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Mechanical Properties of Ordinary, Standard and High Strength Concrete Using Scrap Steel Slag as Coarse Aggregate.

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Abstract*: *This experimental work reports on the mechanical strength properties of three grades of concrete – Ordinary (M20), Standard (M40) and High strength (M60) concrete using scrap steel slag as coarse aggregate. No conventional gravel was used in making of concrete. Scrap steel slag is analyzed for its suitability to be used as coarse aggregate in concrete by evaluating its physical, chemical and durability performance. Detailed report on the material characterization of scrap steel slag is presented. The concrete was tested for its compressive strength, flexural strength and tensile strength at 28 days. Experimental work reports that scrap steel slag excels in mechanical performance in all there grades of concrete, except for that, the crushing value of scrap steel slag is higher than that of IS code's specification for wearing surfaces. Hence it is observed that the scrap steel slag is suitable to be used as coarse aggregate in concrete other than wearing surfaces.

Index Terms*: *Coarse aggregate, Scrap steel slag, Mechanical properties, 100% no natural gravel.

I. INTRODUCTION

Million tones of natural aggregates are involved in making of concrete annually since coarse aggregates form 70% of total volume of concrete. This contributes to the faster resource depletion. Also, the industrial waste production is expanding significantly. Out of the various solid wastes from industries, scrap steel slag was selected for the purpose of this study because it well suits the requirements of IS 383-2016 to be used as coarse aggregate in concrete. Rough estimates put that India generates around 10 million tones of scrap steel every year. Effective recycling opportunities of the scrap steel exist with assured availability of its slag in significant amount. This research work promotes the utilization of scrap steel slag in concrete so as to find a way making concrete more sustainable and resource friendly.

A. Objective

The main objective of this study is to make three grades of concrete – M20, M40 and M60 with 100% scrap steel slag as coarse aggregate and study its mechanical properties.

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II. LITERATURE REVIEW

R. Padmapriya et al [1] reports that steel slag performs well with increased strength values upto a replacement level of 40% by conventional gravel because of the shape, size and surface texture of steel slag which shows greater adhesion with the cement matrix. Beyond this replacement level performance of concrete drops due to the inherent porosity of steel slag . Recommends that steel slag aggregate concrete is more suitable for applications in areas not exposed to marine conditions.

Tarek U. Mohammed et al [2] reports that the absorption capacity of steel slag aggregate is lower than that of brick aggregates and shows relatively better workability. The work reports the relationship between compressive strength, tensile strength and modulus of elasticity of concrete with different slag aggregates.

Shekhar Saxena et al [3] replaced natural coarse aggregate with steel slag in ratios of 15%, 25%, 50%, 75% and 100%and used waste water in making concrete and found that 50% replacement of basalt aggregate with steel slag gave higher compressive strength, flexural strength and modulus of elasticity of concrete by 33%, 9.8% and 22% at age of 28 days respectively. SEM analysis, UPV test and RCPT indicates dense microstructure of concrete with enhanced durability.

Karolina. R and A L A Putra [4] reports that the high quality concrete made with steel slag coarse aggregate has higher compressive strength than conventional high quality concrete at 28 days. But the tensile strength of steel slag concrete was lesser than conventional concrete at 28 days. Fracture modulus and flexure moment of high quality steel slag concrete is greater than that of high quality conventional concrete

Gozde Inan Sezer and Mert Gulderen [5] reports that steel slag can be used as coarse aggregate or fine aggregate in concrete. But it cannot be used as both coarse and fine aggregate. Flexural strength of steel slag concrete is higher than that of its tensile strength. Steel slag performs well as coarse aggregate than that of fine aggregate based when evaluated for its water penetration depth and freeze thaw resistance.

Deepa. B and Felix Kala. T [6] replaced conventional granite coarse aggregate by steel slag aggregate in concrete and found that upto 80% replacement level, the concrete show enhanced compressive strength.

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Beyond that though decrease in strength was found, minimum required strength was achieved.

Ravikumar H et al [7] studied M20, M30, M40 and M50 grades of concrete with steel slag coarse aggregate and reports that the compressive strength of all grades of concrete improved by 4 to 7% upto a replacement level of 60% of natural aggregate by steel slag. Bleeding and seggregateion was found in 100% steel slag concrete but the density of steel slag concrete was 7% higher than conventional aggregate concrete.

III. MATERIALS USED

A. Cement

Ordinary Portland cement of grade 43, conforming to IS 8112-2013 was used. Physical properties of cement used are reported in Table 1. Method of tests were referred with IS 4031-1988 Part 2,3,5,8 and IS1727 – 1967.

Table 1 Properties of Cement

Parameter	Result	Requirement as per IS 8112-2013
Fineness, m^2/kg	300	Min 225
Soundness (By Le Chatelier method), mm	1	Max 10
Setting time a) Initial, min b) Final, min	 35 420	 30 600
Specific gravity	3.15	-
Standard Consistency	32%	-

B. Scrap steel slag

Steel slag was collected from a local scrap steel rerolling mill. They were collected in irregular shapes and then crushed using mechanical jaw type crusher, graded to required size, Figure 1. Various tests were conducted to check the properties of scrap steel slag, its durability and chemical composition. The results are listed below.

Figure 1 Graded Scrap Steel Slag

1. Physical appearance and Surface texture

The steel slag was dark grey in colour with rough surface texture. Voids were visible on the surface. Surface was well angular with sharp points around.

2. Physical properties

The specific gravity of scrap steel slag was lesser than that of the conventional gravel aggregate. Absorption capacity, flakiness and elongation indices with other mechanical strength values are all reported in Table 2. It is observed that the crushing value of scrap steel slag is higher than that recommended by IS code to be used as coarse aggregate for application in wearing surfaces. Methods of testing was referred with IS 2386 Part 1,3 and 4.

Table 2 Physical Properties of Scrap Steel Slag

Parameter	Result	Requirement as per IS 383-2016
Specific gravity	2.18	-
Water absorption	1.5%	-
Flakiness index	6.2	Combination shall not exceed 40%
Elongation index	24.8	
Abrassion (Loss Angles)	32%	Max 50%
Crushing Value	50%	30% for wearing surfaces
Impact Value	38%	Max 45%

3. Soundness

When put to 5 cycles in Sodium Sulphate solution, scrap steel slag suffered a reduction of 1.2% by weight. When observed with Magnesium Sulphate, 1.4% reduction in weight was observed.

4. p^H

Scrap steel slag was ground powder and then mixed with distilled water to get a paste. Handheld p^H meter was then used to find the p^H of the material. The p^H of the scrap steel slag used in this study was found to be 7.9.

5. Alkali Aggregate Reactivity

Alkalinity of 1N NaOH solution was observed to get reduced by 110 millimoles /lit and the dissolved silica was 21.64 millimoles/lit on reaction with scrap steel slag.

6. Chemical Composition

The major constituent of scrap steel slag is Calcium oxide. It constitutes 48% of the total oxides. SiO_2 was found available 18%, Al_2O_3 7%, FeO 10%, MnO 15% and traces of oxides of K, Ti, Cr, Mg, Cl are found. Free Calcium in the form of CaO was found 2%.

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C. Sand

River sand of maximum size 4.75mm conforming to Zone II of IS 383-1970 was sourced from a local supplier and used as fine aggregate in this study. The properties of sand used in this study are listed in Table 3.

Table 3 Properties of Sand

Parameter	Value
Bulk density	1420 kg/m^3
Specific gravity	2.6
Water absorption	0.5%
Fineness Modulus	2.7

D. GGBS

GGBS with specific gravity 2.8, conforming to IS 12089-1987 with chemical composition as listed in Table 4 was used in this study.

Table4 Chemical Composition of GGBS

Element	Si	Al	K	Mg	Ca
Weight %	42.2	16.87	1.69	5.24	33.36

E. Superplasticizer

Sulphonated naphthalene formaldehyde – a naphthalene based super plasticizer Conplast SP430 @ 2% dosage was used in this research work.

IV. MIX PROPORTIONING

Three grades of concrete – M20, M40 and M60 was selected for the purpose of this study as an attempt to check the mechanical properties of all three strength categories of concrete – Ordinary, Standard and High strength concrete. Mix proportioning of ingredients of concrete was based on IS 10262 – 1982 and is presented in Table 5.

Table 5 Mix Proportioning of Ingredients

	Cement	GGBS	Sand	Scrap steel slag	W/C Ratio
	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	
M20	311	-	727	1038	0.45
M40	311	133	815	870	0.36
M60	374	161	870	721	0.29

V. EXPERIMENTAL WORK

Cubical specimens (150x150x150mm), Cylindrical specimens (150mm dia and 300mm length), Prism specimens (100x100x500mm) were cast for each grades of concrete based on the mix proportion presented in Table 5 and the specimens were put to Compressive strength, Splitting tensile strength and Flexural strength respectively at 28 days.

Conventional method of casting and testing of concrete was carried out. Workability was achieved by using required dosage of SP which was fixed based on trial. Figure 2,3,4 and 5 indicate specimens cast for testing, compression test, tensile test and flexural test respectively.

Figure 2 Specimens Cast for Testing

Figure 3 Compression Test

Figure 4 Tensile Test

Figure 5 Flexural Test

VI. RESULTS AND DISCUSSION

A. Physical properties of scrap steel slag

Specific gravity of scrap steel slag is 2.18 which is less than that of the conventional gravel aggregate, which would be around 2.7. The absorption capacity of the steel slag aggregate was not found to affect the properties of concrete. Shape indices were well conformed to the code. Abrasion and impact value of the scrap steel slag meets the code's requirement to be used as coarse aggregate in concrete. Crushing strength of slag aggregate was found 50% which makes the aggregate not suitable to be used in wearing surfaces.

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Hence this scrap steel slag is not recommended for applications involving wearing surfaces.

B. Chemical properties of scrap steel slag

Scrap steel slag coarse aggregate has no harmful alkali aggregate reaction . Also they passed soundness test when subjected to sodium sulphate and magnesium sulphate solution with minimum reduction in weight – 1.2% and 1.4% respectively after 5 cycles which indicate that the material is sound enough to be used as coarse aggregate

C. Workability of Concrete

No issues was found in achieving workability of concrete when scrap steel slag was used as coarse aggregate. Absorption capacity of steel slag did not affect the workability. Since Superplasticizer was used, the workability of concrete was easily achievable.

D. Unit Weight of Concrete

The unit weight of fresh concrete varied from 2215kg/m^3 to 2250 kg/m^3 which is lesser than the conventional aggregate concrete and is advantageous as the dead load of the overall construction will get reduced when scrap steel slag is used as coarse aggregate.

E. Compressive Strength of Concrete

Compressive strength of all the three grades of concrete at 28 days is listed in Table 6. Characteristic compressive strength is exceeded in all three grades of concrete.

Table 6 Compressive Strength Report

Grade of Concrete	Compressive strength at 28 days in Mpa
M20	26.52
M40	49.92
M60	68.59

F. Splitting Tensile Strength of Concrete

Splitting tensile test was carried out on cylindrical specimens . Table 7 reports the tensile strength of concrete mixes studied.

Table 7 Tensile Strength Report

Grade of Concrete	Tensile strength at 28 days in Mpa
M20	2.52
M40	4.98
M60	7.78

The tensile strength of concrete made with scrap steel slag as coarse aggregate was found good and found to be around 12% of its compressive strength.

G. Flexural Strength of Concrete

Flexural strength values of plain cement concrete prisms are reported in Table 8.

Table 8 Flexural Strength Report

Grade of Concrete	Flexural strength at 28 days in Mpa
M20	4.75
M40	9.53
M60	13.55

Flexural strength of concrete obtained was found around 23% of its compressive strength.

H. Failure Surface of Concrete

The failure surface of concrete was found to cross through the aggregate when the specimens after crushing were examined.

VII. CONCLUSION

Based on this experimental study on ordinary, standard and high strength concrete using scrap steel slag as coarse aggregate, the following conclusions are made.

1. The specific gravity of scrap steel slag is lesser than that of conventional gravel aggregate.
2. The higher crushing value of scrap steel slag makes it unsuitable for wearing surfaces.
3. The absorption capacity of scrap steel slag not seem to affect the properties of concrete.
4. The workability of concrete was good for all three grades of concrete.
4. The unit weight of concrete is of the range 2215kg/m^3-2250kg/m^3, which is lesser than conventional aggregate concrete.
5. Compressive, Tensile and Flexural strength of concrete were achieved as per mix design at 28 days.
6. Splitting tensile strength was found to be 12% of its compressive strength at 28 days.
7. Flexural strength of concrete was found 23% of its compressive strength at 28 days.

From the observations made, it is clear that scrap steel slag can be used as coarse aggregate in all grades of concrete except for wearing surfaces.

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