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Study on Elastic Properties of Concrete with Eof Steel Slag as Coarse Aggregate

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Abstract : The elastic properties of concrete matrix are known to be effected by the elastic behaviour of its constituents and formation of interfacial transition zone between aggregate and cement paste. Because of inherent stiffness and large volume fraction it conquers in concrete, the aggregate exerts foremost influence on the modulus of elasticity of concrete. The modulus of elasticity is also affected by the type of the aggregate. Steel slag is a waste product generated by steel industry which is obtained from the conversion of iron to steel. Also, the application of steel slag, in concrete helps in reducing greenhouse gases and makes an eco-friendly material. Steel slag reduces the need of natural aggregate hence preserving our natural resources. The steel slag aggregate have high degree of internal friction and also highly angular in shape with rough surface texture. Due to rough surface texture and irregular shape of aggregate, the mechanical interlocking property strengthens which in turn increases the bond strength between cement matrix and aggregate. Steel slag aggregate helps in the enhancement of the mechanical properties of concrete in terms of compressive, flexural strength and modulus of elasticity than those of the concrete using natural aggregate. In this paper, an investigation is carried out to analyse the relationship between the mechanical properties of natural aggregate and that of steel slag aggregate concrete.
Key words : Steel slag, compressive, flexural strength, modulus of elasticity.

Introduction

Waste management has become one of the challenging and most complex problems which arise due to the rapid growth of industrialization [1]. This tremendous growth leads to the depletion of good quality aggregates which directly affects the fresh & hardened properties of concrete and the construction industry is at forefront in consuming these waste products. Various kinds of waste by-products are produced which are environmentally hazard and create problems of storage [5].Hardened concrete consist of more than 70% aggregate in construction works. The amount of disposed waste material is increasing gradually, researches and suppliers are exploring the alternative use of materials which could conserve natural sources and save the surroundings [1].

In India, the total steel production is about 72.20 Million Tones and the waste generated per annum is around 18 Million Tonnes (considerably higher than the world average) but only just 25% are being used mostly in cement production [4]. Steel Slag is one such waste product generated by steel industry and is a by-product obtained from the conversion of iron to steel in a basic oxygen furnace or by melting of scrap to make steel in the electric arc furnace [10].Also, the steel slag, in concrete helps in reducing greenhouse gases and makes an eco-friendly material [4].Steel slag reduces the need of natural aggregate hence preserving our natural resources and high degree of internal friction and also highly angular in shape and have rough surface texture[6]. Concrete that is produced with steel slag aggregate has high specific gravity compared to that of conventional concrete [6].

With rough surface texture and irregular shape of aggregate, mechanical interlocking property strengthens which in turn increases the bond strength between cement matrix and aggregate. More than the aggregate type, surface characteristics of aggregates and the quality of mortar help in the improvement of compressive strength of concrete [11]. Steel slag aggregate helps in the enhancement of the mechanical properties of concrete interms of compressive, tensile and flexural strength and modulus of elasticity than those of the concrete using natural aggregate [9]. The density of concrete increases with the use of steel slag and makes the workability of fresh concrete decrease. Steel slag was mainly selected due to its characteristics, which are almost comparable to conventional aggregates and it is easily obtainable from the steel industry as a by-product [1].The slag is tested and found to be safe. The slag is produced after the material is treated about 1500° Celsius [10]. As a result, use of steel slag will clean the environment and save natural resources [1].

EAF steel slag was used to make concrete mixtures that could be used in pumps with high workability. Compared to conventional concrete, this slag has produced high strength concrete [7].

Blast furnace slag aggregates in concrete is replaced with natural aggregates because the impact strength of steel slag aggregate is more than the natural aggregate. Steel slag aggregates have already used as aggregates in asphalt paving road mixes due to their stiffness, wear resistance, porosity, mechanical strength, and water absorption capacity. The results showed that it has similar properties to natural aggregates and it does not cause any harm if included into concrete. The research shows that usage of blast furnace slag as coarse aggregates in concrete has no negative impact on the short term properties of hardened concrete [8]. Compared to the conventional coarse aggregate concrete, the compressive strength of steel slag aggregate concrete is increased by 6%. Similarly the Split tensile strength of steel slag concrete is increased by 28%.Also the Flexural strength increases by 34% [2].

Then it was concluded that replacing some percentage of coarse aggregate with that of steel slag enhances the strength properties [3]. Also it was stated that 100% replacement of conventional coarse aggregate with steel slag aggregate was found as optimum level of replacement and it has improved the split tensile and flexure strength by about 6% to 8% in all mixes [12]. This improvement in strength was attributed to the rough surface texture which ensured strong adhesion and bonding between cement paste and aggregate particles [4]. Previous research papers have indicated that using steel slag as a replacement of coarse aggregate will progress the compressive strength of concrete to a significant amount [1]. In the present study, steel slag is used as replacement of coarse aggregate with optimum percentage of replacement in conventional concrete mixes.

Material Properties And Mix Design

Cement

Ordinary Portland cement (Ultratech 53 Grade) confirming to IS: 269-1967 was used throughout the investigation. The specific gravity of cement is 3.16 and the fineness modulus is 8%. The initial setting time of cement is 35minutes and its consistency is 31%.

Sand (Fine aggregate)

Sand used for the experiment was locally procured river sand and conformed to Indian Standard Specifications IS: 383-1970. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm. Fine aggregate was tested as per IS: 2386-1963.The specific gravity of fine aggregate is 2.57 and has water absorption of 1.57%. The fine aggregate comes under zone II classification with fineness modulus 3.15%. The bulk density of the fine aggregate is 1773.3 kg/m^3.

Natural Coarse Aggregate

The material which was retained on test sieve of 4.75 mm was termed as coarse aggregate. Machine crushed locally available hard granite; well graded 20 mm was used in this work. The nature of work decides the maximum size of coarse aggregate. The aggregate was tested as per Indian Standard Specifications IS: 2386-1963 and its property is assessed as per IS 2386 and given in Table 1.

Energy Optimized Furnace (EOF) Steel Slag

EOF slag is a by-product from steel manufacturing industry in which the constituents of steel-scrap and pig iron are improved in order to produce steel which is highly valued for outstanding toughness and workability. For each tons of steel produced, 2 – 4 tons of wastes (including solid, liquid and gas) are produced, in an integrated steel plant. Among the entire wastes, slag is produced at larger rate. 12000-13000 tons of EOF steel Slag shown in Fig.1, is produced per month in JSW Steel Ltd., Salem Works (JSWS), India and annual production of steel slag is about 2, 00,000 m^3 – 3, 00,000 m^3.

Figure 1: EOF steel slag aggregate

Table1. Physical Properties of Natural aggregate and EOF

Test	Natural aggregate	EOF steel slag
Specific gravity	2.72	2.89
Bulk density (kg/m^3)	1573.3 kg/m^3	1633.3 kg/m^3
Water absorption (%)	0.8	3

From Table 1 it is observed that, as the water absorption of EOF steel slag is around 3%, which in turn will affect the workability of the fresh concrete. So in order to reduce the absorption capacity of EOF steel slag, it is necessary to saturate the EOF steel slag before used in concrete. The bulk density result indicates EOF steel slag is heavier than natural coarse aggregate. The specific gravity of steel slag and natural coarse aggregate has very thin difference only. The EOF steel slag is graded to confirm IS: 383-1970 which specifies the coarse aggregate for concrete. The particle size distribution of EOF steel slag is within the limits of 20mm coarse aggregate and it is shown in Fig.2

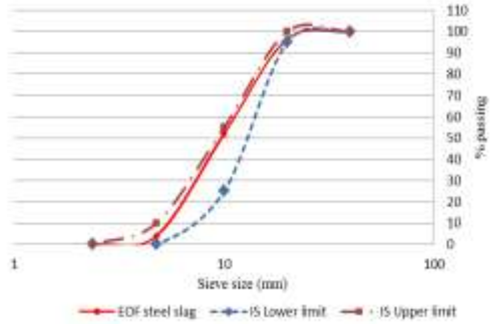

Figure 2: Particle size distribution curve of EOF steel slag aggregate

Mix Design

The mix design for concrete M20, M30 and M40 grades were arrived based on the code IS 10262:2009. The design is stipulated for mild exposure condition and good degree of quality control, and arrived mix proportion for M20 grade as 1:1.94:3.21 with water cement ratio 0.55, for M30 grade the mix proportion as 1:1.45:2.60 with water cement ratio 0.45 and for M40 grade the mix proportion as 1:1.42:2.62 with water cement ratio 0.40 with admixture of 4.43kg/m^3

Methodology

The effect of partial replacement of EOF steel slag is studied by keeping the water cement ratio, cement content, method of curing and compaction are constant. The fresh concrete property is studied by Slump Flow test as per IS 1199:1959 and hardened concrete is tested for Compressive Strength, Flexural Strength and Modulus of Elasticity as per IS: 516-1959. The concrete cubes of size 150 × 150 × 150 mm, cylinders of size 150x300mm and prism of size 100× 100× 500mm with 0% and 100% of slag as replacement for natural coarse aggregate were cast. After 24 hours, the specimens were de-moulded and subjected to water curing. After 28 days the specimens were tested as per IS: 516-1959.In this paper, the specimens with Natural aggregate are represented as $M_{0\%}$ and with 100% EOF steel slag as $M_{100\%}$

Results and Discussion

Relationship between Modulus of elasticity and Cube Compressive Strength

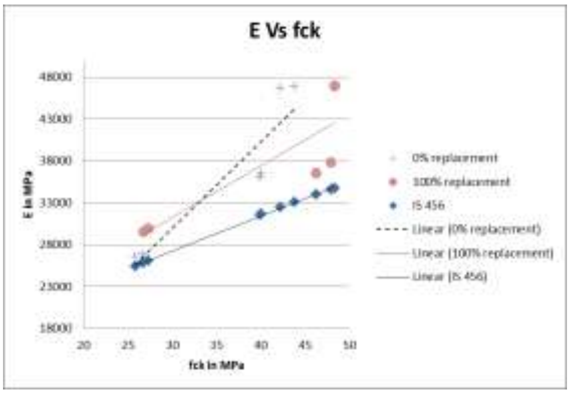

Figure 3: Relationship between Modulus of elasticity and Cube Compressive Strength

The influence of the aggregate shape is more evident in modulus of rupture or Elasticity (E) than in uniaxial compression. The fig 3 shows the relationship between modulus of elasticity and cube compressive strength (fck) of concrete. From fig 3 it can be seen that the $M_{100\%}$ concrete has progressive increment in modulus of elasticity in lower grades i.e from 25 N/mm^2- 33 N/mm^2, when compared with $M_{0\%}$ concrete. Beyond that 33 N/mm^2, the $M_{100\%}$ concrete gradually reduces its effect on E and produces lower E value than $M_{0\%}$ concrete. So, it can be concluded that EOF steel slag contributes to the increment of E at lower cubical compressive strength and its contribution is less pronounced and even lower than the contribution of natural aggregates at higher cubical compressive strength. But it can be evidently seen that both the experimental values of $M_{0\%}$ and $M_{100\%}$ outperform the theoretical value as per IS:456.

Table 2. Relationship between Modulus of Elasticity and cube compression strength

S.No	IS 456:2009	$E = 5000\sqrt{f_{ck}}$;
1.	$M_{0\%}$	$E = 6161\sqrt{f_{ck}}$; R^2 =0.65
2.	$M_{100\%}$	$E = 6013\sqrt{f_{ck}}$; R^2 =0.70

A statistical regression analysis is done between E and f_{ck} for $M_{0\%}$ and $M_{100\%}$ which are shown in table 2.From Table 2.it is observed that both $M_{0\%}$ and $M_{100\%}$ concrete have higher modulus of elasticity than the recommended value as per IS 456:2009. This can be due to the higher modulus of aggregate, the higher the modulus of concrete [13]. The E of $M_{100\%}$ concrete is only 2% lesser than that of $M_{0\%}$ concrete. This implies that the EOF steel slag has more or less same modulus as that of natural aggregate.

Relationship between modulus of elasticity and Cylinder Compressive Strength

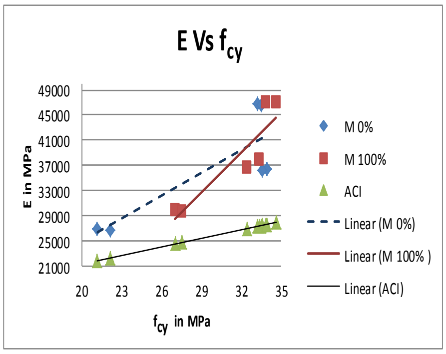

Figure 4: Relationship between Modulus of elasticity and cylinder compressive strength

Figure 4. Shows the relationship between modulus of elasticity and cylinder compressive strength of concrete and it is observed that modulus of elasticity of EOF steel slag aggregate is steeply increasing as the f_{cy} increases. But in $M_{0\%}$ concrete, the improvement in modulus of elasticity with respect to f_{cy} is not evidently pronounced as that of $M_{100\%}$ concrete.

Table 3. Relationship between Modulus of elasticity and cylinder compressive strength

S.No	**ACI- 318**	**$E = 4734\sqrt{f_{cy}}$**
1.	$M_{0\%}$	$E = 6814\sqrt{f_{cy}}$
2.	$M_{100\%}$	$E = 6810\sqrt{f_{cy}}$

From Table 2. it is observed that both $M_{0\%}$ and $M_{100\%}$ concrete have higher modulus of elasticity than the recommended value as per ACI-318 [18]. The E of $M_{100\%}$ concrete is only 0.058% lesser than that of $M_{0\%}$ replaced concrete. This implies that the EOF steel slag aggregate has same modulus of elasticity as that of natural aggregate.

Relationship between flexure strength and Cube Compressive Strength

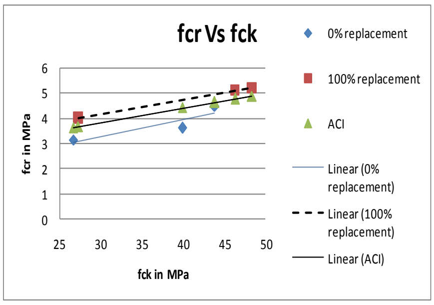

Figure 5: Relationship between flexure strength and cube compressive strength

The shape of the aggregate and its surface roughness has a significant effect on the flexural strength of the concrete. The angular shape of the aggregate delays the progress of cracking leading to ultimate failure [13]. In order to access the effect of angular and rough texture of steel slag aggregate, flexural test is done on concrete with natural aggregate ($M_{0\%}$) and steel slag aggregate ($M_{100\%}$). As the EOF steel slag aggregate are much angular than the natural aggregates, the ratio of flexure strength to the compressive strength is greater for $M_{100\%}$ concrete than the $M_{0\%}$ concrete [13]. From fig 6 it can be seen that the IS equation gives a similar values when compared to $M_{0\%}$ and $M_{100\%}$ concrete. Based on the test results a statistical regression analysis is done for the following equation, $f_{cr} = k\, f_{ck}$

Table 4. Relationship between flexure strength and cube compressive strength

S.No	IS 456-2009	$E = 0.7\sqrt{f_{ck}}$;
1.	$M_{0\%}$	$E = 0.792\sqrt{f_{ck}}$; $R^2 = 0.78$
2.	$M_{100\%}$	$E = 0.752\sqrt{f_{ck}}$; $R^2 = 0.993$

The $M_{0\%}$ concrete produces the regression coefficient k= 0.792 with a correlation coefficient $R^2 = 0.78$, while the $M_{100\%}$ concrete produces as k= 0.752 and $R^2 = 0.993$. The proposed equations for $M_{0\%,}$ $M_{100\%}$ concrete are compared with IS equation in Table 5. the $M_{0\%}$ concrete i.e. natural aggregate concrete produces higher flexural value when compared with EOF steel slag concrete i.e. $M_{100\%}$ but the percentage increment of $M_{0\%}$ concrete is only 5% when compared with $M_{100\%}$ concrete.

Relationship between flexure strength and Cylinder Compressive Strength

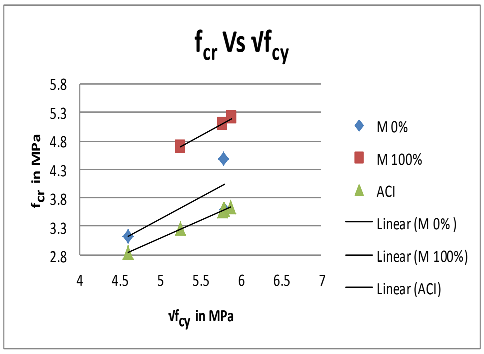

Figure 6: Relationship between flexure strength and cylinder compressive strength

The tensile strength of the concrete is often calculated from the flexure strength of the concrete. From fig 6. it can be seen that the ACI equation gives an underestimated values when compared to $M_{0\%}$ and $M_{100\%}$ concrete. Based on the test results a statistical regression analysis is done for the following equation, $f_{cr} = k\sqrt{f_{cy}}$

Table 5. Relationship between flexure strength and cylinder compressive strength

S.No	ACI – 318	$E = 0.62\sqrt{f_{cy}}$
1.	$M_{0\%}$	$E = 0.766\sqrt{f_{cy}}$; $R^2 = 0.60$
2.	$M_{100\%}$	$E = 0.777\sqrt{f_{cy}}$; $R^2 = 0.998$

The $M_{0\%}$ concrete produces the regression coefficient k= 0.766 with a correlation coefficient $R^2 = 0.60$, while the $M_{100\%}$ concrete produces as k= 0.777 and $R^2 = 0.998$. The proposed equations for $M_{0\%,}$ $M_{100\%}$ concrete are compared with ACI equation in Table 4. the $M_{100\%}$ concrete i.e. EOF steel slag concrete produces the better flexural property than the natural aggregate ($M_{0\%}$).

Conclusion

By using steel slag as coarse aggregate in various grades of concrete, the following conclusions are observed over the elastic properties of the concrete.

1. The modulus of elasticity of steel slag aggregate concrete is highly distinct at lower cube compressive strengths and cylinder compressive strength than that of natural aggregate concrete.

2. When the cube and cylinder compressive exceeds 30 N/mm^2, the modulus of elasticity of steel slag aggregate concrete is more or less same as that of natural aggregate concrete.

3. The modulus of elasticity of steel slag aggregate meets the recommended values as per ACI- 318 and IS: 456.

4. The flexural strength of steel slag aggregate concrete is steadily increasing with increase in cube and cylinder compressive strength and also meets ACI and IS recommendation.

5. The flexure strength of steel slag aggregate outperforms the natural aggregate concrete. This is due to the improved bonding of rough textured and high angular surface of the steel slag aggregate.

6. The elastic properties are influenced and satisfactorily improved because the steel slag aggregate's higher elastic modulus and consolidated bonding at the interfacial transition zone.

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