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Mechanical Properties of Concrete Using Steel Slag Aggregate

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Abstract: This study presents an evaluation of steel slag aggregate concrete in comparison with the conventional natural aggregate concrete. Hardened concrete consist of more than 70% aggregate due to the high demand in building construction and the increase of the amount of disposed waste material, suppliers and researchers are exploring the use of alternative materials which could preserve natural sources and save the environment. Steel slag was used as an aggregate replacement in conventional concrete mixes. Steel slag which is mainly consists of calcium carbonate is produced as a by-product during the oxidation process in steel industry. Steel slag was selected due to its characteristics, which are almost similar to conventional aggregates and the fact that it is easily obtainable as a by-product of the steel industry. As a result, utilization of steel slag will save natural resources and clean environment. Particle packing analysis is made to optimize the gradation of coarse aggregate which would decrease the cement requirement and increase the density of packing which would result in its improved performance in terms of strength and other parameters.

Keywords: *Compressive strength, Flexural strength, Tensile strength, Steel slag, Replacement*

1.1 GENERAL

Concrete is the most widely used material on earth after water. Many aspects of our daily life depend directly or indirectly on concrete. Concrete is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete is unique among major construction materials because it is designed specifically for particular civil engineering projects. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues those together (Mindess et al. 2003).

Concrete plays a critical role in the design and construction of the nation's infrastructure. Almost three quarters of the volume of concrete is composed of aggregates. To meet the global demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete. Natural aggregates are obtained from natural rocks. They are inert, filler materials and depending upon their size they can be separated into coarse aggregates and fine aggregates. The coarse aggregate fraction is that retained on 4.75 mm (No 4) sieve, while the fine aggregates fraction is that passing the same sieve. According to some estimates after the year 2010, the global concrete industry will require annually 8 to 12 billion metric tons of natural aggregates (U.S.G.S and nationalatlas.gov, accessed Nov 2008).

During the past 25 years, the production of crushed stone has increased at an average annual rate of about 3.3 percent. Production of sand and gravel has increased at an annual rate of less than 1 percent. Based on these numbers, by 2020 U.S. production of crushed stone, which is expected to increase by more than 20 percent, will be about 1.6 billion metric tons, while production of sand and gravel will be just under 1.1 billion metric tons, an increase of 14 percent. In essence the amount of crushed stone to be produced in the next 20 years will equal the quantity of all stone produced during the previous century i.e. about 36.5 billion metric tons.. (U.S. Geological survey)Therefore the use of alternative sources for natural aggregates is becoming increasingly important.

1.2 NEED FOR AGGREGATE REPLACEMENT

The aggregates typically account about 75% of the concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability.

Conventional concrete consists of sand as fine aggregate and gravel, limestone or granite in various sizes and shapes as coarse aggregate. There is a growing interest in using waste materials as alternative aggregate materials and significant research is made on the use of many different materials as aggregate substitutes such as coal ash, blast furnace slag, steel slag aggregate. This type of use of a waste material can solve problems of lack of aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. The use of waste aggregates can also reduce the cost of the concrete production (Kalyoncu, 2001; Farrand and Emery, 1995).

1.3 NEED FOR OPTIMIZING AGGREGATE PACKING

From the production of concrete, cement is the most expensive material and can account for upto 60% of the total materials cost. Its manufacturing process is also the largest greenhouse gas contributor, and the most energy and resource intensive. Approximately 5% of global carbon dioxide emissions are attributed to the manufacturing of cement. The paste fraction of a concrete mix is usually 25% to 40% of the total volume. A portion of cement can be substituted by supplementary cementing materials (SCMs), but there is greater potential to reduce the cement content needed for concrete mixes by optimizing the combined aggregate gradation of mixes.

Optimizing the packing of the aggregate particles will improve concrete's:

i) Sustainability and cost by reducing cement content required;
ii) Durability by decreasing its permeability and potential for drying shrinkage cracking;
iii) Workability by decreasing segregation potential; and
iv) Structural performance by decreasing porosity and increasing the total aggregate volume. The shape and texture of the aggregates have a significant effect on the packing ability of individual aggregates and therefore, potential for optimizing blended aggregates.

Typical concrete mixtures have a binary blend of fine and coarse aggregates, each meeting gradation envelopes, which are often defined as "gap-graded" mixtures because of a lack of intermediately sized particles ranging between 2.36 mm and 9.5 mm, as illustrated in Fig. 1.

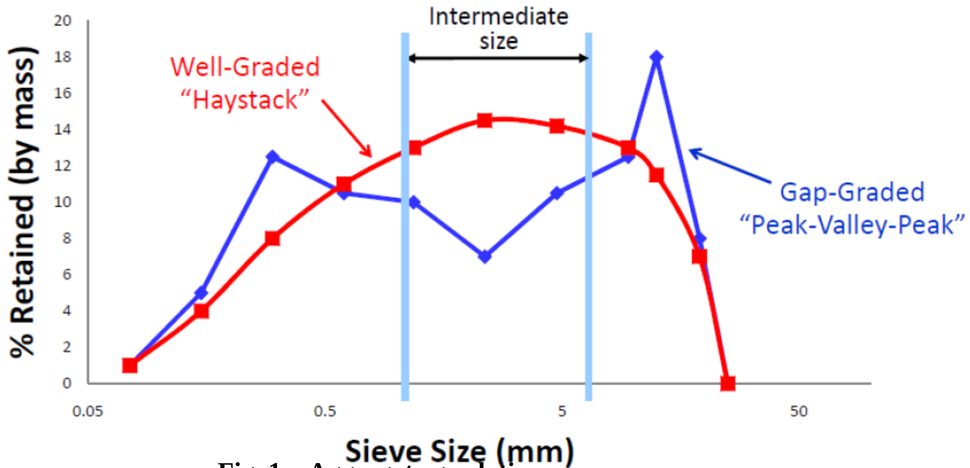

Fig. 1. Aggregate gradation

1.4 USE OF STEEL SLAG AS AGGREGATE

Always, construction industry has been at forefront in consuming these waste products in large quantities. The consumption of Slag in concrete not only helps in reducing greenhouse gases but also helps in making environmentally friendly material. During the production of iron and steel, fluxes (limestone and/or dolomite) are charged into blast furnace along with coke for fuel. The coke is combusted to produce carbon monoxide, which reduces iron ore into molten iron product. Fluxing agents separate impurities and slag was produced during separation of molten steel. Slag is a nonmetallic inert waste byproduct primarily consists of silicates, alumina silicates and calcium-alumina silicates. The molten slag which absorbs much of the sulfur from the charge comprises about 20 percent by mass of iron production. As the aggregates can significantly control the properties of concrete, the properties of the aggregates have a great importance (Beshr*et al*., 2003).Maslehuddin*et al*. (2002) have indicated that the durability of steel slag cement concrete was better than the same for crushed limestone aggregate.

K.G. Hiraskar and ChetanPatil (2013), investigated the use of blast furnace slag as aggregates in concrete. The results showed that it has properties similar to natural aggregates and it would not cause any harm if incorporated into concrete. The research was encouraging, since they show that using blast furnace slag as coarse aggregates in concrete has no negative effects on the short term properties of hardened concrete.

Mohammed Nadeem1, Arun D. Pofale (2012), studied on replacement of coarse and fine aggregate in concrete by slag. Concrete of M20, M30 and M40 grades were considered for a W/C ratio of 0.55, 0.45 and 0.40 respectively for the replacements of 0, 30, 50, 70 and 100% of aggregates (Coarse and Fine) by slag. Whole study was done in two phases, i.e. replacement of normal crushed coarse aggregate with crystallized slag and replacement of natural fine aggregate with granular slag. The investigation revealed improvement in compressive strength, split tensile and flexure strength over control mixes by 4 to 8 %. The replacement of 100 % slag aggregate (coarse) increased concrete density by about 5 to 7 % compared to control mix. The study concluded that compressive strength of concrete improved by 4 to7 % at all the % replacements of normal crushed coarse aggregate with crystallized slag.

Anastasiou and Papayianni, (2006), investigated on using steel slag aggregates in concrete and found out that the 28 day strength was increased by 21% with replacement of natural aggregates, while there was no increase in the setting time of concrete mixtures.

Manso and Gonzalez (2004), studied on durability of the concrete made with Electric Arc Furnace slag as an aggregate was done and the results showed that it was acceptable. The concrete mixes using conditioned EAF slag showed good fresh and hardened properties and acceptable behavior against aggressive environmental conditions. It was observed that the compressive strength was similar to that of traditional concrete. The durability was slightly lower than conventional concrete. The concrete had good physical and mechanical properties, but results showed that special attention should be paid to the gradation and crushing process. The results showed that the high porosity of EAF slag aggregates affects concrete resistance to freezing and thawing but improvements in the field could be possibly obtained by adding air entraining admixtures.

Maslehuddin, et al, (2003), compared steel slag and crushed limestone aggregate. They studied the mechanical properties and durability characteristics of steel slag aggregate concrete in comparison with limestone aggregates. Abrasion resistance, specific gravity, water absorption, chemical soundness, alkalinity, concentration of chloride and sulfates were tested and compared with lime stone aggregates. Shrinkage and expansion characteristics of steel slag and sand cement mortar specimens were evaluated and length was measured at periodic intervals. Compressive strength of steel slag aggregates increased with the proportion of coarse aggregates from 31.4 MPa with 45% coarse aggregates to 42.7 MPa with 65% coarse aggregates. The flexural strength and split tensile strength also increased while the water absorption capacity was reduced. Shrinkage of steel slag exposed to a dry environment was similar to limestone aggregate.

1.5 OBJECTTIVES

The objective of this research was to find combined aggregate gradations, using Steel slag aggregate, which will significantly reduce the amount of cement required by 10% to 15% without compromising concrete properties. To achieve this objective, several optimization techniques were being applied to typical M 40 design. These techniques include:

(i) Introducing an intermediate aggregate with particle sizes mostly between 2.36mm to 9.5mm, which is intended to fill the gap between the traditional binary combination of coarse and fine aggregates;

(ii) applying theoretical particle packing models, such as the Theoretical Packing Model by Dewar and the Modified Toufar Model by Goltermann, Johansen and Palbol; and

(iii) Applying particle density method for standardizing aggregate gradations.

II. MATERIALS

2.1 Concrete

The concrete used for casting the specimens was designed for strength of 40 MPa. The Mix proportioning of ingredients are presented in Table 1 and aggregate gradation in Table 2.

Table 1 Mix Proportioning of Ingredients

Mix	Mix Description	Fine Aggregate kg	Coarse Aggregate kg	Steel Slag kg	Cement Content kg	W/C Ratio
1	Control	545.29	1185.78	-	425.78	0.45
2	Steel Slag Coarse Aggregate	545.29	-	1521.37	425.78	0.45

Table 2.Gradation of Coarse Aggregate

MIX	Mix Description	Aggregate Volume Fraction			
		Coarse Aggregate		Intermediate Aggregate	Fine Aggregate
1	Control (Binary)	0.685		-	0.315
1A	Packing Density Method	20mm	12.5mm	-	0.384
		0.431	0.185		
1B	Modified Toufar Particle Packing Model	0.508		-	0.492
1C	Theory of Particle Packing Model	0.410		0.192	0.399
2	Conventional (Binary)	0.736		-	0.264
2A	Packing Density Method	20mm	12.5mm		0.4
		0.42	0.18		
2B	Modified Toufar Particle Packing Model	0.445		0.184	0.327
2C	Theory of Particle Packing Model	0.559		0.217	0.224

The specimens are designated as,

1 - Conventional CA control
1A - Packing Density Method (conventional aggregate)
1B - Modified Toufar Particle Packing Model (conventional aggregate)
1C - Theory of Particle packing model (conventional aggregate)
2 - Steel slag CA control
2A - Packing Density Method (Steel slag aggregate)
2B - Modified Toufar Particle Packing Model (Steel slag aggregate)
2C - Theory of Particle packing model (Steel slag aggregate)

2.1.1 Cement
The cement used in this study of steel slag concrete was OPC Grade 43. The specific gravity result of cement test was 3.15

2.1.2 Coarse Aggregate
Locally available natural aggregates were used to manufacture specimens for the control mix to be compared with that of the proposed mixes. The specific gravity result of aggregate was 2.75.

2.1.3 Steel Slag
Steel slag was obtained from local Steel industries in Pudhucherry. Steel slag was obtained in lumps which was then crushed manually into smaller fractions and then sieved to required size. No special treatment was made prior to use. They were packed in sacks and stored in the laboratory under dry condition. The specific gravity results of steel slag aggregate were 3.42.

2.1.4 Sand
The sand used in this project work was locally available river sand. Sand was stored in sacks inside the laboratory in dry condition. Specific gravity of sand was 2.65.

III. TEST SPECIMENS

3.1. Casting of Test Specimens
In this test, size of the cubical specimen 150 mm, size of the cylindrical specimen 150 mm diameter and height 300 mm and size of the prism 100 mm X 100 mm X 500 mm were used. The casting of mould was shown in Fig.2.

Concrete were cast based on the mix ratios. Conventional method of concrete batching and mixing was done. The weighing of the ingredients viz., Cement, fine aggregates, coarse aggregates were made just prior the beginning of producing concrete. This came under recommendation in order to avoid any disproportioning of the ingredients, an outcome that would deem the concrete mix design to differ if the contents were mistakenly added. Casting and curing was shown in Figs. 3 and 4.

The coarse aggregate and the fine sand were first mixed together for about 3 minutes. Water was then added to the dry materials and the mixing continued for further about 4 minutes or until an adequately combined mixture was formed. The fresh concrete was then cast into the mould immediately after mixing without any delay. Each layer was given strong manual roding. Each layer received nearly 25 manual strokes.

Thus the moulds were well compacted and the top surface is finished. The casted cubes were left undisturbed in the laboratory along with the mould for 24 hrs. The cubes were released from the moulds the next day of casting and were put to curing in the curing tank.

Fig. 2. Moulds used

Fig.3 Casting of Test Specimens

Fig.4 Curing of Test Specimens

3.2 Testing of Specimens

The specimens were tested for their compressive strength, split tensile strength and flexural strength.

3.2.1 Compressive Strength Test

Out of many test applied to the concrete, this was the almost important which gives an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. For cube test specimen cubes of 15 cm X 15 cm X 15 cm and for cylinders 15 cm dia and 30 cm height cylindrical specimens were used. These specimens are tested by compression testing machine after 7 days curing and 28 days curing. Load was applied until failure of specimens. Load at the failure divided by area of specimen gives the compressive strength of concrete. Compressive strength test was shown in Fig.5.

Compressive strength = (P/A)

3.2.2 Split Tensile Strength Test

The tensile strength was one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. Apart from the flexure test the other methods to determine the tensile strength of concrete can be broadly classified as (a) direct methods, and (b) indirect methods. The direct method suffers from a number of difficulties related to holding the specimen properly in the testing machine without introducing stress concentration, and to the application of uni- axial tensile load which is free from eccentricity to the specimen. As the concrete is weak in tension even a small eccentricity of load will induce combined bending and axial force condition and the concrete fails at the apparent tensile stress other than the tensile strength. Similar to the splitting of the cylinder cubes can also be split either (a) along its middle parallel to the edges by applying opposite compressive forces through 15 mm square bar of sufficient length or (b) along one of its diagonal planes by applying compressive forces along two opposite edges. Split tensile strength test was shown in Fig.6.

Split tensile strength = $(2P/\pi dl)$

Where, P = applied load, D = diameter of specimen, L = length of the specimen

3.2.3 Flexural Strength Test

Flexural strength is one measure of the tensile strength of concrete. It was a measure of an unreinforced concrete beam or slab to resist failure in bending. It is measured by loading 10 x 10 x 50 cm concrete beams. The flexural strength is expressed as Modulus of Rupture (MR) in psi (MPa) and is determined by standard test methods ASTM C 78 (third-point loading) or ASTM C 293 (center-point loading). Flexural strength test was shown in Fig.7. Flexural Strength of Concrete Flexural MR is about 10 to 20 percent of compressive strength depending on the type, size and volume of coarse aggregate used. However, the best correlation for specific materials is obtained by laboratory tests for given materials and mix design.

Flexural strength = $(3PL/bd^2)$

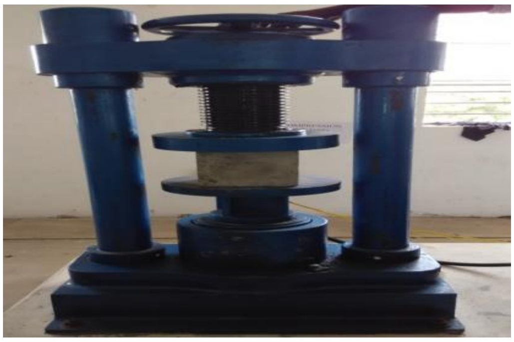

Fig. 5 Compressive Strength Test

Fig. 6 Split Tensile Strength Test

Fig.7 Flexural Strength Test

3.2.4 E – For Concrete Test

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The modulus of elasticity of concrete is relatively constant at low stress levels but start decreasing at higher stress levels as matrix cracking develops. The test was carried out with cylindrical specimens. Compressometer with gauge length of 205 mm was fitted to the specimen. The specimen is then loaded in compression testing machine and the compressive load was gradually applied. A dial gauge attached with the compressometer reads the change in the gauge length. For each increment in compressive load, the change in gauge length was noted. The same was repeated for required number of readings and tabulated. Then the strain value is calculated and a plot is made between stress and strain values and a initial tangent was drawn to the plotted curve to read the initial tangent modulus of the concrete specimen.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The standard specimens were tested at both 7 and 28 days. Initially cubical and cylindrical specimens were put to compressive strength test in order to get optimum number of proportions. This was not unusual as compressive strength has fundamental importance in the design of concrete mixtures. The entire test results stated above was obtained as average value of three test specimens under each mixes considered. Casting and testing of specimens were with due care confined to a possible extent with the standards.

4.1 Compressive Strength

The compressive strength results of cubical specimens are presented in Table 3.and the cylindrical specimens are presented in Table 4.

Table 3. Compressive Strength of Cubical Specimens

Mix	Compressive Strength, MPa	
	7 days	28 days
1	34	39.64
1A	34	42
1B	35.24	42.36
1C	31.36	37.64
2	28.24	36.34
2A	36	42.24
2B	36.24	43
2C	33.54	39.8

Table 4. Compressive Strength of Cylindrical Specimens

Mix	Compressive Strength, MPa	
	7 days	28 days
1	34	39.64
1A	36	42
1B	36.23	42.36
1C	31.36	37.64
2	33	36.34
2A	38.64	42
2B	36.24	43.24
2C	33.54	38

Particle density method for conventional coarse aggregate gave 6% higher compressive strength than the control mix. Modified Toufar particle packing model for conventional coarse aggregate gave 7% higher compressive strength than the control mix and Theory of Particle packing model for conventional coarse aggregate gave 5% lower compressive strength than the control mix.

Particle density method for steel slag coarse aggregate gave 16% higher compressive strength than the control mix. Modified Toufar particle packing model for steel slag coarse aggregate gave 18% higher compressive strength than the control mix and Theory of Particle packing model for steel slag coarse aggregate gave 10% higher compressive strength than the control mix.

Comparing Conventional coarse aggregate and steel slag aggregate concrete, steel slag coarse aggregate concrete gave 8% lower compressive strength than Conventional coarse aggregate concrete. Particle density method for steel slag coarse aggregate gave 0.6% higher compressive strength than the conventional coarse aggregate concrete. Modified Toufar particle packing model for steel slag coarse aggregate gave 0.9% higher compressive strength than the conventional coarse aggregate concrete and Theory of Particle packing model for steel slag coarse aggregate gave 6% higher compressive strength than the conventional coarse aggregate concrete. And it was found that A and B type mix were yielding higher strengths both in conventional and steel slag coarse aggregate concrete.

Table 4 indicates that as similar to that of the cubical specimens, cylindrical specimens also showed a positive increase in compressive strength of steel slag aggregate specimens than that of conventional aggregate specimens. No much variation was found with compressive strength results of cubes and cylinder specimens. From the results, it was ended up continuing further course of work with mix 1A, 1B, 2A & 2B. Fig. 8shows the compressive strength of various mix ratios of 7 days and 28 days.

Further flexural strength test, split tensile strength test was restricted to those 4 mixes - 1A, 1B, 2A and 2B. The tests were continued with cylindrical specimens and their split tensile results are presented in Table 5.

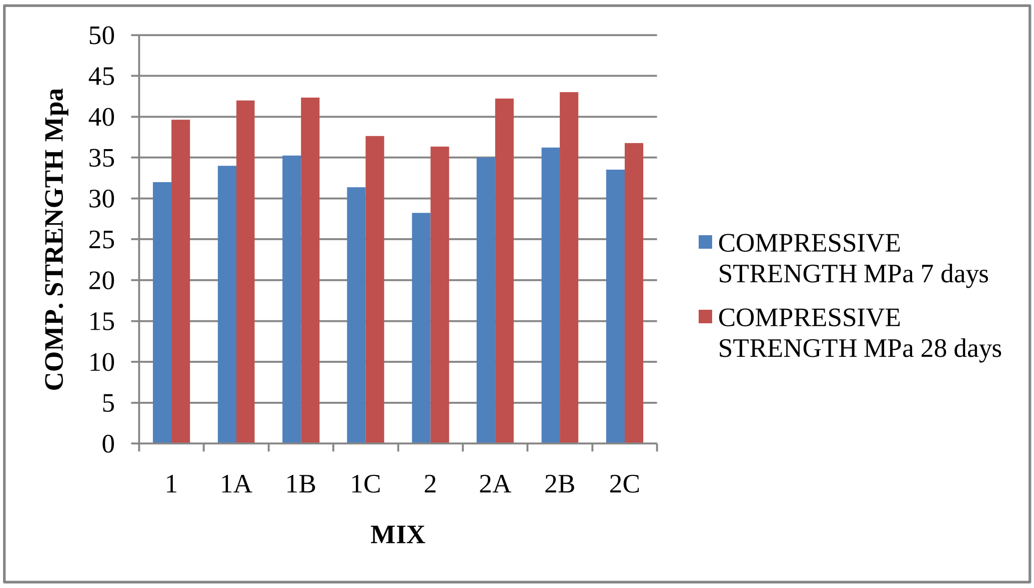

Fig. 8 Mix Vs Compressive Strength (Cubes)

4.2 Split Tensile Strength

The split tensile strength results of specimens are presented in Table 5.

Table 5. Split Tensile Strength

Mix	Split Tensile Strength 28 Days, MPa
1A	1.20
1B	1.44
2A	1.32
2B	1.85

Table 6. Flexural Strength

Mix	Flexural Strength 28 Days, MPa
1A	7
1B	8.4
2A	9.2
2B	10.4

Modified Toufar particle packing model for conventional coarse aggregate concrete gave 20% higher split tensile strength than that of control coarse aggregate concrete. Modified Toufar particle packing model for steel slag coarse aggregate concrete gave 40% higher split tensile strength than that of control steel slag coarse aggregate concrete. Modified Toufar particle packing model found to give higher split tensile strength. It gave 28% higher split tensile strength compared to that of conventional coarse aggregate concrete. Fig. 9 shows the split tensile strength of various mix ratios of 28 days.

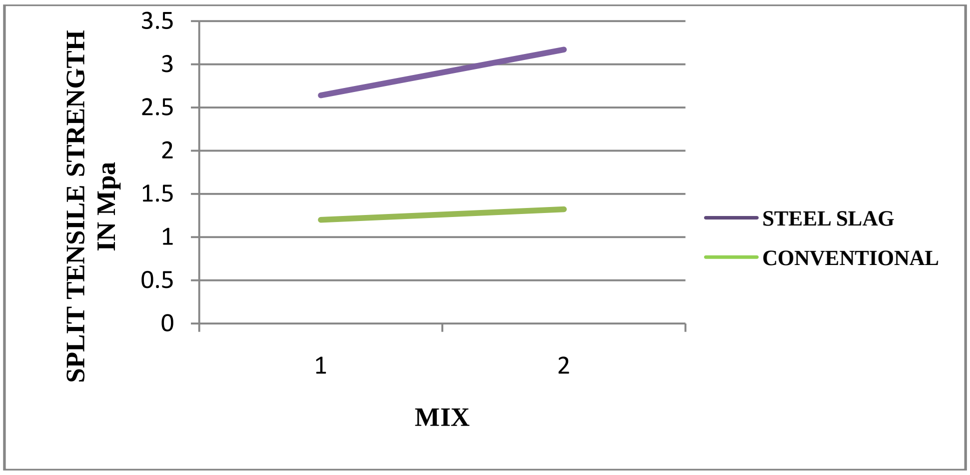

Fig. 9 Mix Vs Split Tensile Strength

4.3 Flexural Strength

The flexural strength of the specimens at an age of 28 days was presented in Table 6. Fig.10 shows the flexural strength of various mix ratios of 28 days.

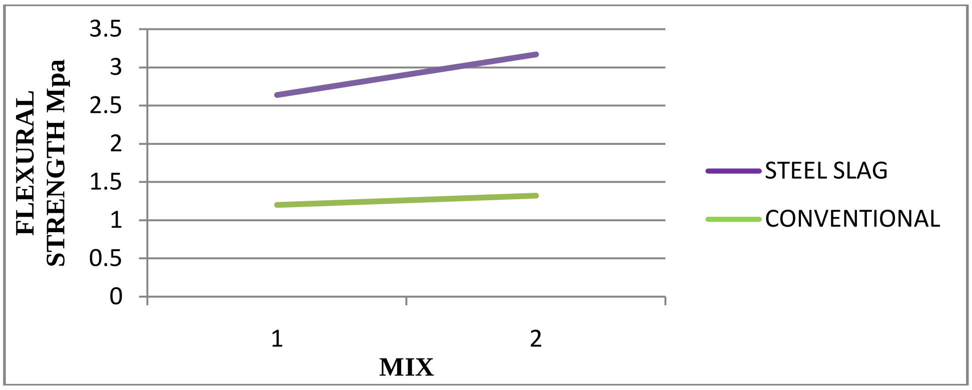

Fig. 10 Mix Vs Flexural Strength

Modified Toufar particle packing model for conventional coarse aggregate concrete gave 20% higher flexural strength than that of control coarse aggregate concrete. Modified Toufar particle packing model for steel slag coarse aggregate concrete gave 13% higher flexural strength than that of control steel slag coarse aggregate concrete.

Modified Toufar particle packing model found to give higher flexural strength. It gave 34% higher flexural strength compared to that of conventional coarse aggregate concrete. From the results of compressive strength, split tensile strength and flexural strength test, it is clear that Modified Toufar Particle packing method of steel slag coarse aggregate concrete gave the highest strength compared to other concrete specimens. It was also found that steel slag aggregate specimens gave better strength values compared to all other conventional concrete specimens.

4.4 MODULUS OF ELASTICITY

Modulus of elasticity of concrete was found by plotting Stress – Strain curve with tested data. Fig.11 shows the stress – strain curve for steel slag concrete. Fig.12. shows the stress – strain curve for conventional concrete.

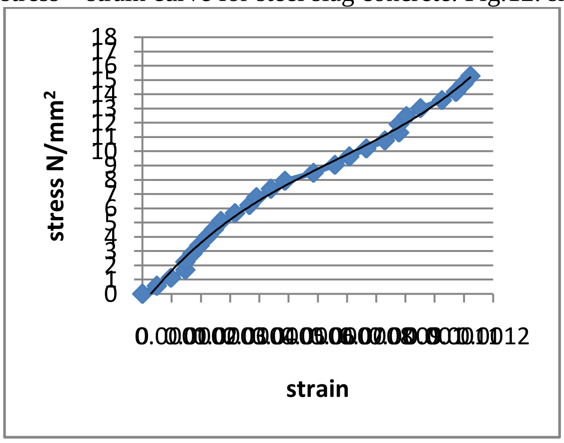

Fig. 11 Stress Strain Curve – Steel Slag Aggregate Concrete

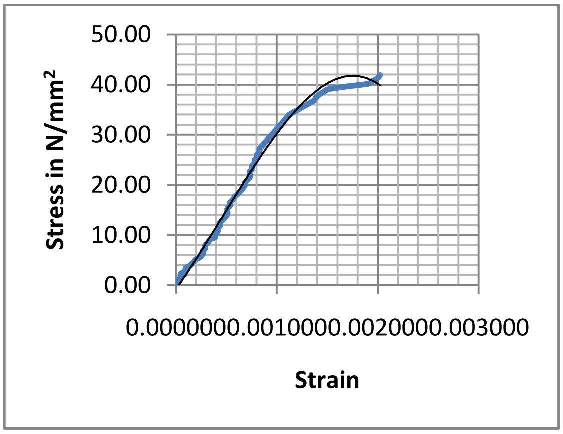

Fig. 12 Stress Strain Curve – Conventional Concrete

The initial tangent modulus for conventional aggregate concrete was 1.82×10^4 N/mm^2 and for steel slag aggregate concrete was 1.7×10^4 N/mm^2. The initial tangent modulus of steel slag aggregate concrete was found that the marginally lower than that of the conventional aggregate concrete.

V. CONCLUSION

- From this work it was found that 100% replacement of conventional aggregate with steel slag aggregate was not found to yield better strength, when conventional aggregate ratio was given. With modified aggregate sizes and ratio, based on aggregate packing analysis, better strength results was obtained both cases of conventional and steel slag aggregates.

- Modified Toufar particle packing model gave the highest strength with steel slag as coarse aggregate.
- Steel slag coarse aggregate gave up to,

  - Compressive strength of steel slag concrete increases in 6 % compared to the conventional coarse aggregate concrete.
  - Split tensile strength of steel slag concrete increases in 28 % compared to the conventional coarse aggregate concrete.
  - Flexural strength of steel slag concrete increases in 34 % compared to the conventional coarse aggregate concrete.
- The initial tangent modulus of Modified Toufar particle packing model for conventional coarse aggregate concrete was found that the marginally higher than of the steel slag coarse aggregate concrete.

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