UTILIZATION OF STEEL SLAG AS CEMENTITIOUS MATERIAL IN CONSTRUCTION INDUSTRY

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ABSTRACT. Blast furnace slag (BFS) and Linz-Donawitz slag (LDS) are huge industrial waste in the environment. Now a day, the iron and steel slag is used in many fields where its unique characteristics can be put to effective use. The effort of introducing a value added product can reduce environmental impacts due to its resource-conservation and energy-saving effects. In the present paper, Ground granulated blast furnace slag (GGBFS) and Linz-Donawitz slag (LDS), has been considered as a binder which is being used in many cement industry. GGBFS and LDS both have been used as cementations material (binder) with some alkali activator and the resulting binder is termed as slagcem-II. The standard specimens of concrete cube, cylinder and prism using slagcem-II as binder has been cast, cured and then tested for compressive strength, split tensile strength and flexural strength at 7 days and 28 days age of maturity. The test results indicate that the strength of concrete with binder i.e. slagcem-II is comparable as that of the reference concrete mix with Portland slag cement.

Keywords: Ground granulated blast furnace slag; Linz-Donawitz slag; Alkali-activator, Portland slag cement, Industrial waste.

INTRODUCTION

The term “LD” stands for “Linz-Donawitz”, though it can be seen from a report dated December 9, 1949, “Linz-Donawitz” was first suggested in 1952 in an article that appeared in 1954. Herbert Trenkler wrote that the new process would be known as the “LD process. Basic oxygen steelmaking (BOS) also known as Linz–Donawitz-steelmaking or the oxygen converter process, is a method of primary steelmaking in which carbon-rich molten pig iron is made into steel. Blowing oxygen through molten pig iron lowers the carbon content of the alloy and changes it into low-carbon steel. The process is known as basic because fluxes of burnt lime or dolomite, which are chemical bases, are added to promote the removal of impurities and protect the lining of the converter. Linz and Donawitz (LD) slag originates during the transformation of molten pig iron produced in a blast furnace into liquid steel. The LD process is carried out in an oxidizing atmosphere to reduce the carbon content of the pig iron to adequate levels. In terms of quantities, LD slag (aka Basic Oxygen Furnace or BOF slag) ranks second [1-4], with typical production percentages fluctuating around 10-20% by weight of steel outputs. The composition of the LD steel slags limits to some extent their re-use within the integrated process. For instance, residual amounts (> 0.05 wt.%) of phosphorous and sulfur make the slag unfeasible to replace raw materials (limestone, iron ore) in the blast furnace, whereas recycling through the sinter plant is also limited by phosphorous, alumina and titanium contents [5]. Other uses in the steel plants are mostly constrained by costs and nowadays in-situ valorization of the slag seems restricted to the magnetic recovery of metals. Therefore, there is a continuous search for markets that could eventually absorb the massive amounts of LD slags produced per year. Civil construction has been already spotted and LD slags are currently employed as sub-bases in roads. However, materials for civil engineering must comply with tight specifications in terms of hydraulic expansion, which most LD slags find difficult to fulfill, due to their significant CaO, MgO and metallic Fe contents [6].This situation has prompted an increasing interest in alternative routes of LD slag valorization. Among them, their use as low-cost adsorbents of pollutants in gaseous effluents [7-8], and wastewater has been widely investigated. Although these alternatives may seem rather limited in terms of the amounts of slag eventually reused, they have caught the attention of steel companies. Indeed, replacing conventional adsorbents for steel by-products in the treatment of the effluents generated within the steel integrated process sounds most advantageous from both environmental and economic viewpoints.

Blast furnace slag is produced when iron ore is reduced by coke at about 1350°C –1550 °C in a blast furnace. The molten iron, main product of a blast furnace, is formed from the ore, while the other components form a liquid slag. When flowing to the bottom of the furnace, the liquid slag forms a layer above the molten iron due to the smaller density of slag. After being separated from the molten iron, the liquid slag is cooled down in the air or with water and is prepared for further use. Typically, about 220 to 370 kilograms of blast furnace slag are produced per metric ton of pig iron. Lower grade ore results in more slag—sometimes as much as 1.0 to 1.2 tons of slag per ton of pig iron [9]. There are three main types of blast furnace slag, categorized by the way of cooling it. The granulated slag is produced by quenching the liquid slag with large amount of water to produce sand-like granulates. Granulates normally contain more than 95 percent of glass. Normally, they are ground to fine powder, called ground granulated blast furnace slag (GGBFS). Among the three types of blast furnace slag, GGBFS is the most valuable due to its cementitious properties and it is often mixed with Portland cement to produce slag (blended) cement. According to the standard in the India [10] the slag content in the Portland slag cement can be up to 65 percent in mass. The use of GGBFS as a cementitious material dates back to 1774 when Loriot made a mortar using GGBFS in combination with slaked lime [11]. In 1862, Emil Langen proposed a granulation process to facilitate removal and handling of iron blast-furnace slag leaving the blast furnace. Glassy iron blast furnace slags were later investigated by Michaelis, Prussing, Tetmayer, Prost, Feret, and Green. Their investigation, along with that of Pasow, who introduced the process of air granulation, played an important part in the development of iron blast furnace slag as a hydraulic binder [12]. This development resulted in the first commercial use of slag-lime cements in Germany in 1865. In France, these slag cements were used as early as 1889 to build the Paris underground metro system [12]. The use of GGBFS in the production of blended cements accounted for nearly 20 percent of the total hydraulic cement produced in Europe [13]. The first recorded production of Portland blast furnace slag cement was in Germany in 1892; the first United States production was in 1896. Until the 1950s, GGBFS was used in production of cement or as a cementitious material in two basic ways: as a raw material for the manufacture of Portland cement, and as a cementitious material combined with Portland cement, hydrated lime, gypsum, or anhydrite [14]. Since the late 1950s, use of GGBFS as a separate cementitious material added at the concrete mixer with Portland cement has gained acceptance in South Africa, Australia, the United Kingdom, Japan, Canada, and the United States.

MATERIAL

GGBFS and Linz-Donawitz, used in making binder, are being supplied as industrial waste of Tata Steel Pvt. Ltd., Jamshedpur conforming the IS code 12089:1987 [15]. The ground granulated blast furnace slag (GGBFS) used in this study has been supplied in our laboratory from Tata Steel Pvt. Ltd, Jamshedpur. The Linz-Donawitz was also taken from Tata Steel Pvt. Ltd., Jamshedpur. This study used a slagcem-II; The alkali activator used was a combination of sodium hexameta phosphate (Na_3PO_6) and sodium sulphate (Na_2SO_4). Locally available fine aggregate from Kharkai river are used conforming to zone II of IS 383:2016 [16]. The specific gravity, compacted bulk density and fineness modulus of sand are 2.59, 1670 kilogram per cubic meter and 2.83, respectively. Natural coarse aggregate has been used to perform the study conforming to IS 383:2016 [16]. Specific gravity, compacted bulk density and fineness modulus of course aggregate were found to be 2.83, 1670 kilogram per cubicmeter and 6.60, respectively. Water is used for preparing the binder mix conforming IS code 456:2000 [17].

Mix Proportions

The mix proportions of concrete has been adopted similar to conventional cement concrete conforming the code IS 10262:2009 [18] The binder amount of was351.69 kg/m^3 for all mix and the water: binder ratio is kept 0.49. The quantity of slagcem-II binder, coarse aggregate, fine aggregate and water was calculated as per the IS code [18].

Table1 Concrete mix proportion for one cubic meter

S.N	DESCRIPTION OF MATERIAL	MASS OF MATERIAL IN kg	MIX RATIO
1	Binder Content	351.69	
2	Fine Aggregate	666.53	1:1.90:3.38
3	Coarse Aggregate	1188.27	
4	Water	172.32	

METHODOLOGY

The binder, fine aggregate, coarse aggregate and water conforming the respective code were mixed to form concrete specimens. The process specimen preparation was kept similar to conventional cement concrete mixing. Following the similar mixing procedure, it allows the addition of water for achieving desired strength and workability. After mixing the binder, sand and aggregate properly, the concrete mix was cast in 150 mm × 150 mm × 150 mm size cube, cylindrical specimen of diameter 150 mm and length 300 mm and prism specimen of 500 mm × 100 mm × 100 mm. The cast specimens were kept in mould for 24 hours and then put for water curing conditions after removal from the mould. All the concrete specimens were cured in water. The cube specimen was tested for compressive strength using a universal testing machine with a 3,000-kN capacity as description in Fig.1.The loading rate used in the compressive strength and split tensile strength tests was 140 kg/cm^2/min. and 1.2 N/mm^2/min to 2.4N/mm^2/min as per code IS 516:1959 [17] and IS 5816(1999), respectively [18].The experimental setup for split tensile strength test has been shown in Fig.2 on cylindrical specimen of size 150 mm diameter and 300 mm length. The flexural strength testing setup has been shown in Fig. 3 which has conducted on the specimens of size 500 × 100 × 100 after 7 days and 28 days of maturity.

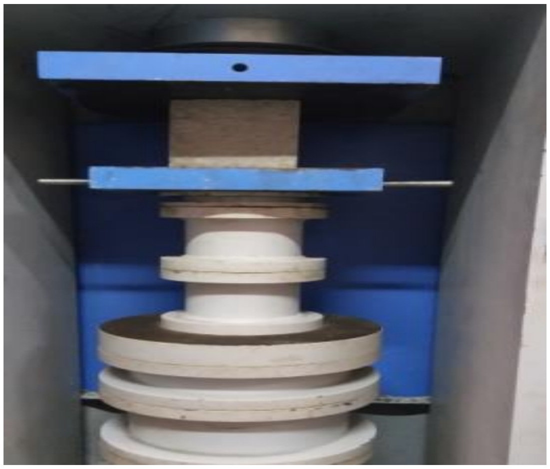

Figure 1 Compressive strength test setup

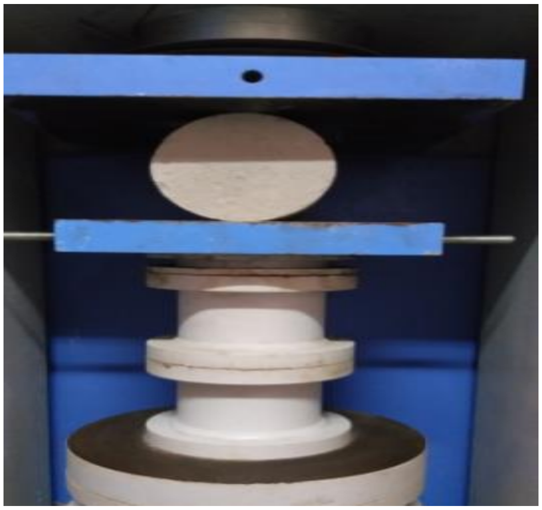

Figure 2 Split tensile strength test setup

Figure 3 Flexural strength test setup

TEST RESULTS AND DISCUSSION

Physical properties of binders

The binder was tested for the physical property such as specific gravity [19], fineness [20], soundness [21], standard consistency [22], initial and final setting time [23] as per the respective IS codes. The test results of physical properties of binder are given shown in Table 3 along with the limits as per IS 8112:1989 for PSC grade [24].

Table 2 Physical property of binder

PHYSICAL REQUIREMENTS	SLAGCEM-II BINDER	PSC
Fineness (m^2/kg)	330	300
Specific Gravity	2.81	2.89
Soundness Le-Chatelier (mm)	1.0	1.5
Standard Consistency	30 %	35
Setting time initial (min)	112	61
Setting time final (min)	362	340

Strength development in binder

For the compressive strength test, the binder and standard Ennore sand were used in 1:3 ratio and Then 70.6 mm size cubes were cast by vibration method as per IS:650-1970 [25]. Water was taken equivalent to (p/4+3) % of total weight of binder plus sand, where p is the consistency of the cement. The cube specimens were de-molded after 24 hours and cured in water at 27 ± 2^0C and compressive strength were determined on 3, 7 and 28 days of maturity. The sample has also been prepared using PSC for comparison. The test results of compressive strength for binder has been depicted in Fig. 4. The strength of binder is slightly lower than that of the strength of PSC cement in early ages but it reaches to almost equal strength at 28 days of maturity. It reflects that the strength development with binder i.e. slagcem-II is slightly slower in early ages as compared to the Portland slag cement.

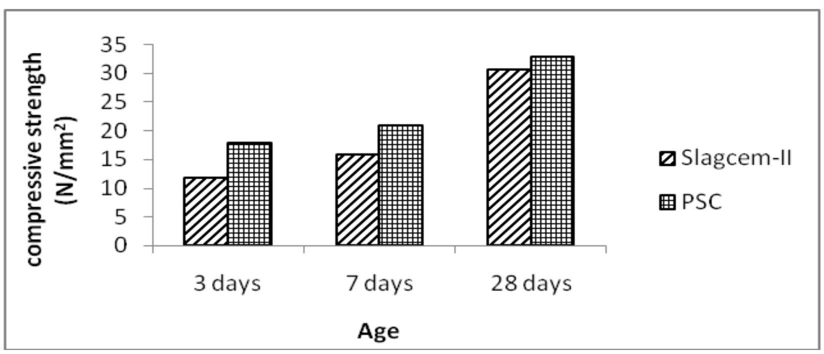

Figure 4 Compressive strength vs age of new binder and Portland slag cement

Test results of concrete specimen

For compressive strength three cube specimen of mix proportion1:1.90:3.38 of concrete were cast for 7 and 28 days of maturity keeping the water binder ratio 0.49. The value of the slump for the mix found to be 60 mm. The test result for compressive strength concrete specimen for 7 days and 28 days of maturity is shown in Figure 5

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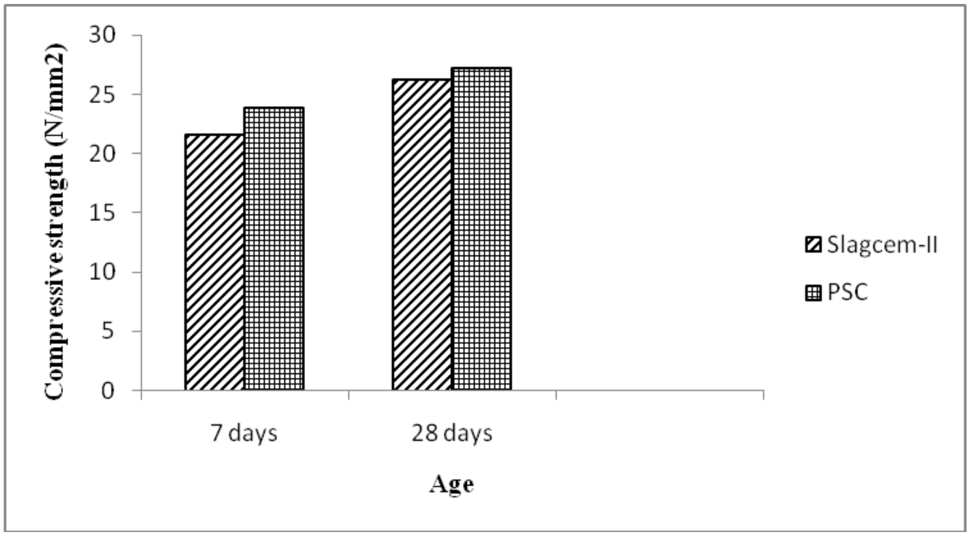

Figure 5 Compressive strength vs age

The compressive strength of slagcem-II concrete after 7 and 28 days maturity are 21.57 N/mm^2, 23.85N/mm^2, respectively whereas for concrete with PSC are 26.23 N/mm^2, 27.18 N/mm^2, respectively. At 28 days maturity, the PSC concrete shows the slightly higher compressive strength than that of the concrete with slagcem-II binder.

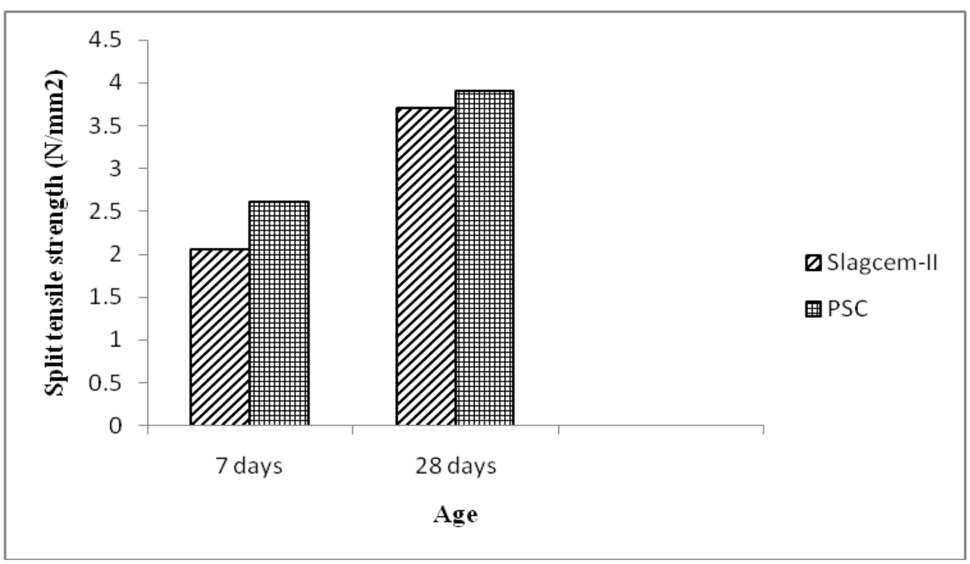

Figure 6 Split tensile strength vs age

The test result of split tensile strength for slagcem-II concrete and PSC concrete at 7 & 28 days maturity are 2.06 N/mm^2&2.61 $N/mm^2$and 3.71 N/mm^2&3.90 N/mm^2, respectively. The flexural strength for slagcem-II concrete and PSC concrete at 7 & 28 days maturity are 2.57 N/mm^2, 3.13 N/mm^2 and 5.28 N/mm^2, 5.47 N/mm^2, respectively as shown in fig.6. At 28 days maturity, the PSC concrete shows lesser value of split tensile strength than that of the slagcem-II concrete. Fig.7 represents the test results for flexural strength of concrete with slagcem-II binder and PSC concrete at 7 & 28 days maturity. At 28 days maturity, the PSC binder concrete shows the slightly higher magnitude of flexural strength than that of the slagcem-II concrete. However, the test result for split strength and flexural strength is satisfactory for concrete with slagcem-II binder.

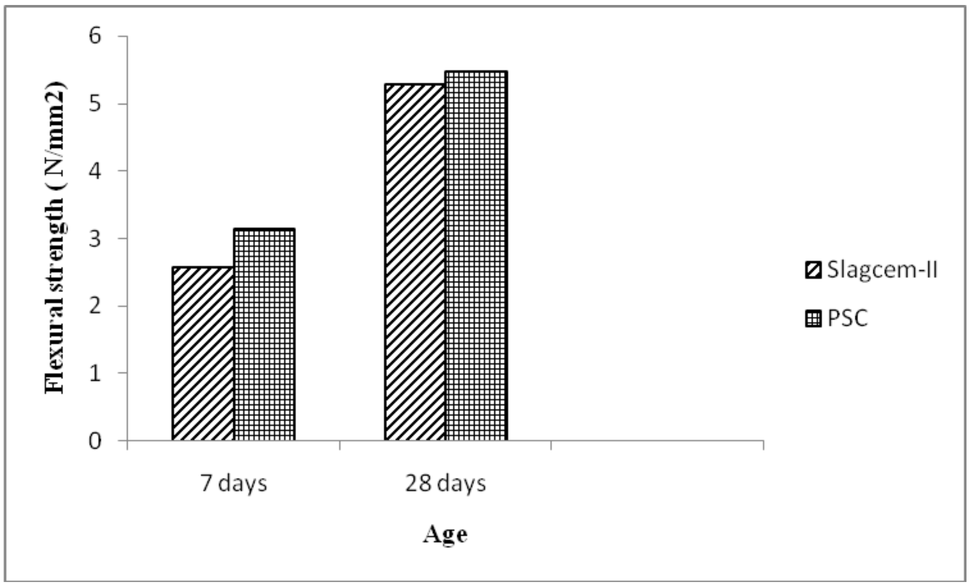

Figure 7 Flexural strength vs age

CONCLUSIONS

The new binder i.e. slagcem-II contains neither clinker nor chemicals. It consists of 56% of GGBFS, 30% of LD slag and 14% of alkali. The strength development in slagcem-II binder is very much comparable with the conventional Portland slag cement. It shows that the slagcem –II may be utilized as cementitiuos material and it can replace the conventional Portland slag cement. The development of compressive strength, split tensile strength and flexural strength with slagcem-II at 7 and 28 days maturity is almost equal to that of the concrete made with the conventional Portland slag cement. Hence, the new developed binder i.e. slagcem-II using industrial waste may be converted to a value added product by replacing the conventional cement made with clinker.

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