powder, it was subjected to a grinding process. For this purpose, mills were used in the grinding process (Fig. 3). The Slag was included in the mortar mixtures as a cement replacement with different levels (0, 10, 20 and 30 by weight). XRF (X-ray fluorescence) 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.

Fig.1 Standard Sand Grade-I, Grade-II, Grade-III

Fig.2 Steel slag Before Granding

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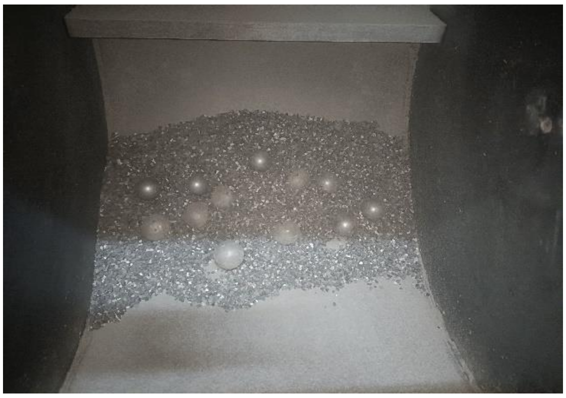

Fig.3 Ball Milling machine

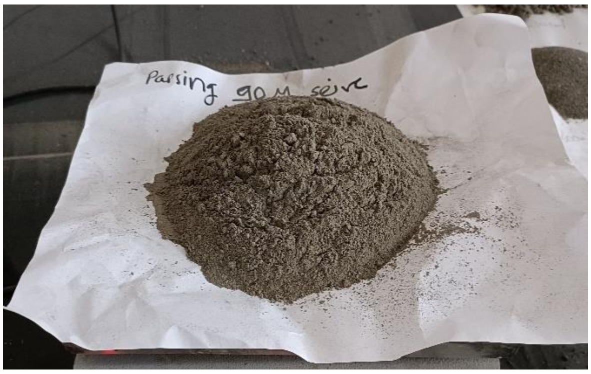

Fig.4 Steel slag after grinding & passing through 90-micron sieve

Table 1 Physical and chemical characteristics of cement and Steel slag powder

Sr. No.	Cement	Steel Slag
Lime (C_aO)	64.64	39.38
Silica (S_iO_2)	21.28	13.54
Alumina (Al_2O_3)	5.60	3.27
Iron Oxide (fe_2O_3)	3.36	28.60
Magnesia (MgO)	2.06	9.79
Sulphar Trioxide (SO_3)	2.14	0.37
N_2O	0.05	---
Loss of Ingnition	0.64	2.06
Lime Saturation Factor	0.92	--
C_3S	52.82	--
C_2S	21.45	--
C_3A	9.16	--
C_4AF	10.2	--

B. Proportions and Mixing Procedure: (As per IS 4031 (Part 6) -1968 (Reaffirmed 2005))

The mortar mixtures shown in Table 2 were used to prepare mortar specimens. Add water content equal to $\left[\left(\frac{P_n}{4}+3\right)\times(mass\ of\ cement\ and\ sand)\right]$ to the mixture of cement and sand, where P_n is the percentage of water required for a paste of standard consistency. After mixing, the molds were filled with mortar and properly compacted by means of a vibrating table.

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Table 2 Mortar Mix Proportion (1:3)

Mix	Slag %	Per weight of binder					
		Cement	slag	Water	Sand (gm)		
					Grade-I	Grade-II	Grade-III
C-0	0	750 gm	0gm	292.5 ml	750	750	750
C-10	10	675 gm	75gm	285 ml	750	750	750
C-20	20	600 gm	150gm	270 ml	750	750	750
C-30	30	525 gm	225gm	208.1 ml	750	750	750

C. Curing of Test Specimens:

The mortar specimens were allowed to set in the mould under laboratory conditions (20±2°C) for 24 hours after casting. Subsequently, specimens were extracted from the mould and stored in curing water at 20°C until the testing dates.

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	60	390	2.1
C-10	75	405	2
C-20	100	585	1
C-30	120	620	0.5

B. Compressive Strength:

According to Figure 5's data, the compressive strength of all mortar specimens rises with increasing curing time. The graph also shows that the rate at which the compressive strength of slag cement mortars develops is higher than that of control mortar (C-0) at curing ages up to 28 days. All slag cement mortars exhibit reduced compressive strengths at an early age when compared to the control mix (C-0). This is consistent with findings published by Bougara et al. [11], which demonstrate that the initial compressive strength of slag cement is lower than that of the OPC control. As Figure 5 demonstrates, the strength of the mortar containing 10% slag (C-10) at 56 and 90

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days of curing, however, increases by roughly 5 and 11.5%, respectively, in comparison to the control mix (C-0). This supports earlier findings by Pan et al. [15], which indicate that adding 10% steel slag powder to concrete improved its mechanical qualities.
Figure 5 shows a clear decline in the compressive strength of mortars containing 20% and 30% slag for all ages. The graph shows that, at 90 days, the compressive strength of mortar containing 30% steel slag powder (C-30) is reduced by approximately 12% in comparison to mortar containing control (C-0).

Table 4 Compressive strength

Age	C-0 %	C-10 %	C-20 %	C-30 %
3 Days	19	18.04	17.11	14.7
7 Days	28.17	26.03	24.03	17.31
28 Days	42.83	41.55	37.85	30.36
56 Days	47.41	48.99	46.44	35.18
90 Days	50.76	55.37	52.46	40.66

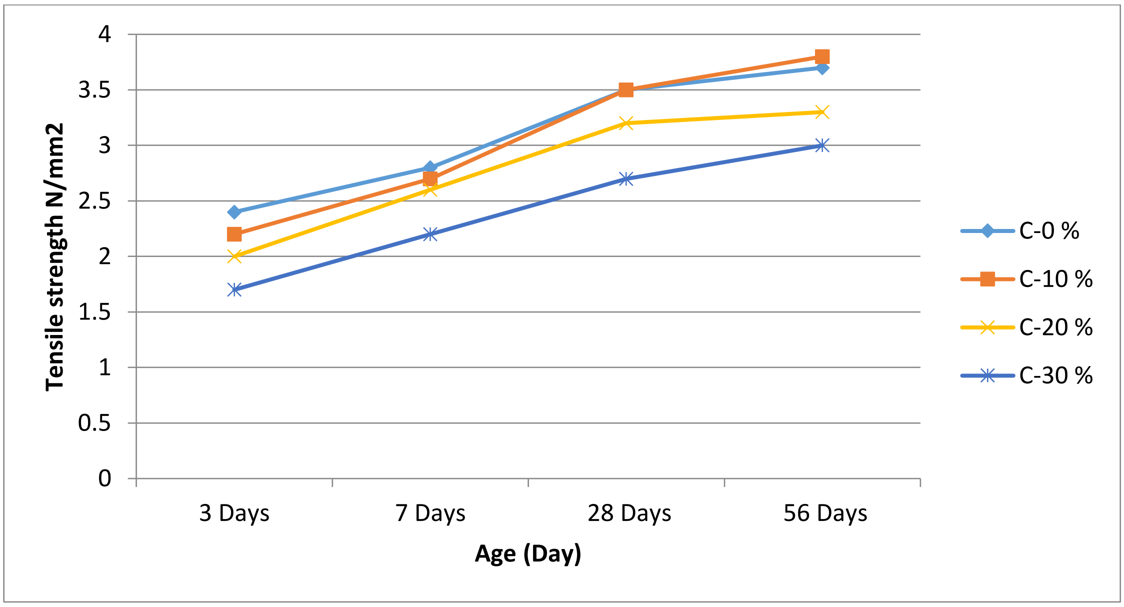

Fig 5 Compressive Strength Results

D. Direct Tensile Strength:

A mortar specimen is subjected to a direct tensile test in Figure 6. Figure 7 displays the cement mortars' direct tensile strength values. Figure 7 illustrates how the direct tensile strength of every mortar specimen rises with curing age. The graph also demonstrates that, as compared to control mortar (C-0), the tensile strength of cement mortar decreases with increasing slag content. However, mortar with 10% steel slag powder exhibits an improvement in tensile strength at 56 and 90 days of curing. After ninety days of curing, the mortar tensile strength of the mix containing 10% steel slag powder (C-10) increased by roughly 2.65% as compared to the control mortar

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(C-0). However, compared to control mortar (C-0), mortar with 30% slag concentration shows a loss in tensile strength of roughly 10.6% (C-30) after 90 days.

Table. 5 Tensile Strength

Curing Days	C-0 %	C-10 %	C-20 %	C-30 %
3 Days	2.4	2.2	2	1.7
7 Days	2.8	2.7	2.6	2.2
28 Days	3.5	3.5	3.2	2.7
56 Days	3.7	3.8	3.3	3
90 Days	3.8	4	3.7	3.1

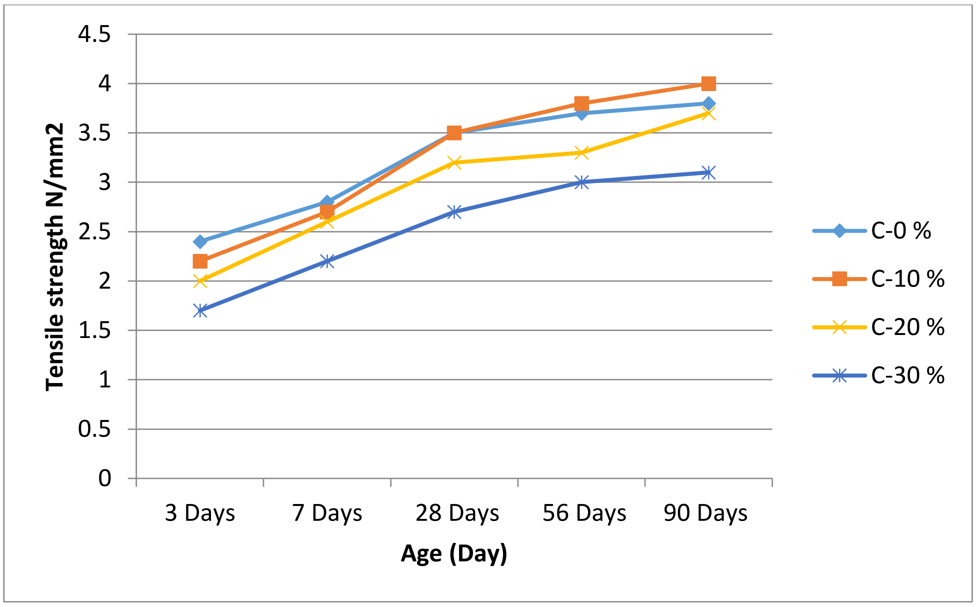

Fig 6 Tensile Strength Results

CONCLUSION AND RECOMMENDATIONS

The following findings can be drawn from the obtained results:

1. An improvement in the workability of mortar can be observed when steel slag powder is in corporated.
2. The replacement of cement by electrical arc furnace steel slag (EAFS) results in retarding setting times and reduction the soundness of cement mortar.
3. Compressive, flexural and tensile strengths of concrete with steel slag powder develops with time
4. The addition of 10% steel slag powder has positive effect on compressive, tensile and flexural strengths of concrete at late age.
5. The addition of steel slag powder by more than 20% causes reduction in the compressive, tensile and flexural strengths of concrete.

When looking into how long concrete lasts, it is suggested that more tests be done. To look into the texture of mortar samples with different amounts of steel slag powder, methods like scanning electron microscopy (SEM), infrared, and X-ray diffraction (XRD) should be used. To find out how well mortar and concrete work, different ways of activating steel slag powder should also be looked into.

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