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Moment Capacity, Cracking Behaviour And Ductile Properties Of Reinforced Concrete Beams Using Steel Slag As A Coarse Aggregate

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Abstract - This research paper outlines the method of preparation, testing procedure and salient results on the eco-friendly concrete that is manufactured using the waste products of steel industries. Results of eight flexural behaviour of Steel slag concrete beams and thier comparison with normal weight concrete (NWC) with reinforcement and without reinforcements are presented and discussed .The concrete is of grade 20 and the reinforced concrete beams of size 150 mm x 150 mm x 900 mm were prepared to study the structural behaviour. Similar grade concrete using NWC were also prepared and reinforced. It has been observed from the experimental investigation of the beams, that the moment capacity of SSRC beams was higher than NWC beams . In addition, the mode of failure observed in SSRC was ductile compared to the brittle failure of NWC beams. Thus, the SSRC beams showed a ductile failure, giving amble warning before failure happened. SSRC beams also exhibited a lot of cracking thus the crack width and crack spacing was small. The other advantage for SSRC beams was deflection. The SSRC beams exhibited higher deflection under constant load until failure, compared to NWC beams that failed in brittle manner without warning.

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MOMENT CAPACITY, CRACKING BEHAVIOUR AND DUCTILE PROPERTIES OF REINFORCED CONCRETE BEAMS USING STEEL SLAG AS A COARSE AGGREGATE

Strictly as per the compliance and regulations of:

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I. INTRODUCTION

Currently India has taken a major initiative on developing the infrastructures such as express highways, power projects and industrial structures etc., to meet the requirements of globalization. In the construction of buildings and other structures concrete plays the rightful role and a large quantum of concrete is being utilized. Use of more and more environment-friendly materials and industrial wastes in any industry in general and construction industry in particular, is of paramount importance. A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using the waste material like fly ash and steel slag. This would pose problem for their safe disposal and Sometimes degrades the environment. The structural grade Steel slag concrete produced using Slag is a byproduct of metal smelting in the process of refining metals and making alloys referred to hereafter as SSRC. Slag appears in concrete, aggregate road materials, as ballast, and is sometimes used as a component of phosphate fertilizer. Like other industrial by products, slag actually has many uses, and rarely goes as waste. Ashour (2000) concluded from his investigation the members with a displacement ductility in the range of 3 to 5 has adequate ductility and can be considered for structural member subjected large displacements, such as sudden force caused by earth quake. Delsye et al.(2006) conducted an experiment on light weight concrete beams made with oil palm shell. From their research it was concluded that all the LSC beams are satisfied all the serviceability requirements as per ACI 318 and BIS 8110 codes. Ganesan et al(2007) conducted an experimental programme has been carried out to compare the behaviour of high performance concrete (HPC) and steel fibre reinforced high performance concrete (SFRHPC) flexural members under two point loading. Results indicate that introduction of steel fibres significantly improves the cracking behaviour in terms of significant increase in first crack load and the formation of large number of finer cracks. However, only marginal improvement was observed in the case of ultimate load. Addition of steel fibres to HPC imparted high ductility to structural members which is essential for seismic force resisting structures. Hisham Qasraui et al. (2009) studied the effect of waste material of steel plant in concrete. In their investigation local unprocessed steel slag was used in concrete as fine aggregate replacing the sand partly or totally. The compressive strength of concrete was reported to be improved when steel slag is used for low sand replacement ratio (up to 30%). Johnson Alengaram et al, (2008) conducted experiments on palm kernel shell concrete and its comparison with normal weight concrete (NWC). From their work they conclude that the PKSC beams showed a ductile failure, giving ample warning before failure. PKSC beams also exhibited a lot of cracking thus the crack width and crack spacing were small. The other advantage for PKSC beams was deflection. The PKSC beams exhibited higher deflection under constant load until failure, compared to NWC beams that failed in brittle manner without warning. Khidhair et al. (2009) has used

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the steel slag as replacement of aggregate in the concrete. The results showed that the density of concrete, compressive strength, flexural strength after 7 days and 28 days were increased by increasing slag content while water absorption was decreased by increasing slag content. Matsunaga et al. (2003) have prepared SSC with small amount of an alkali activator (calcium hydroxide or lime dust). The compressive strength of these SSC products was reported to exceed 18 N/mm^2, which is the general design strength of breakwater blocks. It was also reported that the 91 days compressive strength is approximately 1.3 times greater than 28 days strength. Ramakrishnan et al. (1987) studied the flexural fatigue performance of concrete reinforced with collated hooked-end steel fibres of size 50 mm× 0.50 mm and 60 mm×0.80 mm. Two different fibre volume fractions of 0.50% and 0.75% were tested. After addition of these fibres to the concrete, the ductility and post-crack energy absorption capacity were greatly increased.

II. RESEARCH SIGNIFICANCE

The present investigation was planned to study the performance of SSRC beams containing slags as a coarse aggregate subjected to flexural bending loading. Concrete containing five volume fractions of steel slags of 10%, 20%, 30%, 40% and 50% with steel slag is tested. The flexural bending tests of SSRC were determined for different volume fractions of steel slags and compared with that of plain and reinforced concrete beams.

III. MATERIAL PROPERTIES

a) Steel Slag-Physical and Chemical Properties

Steel slag aggregates are highly angular in shape and have rough surface texture. They have high bulk specific gravity and moderate water absorption (less than 3 percent) The physical properties of steel slag are shown in Table 1.

Figure 1 : Steel slag used for concrete mix

Property	Value
Specific Gravity	3.2 - 3.6
Unit Weight, kg/m^3	1600-1820
Absorption	up to 3%
Maximum size of aggregate, mm	16.00
Aggregate impact value (%)	8.00
Aggregate crushing value (%)	9.00

Table 1 : Typical physical properties of steel slag

Constituent	Composition (%)
CaO	40 - 52
SiO_2	10 - 19
FeO	10 - 40 (70 - 80% FeO, 20 - 30% Fe_2O_3)
MnO	5 - 8
MgO	5 - 10
Al_2O_3	1 - 3
P_2O_5	0.5 - 1
S	< 0.1
Metallic Fe	0.5 - 10

Table 2 : Typical steel slag chemical composition

The chemical composition of slag is usually expressed in terms of simple oxides calculated from elemental analysis determined by X-ray fluorescence. Table 2 lists the range of compounds present in steel slag from a typical base oxygen furnace. Virtually all steel slags fall within these chemical ranges but not all steel slags are suitable as aggregates of more importance is the mineralogical form of the slag, which is highly dependent on the rate of slag cooling in the steel-making process. The cooling rate of steel slag is sufficiently low so that crystalline compounds are generally formed. Free calcium and magnesium oxides are not completely consumed in the steel slag, and there is general agreement that the hydration of unslaked lime and magnesia in contact with moisture is largely responsible for the expansive nature of most steel slags. Steel slag is mildly alkaline, with a solution pH generally in the range of 8 to 10. However, the pH of leachate from steel slag can exceed 11, a level that can be corrosive to aluminum or galvanized steel pipes placed in direct contact with the slag.

b) Concrete Properties

The concrete mix was made with ordinary Portland cement, river sand and coarse aggregate of maximum size 20mm. Cement, sand and coarse aggregates was 1:1.5:3 in proportion by weight. Steel slag of 0.5 mm diameter and 30 mm length was used for the entire concrete mix. Steel slags are obtained from north Chennai steel plant. First dry mix was prepared from ordinary Portland cement, river sand and coarse aggregates maximum 20mm, and steel fibers were added to the dry mix of the materials. Water was then added to the mix to prepare the concrete. The W/C ratio for the mix was 0.50. After through mixing, beam specimens were cast along with companion cube moulds to measure the compressive strength of concrete. All the beams and companion cubes were compacted properly. The beam specimens were stripped from their moulds after 24 hours and submerged in water tank for 28 days for curing after casting. Before testing, the beams were coated with whitewash to facilitate the observation of cracking pattern.

IV. EXPERIMENTAL PROGRAM

In the present investigation, tests (Figure:2) were conducted on ten beam specimens of 150 mmX150 mm X 900 mm cast in moulds. Specimens labels are shown min Table 3 according to the volume of steel slag added in to the concrete. The steel slags are added in to 10%-50%. The beams referred as 10% of steel slag as SSRC1 respectively. The reinforcement used are 2 Nos. of 12mm diameter bar for all the beams. All the nine beams were tested in a Universal Testing Machine (U.T.M) of capacity 40 tonnes available in the structural Engineering Laboratory of Dr.M.G.R University. During testing, the beams were preloaded with a minimal force of 0.5 kN to allow initiation of the diagauges. The developments of cracks were observed and crack width was measured at the level of tensile reinforcement using a hand-held microscope with sensitivity of 0.02 mm. All strain, crack width and deflection measurements were measured at every load increment. The first crack load was noted immediately after its formation and all the cracks were marked as and when they propagated in the beam.

Figure 2 : Experimental set up

V. TEST RESULT AND DISCUSSION

a) Ultimate moments and Cracking Behaviour

A comparison between the experimental ultimate moments (M_{ult}) and the theoretical design moments are shown in Table 3. The theoretical design moments (M_{des}) of the beams was predicted using the parabolic rectangular stress block analysis are recommended by IS 456-2000. For slag beams, the ultimate moment obtained from the experiments was approximately 2% to 32% higher compared to predicted values. From the performed tests, it was observed that for steel slag concrete beams, IS 456 can be used to obtain a conservative estimate of the ultimate moment capacity and also adequate load factor against failure.

Table 3 : Comparison between experimental and theoretical ultimate moments

Beam No.	Experimental Ultimate moment(kN m)	Theoretical design moment (kN m)	Capacity ratio of Steel slag concrete beams
NWC	6.94	5.24	1.32
SSRC1	6.81	5.24	1.30
SSRC2	6.68	5.24	1.27
SSRC3	6.41	5.24	1.22
SSRC4	5.87	5.24	1.12
SSRC5	5.61	5.24	1.07
PSCB1	5.34	5.24	1.02
PSCB2	4.67	5.24	0.90
PSCB3	2.54	5.24	0.50
PCCB	5.34	5.24	1.02

Crack widths were measured at every load interval at the tension steel level and the crack formations were marked on the beam. The initial cracks were occurred at about 15% to 30% of the ultimate load. It was noticed that first crack always appeared close to the midspan of the beam. The cracks formed on the surface of the beams were mostly vertical, suggesting failure in flexure.

Flexure failure pattern of S.S.R.C beam

Shear failure of Plain S.S.C beam

Figure 5 : Failure pattern of concrete beams

b) Deflection behaviour

Figures 4 show the typical experimental load-deflection curves for steel slag concrete beams. In all beams, before cracking occurred, the slope of the load-deflection curved was steep and closely linear. Once flexural cracks formed, a change of slope of the load-deflection curve was observed and this slope remained fairly linear until yielding of the steel reinforcement took place.

Table 4 compares the predicted midspan deflection under service moments with the experimental values. The predicted deflection is calculated from load values according to the strength of materials equation, using the formula

$$\Delta = \frac{5Wl^3}{163EI} \qquad (1)$$

Where,

Δ = Midspan deflection in mm,
W = Load acting on the beam in kN,
l = Effective span of the beam in mm and
EI = Flexural rigidity in N/mm^2.

It was observed that the deflection obtained from the experiment at the service moments compares reasonably well to the predicted deflection. The modulus of elasticity of concrete very much governed by the stiffness of the coarse aggregate. From the properties in Table 1, it can be seen that steel slag is porous in nature also equal density compacted to granite, which directly influence the stiffness of the aggregate. Due to the equal modulus of elasticity of the steel slag beam when compared to R.C.C beam, the deflection under the service loads is acceptable as the span–deflection ratios ranged between 167 to 291 and are within the allowable limit provided by IS 456. IS 456 recommends an upper limit of span/250 for the deflection in order to satisfy the appearance and safety criteria of a structure.

From the load deflection graph it is observed that the beams beam behave similar to conventional R.C.C beams and 10% to 50% steel slag to concrete shows behaviour at the yield point and have further yielded with loads. Particularly the beam specimens with normal concrete have no ductile failure the failing in compression remaining all specimens are failure in shear failure. Hence it is also observed that the grade of concrete and reinforcement ratio and spacing of stirrups have certain effects on the flexural behaviour of reinforced concrete beam.

Table 4 : Deflection of concrete beams at service load moments

Beam No.	Deflection form experiment Δexp (mm)	Theoretical deflection Δthe (mm)	Δexp / Δthe	Span/Δexp	Displacement Ductility ratio μ = Δu/Δy	Mode of failure
NWC	4.50	1.51	2.98	174	3.46	Flexure
SSRC1	5.50	1.63	3.37	167	3.67	Flexure
SSRC2	4.53	1.41	3.21	173	3.11	Flexure
SSRC3	5.72	1.76	3.23	151	3.00	Flexure
SSRC4	4.00	1.35	2.96	291	3.00	Flexure
SSRC5	4.20	1.30	3.23	229	2.80	Flexure
PSCB1	5.50	1.50	3.67	276	2.11	Shear
PSCB2	5.30	1.40	3.78	320	2.00	Shear
PSCB3	4.95	1.25	3.96	267	1.76	Shear
PCCB	4.50	1.20	3.75	162	1.88	Shear

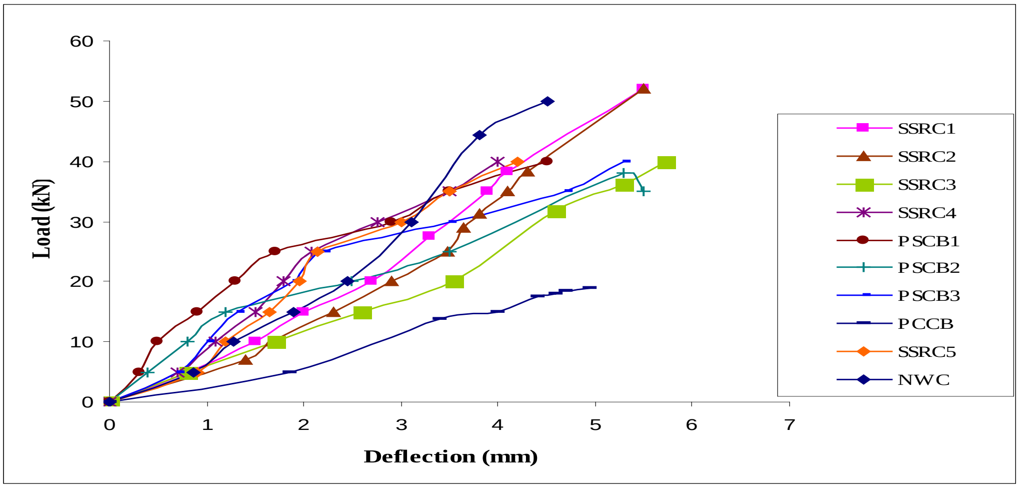

Figure 4 : Load Vs Deflection of tested beams

c) *Ductility Behaviour*

The ductility of reinforced concrete structures is also of paramount importance because any member should be capable of undergoing large deflection at near maximum load carrying capacity, providing ample warning to the imminence of failure. In this study, the displacement ductility was investigated. Table 4 shows the ductility of the tested steel slag concrete beams. The displacement ductility ratio is taken in terms of $\mu = \Delta u/\Delta y$, which is the ratio of ultimate to firest yield deflection, where Δu is the deflection at ultimate moment and Δy is the deflection when steel yields. In general, a high ductility ratio indicates that a structural member is capable of undergoing large deflections prior to failure. In this investigation it was observed that the steel slag beams have ductility ratio of more than 3 which means relatively good ductility. One of the important factors contributing to the good ductility behaviour of the steel slag beam was toughness and good shock absorbance nature of steel slag aggregate as indicated by the aggregate crushing value and aggregate impact value from Table 1. Ashour (2000) mentioned that the members with a displacement ductility in the range of 3 to 5 has adequate ductility and can be considered for structural member subjected to large displacements, due to sudden force caused by earthquake.

VI. CONCLUSION

From the experiments conducted, it was generally observed that the investigation of flexural behaviour of steel slag concrete beam gives encouraging results in favor steel slag to be used as coarse aggregate.

1. All steel slag concrete beams showed typical structural behaviour in flexure. The overall flexural behavior of SSRC beams used in this study closely resembles that of equivalent beam made with NWC.
2. The experimental ultimate moment gives a conservative estimate for steel slag concrete beams for 7% to 32% of a theoretical ultimate moment.
3. Deflection of steel slag concrete beams calculated using Equation (1) under service loads can be used to give reasonable predictions. The deflection under the service loads for beams were within the allowable limit provided by IS 456(2000).
4. Steel slag beams showed good ductility behaviour. All the beams exhibited considerable amount of deflection, which gives enough warning before failure.
5. The crack widths at service loads varies from 0.20 mm to 0.45 mm and this was within the maximum allowable limits.

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Abbreviations

NWC : Normal weight cement concrete beam
SSRC : Steel slag Reinforced cement concrete beam
PCCB : Plain cement concrete beam
PSCB : Plain steel slag concrete beam

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