Studies on properties of concrete prepared with partial replacement of Coarse aggregate by Electric Arc Furnace Slag

Sathiya.M ¹ and Umamaheswari.N ²

¹ Research Scholar, Department of Civil Engineering, SRMIST, Kattankulathur
² Professor, Department of Civil Engineering, SRMIST, Kattankulathur, INDIA

*Corresponding Author E-mail ID: umamahen@srmist.edu.in

Abstract. In recent decades, the construction industry is facing a difficulty arising out of decline in the availability of natural resource material for the preparation of concrete due to depletion. An investigation is carried out on the reuse of waste slag as an alternative material to natural material in concrete production, satisfying relevant international standards. Electric Arc Furnace Slag (EAFS) is a material which is obtained from the steel industry during the production of steel from its raw ore. It can be used as both fine and coarse aggregate in concrete. This paper presents about the usage of EAFS in concrete preparation and results of some tests conducted on it. This study concentrates on 50% replacement of EAFS as coarse aggregate in concrete preparation. The mechanical properties of the EAFS is addressed. The compressive and split tensile strength is analysed for the age of 7, 14 and 28 days. The test results revealed that partial replacement of EAFS as coarse aggregate showed more or less similar results when compared to conventional concrete. Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) techniques are used to study topographic, crystallographic of material and chemical composition of slag and the corresponding results are included.

Keywords: Electric Arc Furnace Slag, Coarse aggregate, Compressive strength, Split tensile strength, XRD, SEM

1. Introduction

Environmental impacts are caused due to the waste disposed in a land. Various attempts are made all over the world to reuse these wastes for construction. Use of Electric Arc Furnace Slag (EAFS) from industries for construction purpose. The reusable materials explored from several decades, in the use of structural materials to various structural engineering applications, building material and as recycled materials in concrete [1].
The application of EAFS in building gives adequate strength. Slag material plays major role in construction industry which makes an alternate source of material. By using slag as a material, it gives more results. The waste comes from steel industry used for various purposes like structural material, building element, bridge element and tunnels and also various materials are made like bricks, ceramic tiles, etc [4,5,6].

The various research as induced by the EAFS mainly steel slag is non-reactive to activated agents organic pollutants and absence of CO$_2$. Most the oxides Fe$_2$O$_3$, CaO, SiO$_2$ and Al$_2$O$_3$ are evaluated. Effective replacement of steel slag as a coarse aggregate or fine aggregate has been tried. The properties of concrete with EAFS are proved to be environmental friendly. The activated pollutants level is in considerable limits. [2,3,7].

Kim et al. carried out characterization of EAFS in structural element, the member shows the better results compared to conventional member. Deflection of the member is minimum when compared to conventional member in structural element [10,11,12,13]. The durability of the steel slag is compared with conventional concrete, it gives adequate durability properties [8,9].

The research shows favourable use of material and non-toxic to the environment. The range of iron oxides, silicon, aluminium, magnesium and magnesium are within permissible limits. Use of the material not only environment favourable but also reduces the cost of the construction at large scale [2]. From the experiments conducted with the EAFS in various percentage level for various elements show that the strength was higher compared to conventional one.

It is a major area of research to evaluate the strength of the concrete and properties of a material, understanding advantages at increment level addition. Compressive and split tensile strength is tested. Microstructural characterization of conventional and modified materials also analysed [14].

2. Materials Used
Electric Arc Furnace Slag is a bye-product of electric steel manufacturing, during the mass production of steel slag. It is appeared as crushed stone sized aggregates. Appearance of slag is shown in Figure 1. The material is visible like a stony material and dark grey in colour. Material is suitable to use in concrete replacement of conventional material.

![EAF slag](image)
3. Experimental Program
Cement, sand, water and gravel are used for preparing conventional concrete specimens. EAF slag is used to produce modified concrete mixes with the partial replacements of coarse aggregate. M 30 concrete grade is considered for this study and mix design is prepared according to the standard IS 10262:2019. OPC 53 grade of cement refer to Indian standard code IS 12269:2013, aggregate size of 20 mm refer to IS 383:2016. Adequate water and super plasticizer is used. Mix proportion is given in Table 1.

| Mixtures    | Cement (kg/m³) | Fine Aggregate (kg/m³) | Coarse Aggregate (kg/m³) | Water Cement ratio | Super plasticizer (kg/m³) |
|-------------|----------------|------------------------|--------------------------|-------------------|----------------------------|
| Conventional | 350.22         | 774.74                 | 1211.76                  | 0.45              | 7.0                        |
| EAF Slag    | 328.33         | 792.9                  | 1240.18                  | 0.45              | 6.5                        |

4. Test procedure

4.1 Compressive and Split tensile Strength Tests
Tests were done as per the following codes of Indian Standards. Compressive strength on cubes (150 × 150 × 150 mm) was performed and the values were at 7, 14, and 28 days of curing as per IS: 516:2018. Similarly, split tensile strength on cylinders (150 × 300mm) was performed and the values were at 7, 14, and 28 days of curing. The testing of cube and cylinder are shown in Figure 2 and Figure 3 respectively.
4.2 Analytical Study on Microstructural and Chemical characteristics

HR-SEM and XRD were recorded for both conventional and modified concrete. Observation of material in various microstructural levels, the characteristics are measured and given in pictorial representation. HR-SEM and XRD give the composition of the elements.

5. Results and Discussions

5.1 Compressive Strength

Conventional coarse aggregate replaced partially by EAF slag in concrete the strength shown in Figure 4. Earlier the specimens were cured for 7, 14 and 28 days results taken for compressive strength. Strength of conventional and modified concrete prepared with 50% of coarse aggregate by EAFS compared and modified concrete showed improvement in compressive strength at all ages of curing (7, 14 and 28 days), the increase being ranged from 4.22- 5.97%. Strength has been marginally high compared to conventional concrete.

![Figure 4. Compressive Strength](image)

5.2 Split Tensile Strength

The conventional coarse aggregate is replaced partially by EAF slag in concrete and its impact in split tensile strength is shown in Figure 5. Earlier specimens were cured for 7, 14 and 28 days and tested for split tensile strength. Split tensile strength of concrete prepared with 50% of coarse aggregate by EAFS were compared and modified concrete showed improvement in split tensile strength at all ages of curing (7, 14 and 28 days), the highest increase being 22% at an age of 14 days. The tensile strength marginally high compared to conventional concrete.
5.3. XRD Analysis

Microstructural analysis plays a major role in analysing the versatile characteristic of the material. The graph is drawn between the 20 and intensity. It is noted in a previous study the EAFS is free from toxic materials. XRD pattern of conventional CA and EAFS is shown in Figure 6 and Figure 7 respectively.

![Figure 6. XRD pattern of coarse aggregate.](image)

![Figure 7. XRD pattern of EAF slag.](image)
5.4. SEM Analysis
The various textures can also be recognized by analysing slag microstructure via SEM images techniques. The microstructural study conducted for both conventional coarse aggregate and EAF slag were analysed. The topographical view of conventional coarse aggregate material and EAF slag material are shown in Figure 8 and Figure 9 respectively. In EAF slag, no pores shown in the figure and it was denser and compact. Topographical data varies for EAF slag and conventional coarse aggregate and within the limit.

![Figure 8. Microstructure of EAF slag.](image1)

![Figure 9. Microstructure of coarse aggregate.](image2)

6. Conclusion
The following conclusions are arrived at after experimental and analytical study carried over on the replacement of conventional aggregates by EAF slag aggregates,

The mix composition of EAFS partial replacement of aggregates can be carried over and included in regular structures. EAFS different physical and chemical properties with respect to conventional material.

However, above said EAF slag properties results in improving concrete strength, in terms of compressive and tensile strength. The test results showed that concrete strength is more or less similar to that of conventional concrete at the replacement level of 50%. Replacement of coarse aggregate with EAF slag has been found suitable to produce concrete of required strength.

XRD image clearly shows the composition of the EAF slag with considerable limit and suitable for the replacement of aggregate. SEM microstructural analysis shows the topographical features of EAF slag suitable to produce concrete with the replacement of conventional materials.

References
[1] Jha V K, Kameshima Y, Nakajima A and Okada K 2004 Hazardous ions uptake behavior of thermally activated steel-making slag (Journals of Hazardous Materials) vol 114 pp 139–144
[2] Zhang Y J, Liu L C, Xu Y, Wang Y C and Xu D L 2012 A new alkali-activated steel slag base cementitious material for photocatalytic degradation of organic pollutant from waste water (journals of Hazardous Materials) vol 209–210 pp 146–150
[3] Yadav S and Mehra A 2017 Experimental study of dissolution of minerals and CO2 sequestration in steel slag (Waste Management) vol 64 pp 348–357
[4] Syeda M I R and Humaria Y 2014 Impact of Iron and steel slag on crop cultivation: a review (Current World Environment) vol 9 pp 216–219
[5] El-Mahlawy M S 2008 Characteristics of acid resisting bricks made from quarry residues and waste steel slag (Construction Building Material) vol 22 pp 1887–1896
[6] Sarkar R Singh N and Das S K 2010 Utilization of steel melting electric arc furnace slag for development of vitreous ceramic tiles (Building Material Science) vol 33 pp 293–298
[7] Rondi L Bregoli G Sorlini S Cominoli L Collivignarelli C and Plizzari G 2016 Concrete with EAF steel slag as aggregate: a comprehensive technical and environmental characterization (Composite Part B Engineering) vol 90 pp 195–202,
[8] Manso J M Polanco J A Losanez M and Gonzalez J J 2006 Durability of concrete made with EAF slag as aggregate (Cement & Concrete Composite) vol 28 pp 528–534
[9] Pellegrino C and Gaddo V 2009 Mechanical and durability characteristics of concrete containing EAF slag as aggregate (Cement & Concrete Composite) vol 31 pp 663–671
[10] Kim S W Lee Y J and Kim K H 2014 Applicability of electric arc furnace oxidizing slag aggregates for RC columns subjected to combined bending and axial loads (Materials Research Innovations) vol 18 pp 793–798
[11] Kim S W Lee Y J and Kim K H 2012 Flexural behavior of reinforced concrete beams with electric arc furnace slag aggregates (Journal of Asian Architecture and Building Engineering) vol 11 no 1 pp 133–138
[12] Kim S W Lee Y J and Kim K H 2012 Bond behavior of RC beams with electric arc furnace oxidizing slag aggregates (Journal of Asian Architecture and Building Engineering) vol 11 no 2 pp 359–366
[13] Kim S W Lee Y J and Kim K H 2014 Application of electric arc furnace oxidizing slag for environmental load reduction (Asian Journal of Chemistry) vol 26 no 17 pp 5867–5870
[14] Vignesh Kumar S Rajkumar R and Umamaheswari N 2019 Study on mechanical and microstructure properties of concrete prepared using metakaolin, silica fume and manufactured sand (Rasayan Journal of Chemistry) vol 12 no 3 pp 1383-1389