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Study on the Fiber Reinforced Concrete using Steel slag as the Coarse Aggregate Replacement

Peram Dhanalakshmi
Department of Civil Engineering
Universal College of Engineering and Technology,
Andhra Pradesh 522005, India.

K.Srinivas
Department of Civil Engineering
Universal College of Engineering and Technology,
Andhra Pradesh 522005, India.

Introduction

Concrete is the most widely used man-made construction material all around the globe because of its superior specialty of being caste in any desirable shape. It is material synonymous with strength and longevity has emerged as the dominant construction material for the infrastructure needs of the present situation. Around five billion tons of concrete have been used around the world wide every year, in terms of cost it is equivalent to 25 to 30% of the nation budget. It is also inevitable material in human life due to its enormous usage in modern way of construction and now the per capita consumption is reached to more than 2 kg. India has taken a sound decision on developing the infrastructural development in 21st century such as express high ways, airports, ports, power projects and tourism projects. In every construction aspects it requires concrete, hence concrete plays a vital role in present scenario of construction industries. Everyone has chosen concrete in infrastructural development because of its characteristics like strength and durability. The continuous usage of natural resources and the consequent energy requirement for this processing has a serious economic impact. More over in the alluvial plain area, where there is no availability of virgin aggregates, such as debris and rubble particles may be recycled and make it into use for new structural applications with variable and effective economy [1-4].

Importance of Concrete

Concrete possess much importance because of its property of being moulded into any desired shape. It is strong, inexpensive, plentiful and easy to make. It possesses the property of versatility. Concrete is friendly to the environment. It is virtually all natural. It is recyclable.

Properties of Concrete

Concrete is an artificial conglomerate stone made essentially of Portland cement, water and aggregates. Concrete has relatively high compressive strength, but significantly lower tensile strength and are usually reinforced with the materials that are strong in tension. The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. It has a very low coefficient of thermal expansion and as it matures concrete shrinks. Concrete subjected to long-duration forces is prone to creep.

Steel Slag:

Steel slag is a by-product obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). The molten liquid is a complex solution of silicates and oxides that solidifies on cooling and forms steel slag. Steel slag is defined by the American Society for Testing and Materials as a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminium, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen and electric arc furnaces [5-7].

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Current Uses of Steel Slag:

- Some of the current uses of steel slag are as follows:
- Steel slag is used as an ideal aggregate in hot mix asphalt (HMA) surface mixture [6] application due to its high frictional resistance and skid resistance characteristics. The cubical nature of steel slag and its rough texture provides more resistance than round, smooth and elongated aggregates. It is used in base application, construction of unpaved parking lots, as a shoulder material. It is also used in agriculture because it has minerals like Iron, Manganese , Magnesium, Zinc and Molybdenum which are valuable plant nutrients.
- It is environment friendly. During the production of cement, the CO_2 emissions are reduced as slag has previously undergone the calcination process.
- Steel slag aggregates are used for soil stabilization or soil improvement material and for remediation of industrial waste water run-off.

Substitution with Steel Slag (iron slag) aggregate:

- The word "Iron slag" was in since 1918", who as NSA has promoted the use of Blast furnace and steel furnace slag. Blast furnace slag has been called "All-purpose Aggregates" as it can be used in all construction applications as either a normal weight or light weight (expanded or pelletized)aggregates depending on how it was formed and processed. Blast furnace slag is also quickly quenched by water or air to produce granulated Blast furnace slag.
- Physical properties‟ of slag can vary greatly depending on processing done once the slag is removed from the furnace. Air cooled BFS produces [8] a durable aggregate that performs well in unbound applications as well as in Portland cement and asphalt concretes. Cooling the slag with water produces a lightweight aggregate for use in masonry blocks and light weight concrete. Pelletized and granulated BFS are both water-cooled slag‟s that can be ground and used to make slag cement. Slag cement provides reduced heat of hydration and improved resistance to sulphate attack and alkali-silica reaction than regular Portland cement. Steel furnace slag typically forms very angular, durable aggregate that makes it ideal for use in the transportation industry. SFS has been used successfully in the friction course of hot mix asphalt pavements, can be used in super pave mix designs and has been used in stone matrix asphalt. In addition, the chemical composition of SFS slag makes it a cost effective and environmentally sound feed stock material for the production of Portland cement.

Environmental Benefits:

An independent nationally renowned chemical laboratory and risk assessment team has conducted a human and ecological risk assessment of both BFS and SFS. The risk assessment scientist‟s analyzed samples from a representative cross-section of the slag industry in accordance with the EPA‟s risk assessment guidelines. The results of this study reinforced that BFS and SFS conforms to the EPA‟s stringent requirements and does not pose a threat to human or plant life. As in most applications [10], when materials are used in environmentally sensitive areas they should be tested to assess environmental impact. It should be noted that BFS and SFS have a long history of environmentally safe application, and that the use of slag have very positive environmental benefits. The use of slag in cement manufacturing significantly decreases carbon dioxide emissions, and reduces the energy needed to calcine limestone. The use of slag as aggregate reduces the need for virgin materials and the energy use and emissions produced during the mining, processing and transportation of those materials.

Steel fibres:

Fibers are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce

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bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter–resistance in concrete. Generally fibers do not increase the flexural strength of concrete, and so cannot replace moment–resisting or structural steel reinforcement. Indeed, some fibers actually reduce the strength of concrete [12].

The amount of fibers added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibers), termed "volume fraction" (Vf). Vf typically ranges from 0.1 to 3%. The aspect ratio (l/d) is calculated by dividing fiber length (l) by its diameter (d). Fibers with a non-circular cross section use an equivalent diameter for the calculation of aspect ratio. If the fibre's modulus of elasticity is higher than the matrix (concrete or mortar binder), they help to carry the load by increasing the tensile strength of the material. Increasing the aspect ratio of the fibre usually segments the flexural strength and toughness of the matrix. However, fibers that are too long tend to "ball" in the mix and create workability problems. Some recent studies indicated that using fibers in concrete has limited effect on the impact resistance of the materials. This finding is very important, people think that ductility increases when concrete is reinforced with fibers. The results also indicated that the use of micro fibers offers better impact resistance to that of longer fibers.

Applications of Fibres

- The applications of steel fibre reinforced concrete (SFRC) depend on the ingenuity of the designer and builder in taking advantage of its much enhanced and superior static and dynamic tensile strength, ductility, energy-absorbing characteristics. Growing experience and confidence by engineers, designers and contractors has led to many new areas of use particularly in precast, cast in-situ, and shotcrete applications.
- Traditional application where SFRC [14] was initially used as pavements, has now gained wide acceptance in the construction of a number of airport runways, heavy-duty and container yard floors in several parts of the world due to savings in cost and superior performance during service.

Materials

Raw materials required for the concrete in the present work are

- Cement
- Fine aggregates
- Natural coarse aggregates
- Steel slag aggregates
- Steel fibre (SF)
- Water

Cement

Ordinary Portland cement 53 grade conforming to IS:12269 has been used in this experimental study.

Fine Aggregates:

The size of the fine aggregate is below 4.75mm. Fine aggregates can be natural or manufactured. The grade of the aggregates must be same throughout the work. The fine aggregate shall consist of natural sand or other inert materials with similar characteristics, or combinations having hard, strong, durable particles. The use of concrete is being constrained by urbanization, zoning regulations, increased cost and environmental concern.

Coarse aggregates

Natural coarse aggregates:

The material whose particles are of size are retained on IS sieve of size 4.75mm is termed as coarse aggregate and containing only so much finer material as is permitted for the various types described in IS: 383-1970 is considered as coarse aggregate. The properties of aggregate greatly affect the durability and structural performance of concrete. Aggregate was originally viewed as an inert material dispersed throughout the cement paste largely for economic reasons. It is possible, however, to take an opposite view and to look on aggregate as a building material connected in to a cohesive whole by means of the cement paste, in a manner similar to masonry construction. In fact, aggregate is not truly inert and its physical, thermal and sometimes also chemical properties influence the performance of concrete. Aggregate is cheaper than cement and it is, therefore, economical to put in to the mix as much of the former and as little of the later possible. But economy is not only the reason for using aggregate, it confers considerable technical advantages on concrete, which has a higher volume stability and better durability than hydrated cement paste alone. Aggregates should be of uniform quality with respect to shape and grading. The size of coarse aggregated depends upon the nature of the work [5].

Steel Slag aggregates:

Slag is a co-product of the iron and steel making process. Iron cannot be prepared in the blast furnace without the production of its co-product, blast furnace slag. Similarly, steel cannot be prepared in the basic oxygen furnace (BOF) or in an electric arc furnace (EAF) without making its co-product, steel slag. The use of steel slag aggregates in concrete by replacing natural aggregates is a most promising concept. Steel slag aggregates are already being used as aggregates in asphalt paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity.

Fig 3.4.2: Steel slag aggregates

Studies and tests are being conducted on ways to use this steel slag as an aggregate in concrete. Steel slag is currently used in bituminous asphalt paving, the manufacture of Portland cement, and in roadway construction as a base course, along with some agricultural applications. The only potential problem with steel slag aggregate is its expansive characteristics and undesirable reactions between slag and components of concrete. This might be a perception, but most of the information is anecdotal in nature rather than documented in published research studies [7].

Steel Fibres:

- The dimensions of the steel fibres are of length 30mm and diameter of 0.5mm with the L\d ratio of 60 and are of crimped type. The steel fibers are used at different volume fractions such as 0.5% , 1% and 1.5%.
- Steel fibres are added to the optimum replacement mix in the slag aggregate concrete to determine the strength properties of the slag aggregate concrete.
- The steel fibres that are utilized in this study are obtained from Jeetmul Jaichandlal pvt.ltd. in Chennai, Tamil Nadu.

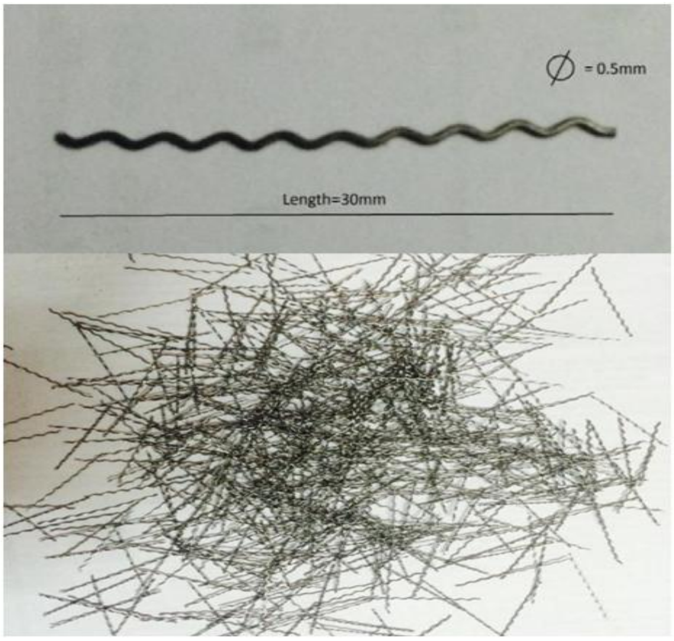

Fig: 3.5 Steel fibres

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Water:

Water is required for the purpose of hydration of cement and to give workability during mixing and furthermore setting of concrete. For this study convenient water with pH7 and adjusting to the determinations of IS456-2000 is utilized for cementing and additionally curing of the specimens. Portable water available in laboratory is used in this study.

Concrete mix design:

The mixture proportioning was done according the Indian Standard Recommended Method IS 10262- 2009 and with reference to IS 456-2000. The target mean strength was 31 Mpa for the OPC control mixture [9], the total binder content was 380 Kg/m3, fine aggregate was taken 691 Kg/ m3 and coarse aggregate was taken 1170 Kg/m3. The water to binder ratio was kept constant as 0.5. The total mixing time was 5 minutes, the samples were then casted and left for 24 hrs before de-moulding. They were then placed in the curing tank until the day of testing cement, sand and coarse aggregate were properly mixed together in the ratio 1:1.82:3.1 by weight before water was added and properly mixed together to achieve homogenous material. Water absorption capacity and moisture content were taken into consideration. Cube and cylindrical and prism moulds were used for casting. The concrete was left in the mould and allowed to set for 24 hours before the specimens were demoulded and placed in curing tank [11]. The specimens with and without fiber were cured in the tank for 7 and 28days. The details of the quantity of the constituent materials were given in the below table 4.2

Table 4.2: Details of the quantity of the constituent materials

Material	Quantity (Kg/m^3)	Proportions
Cement	380	1
Sand	691	1.82
Coarse aggregates(20mm)	1170	3.1
Water	190	0.5

Fig 4.4: Mixing of concrete ingredients

Curing of concrete specimens:

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. Since the hydration of cement does take time days and even weeks rather than hours-curing must be undertaken for a reasonable period of time if the concrete is to achieve its potential strength and durability. Curing may also encompasses the control of temperature since this effects the rate at which cement hydrates.

The curing period may depend on the properties required of the concrete, the purpose for which it is to be used and the ambient conditions, i.e., the temperature and relative humidity of the surrounding atmosphere. Curing is designed properly to keep the concrete moist, by preventing the loss of moisture from the concrete during the period in which it is gaining strength. Curing may be applied in a number of ways and the most appropriate means of curing may be dictated by the site or the construction method [13].

Fig 4.5: Curing of concrete specimens

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Slump cone test:

Workability of fresh concrete shall be carried out by performance of slump test. Slump value can be carried out according to the IS: 1199-1959. To determine the consistency or workability of steel slag, slump cone test has been performed in the laboratory. Before conducting the experiment, apply de-mould agent i.e., oil/grease inside the cone for avoidance of further sticking of the fresh concrete. Unsupported fresh concrete flows to the sides and a sinking in height takes place. This vertical settlement is known as slump. In this test fresh concrete is filled into a mould of specified shape and dimensions, and the settlement or slump is measured when supporting mould is removed. Slump increases as water-content is increased. For different works different slump values have been recommended. The slump is a measure indicating the workability of cement concrete. It gives an idea of water content needed for concrete to be used for different works. A concrete is said to be workable if it can be easily mixed, placed, compacted and finished. A workable concrete should not shown any segregation or bleeding. By this test we can determine the water content to give specified slump value. In this test water content is varied and in each case slump value is measured till we arrive at water content giving the required slump value. This test is not a true guide to workability.

Fig: 4.6.1 Conducting Slump cone test

Compressive Strength of Concrete

The concrete specimens were tested for compressive strength at 7 and 28 days. Specimens were casted in cubical moulds of dimensions 100mm×100mm×100mm and stored in the water curing tank. Three specimens were tested at each age, on a Compressive testing machine of capacity 2000KN in Concrete lab in VIT university. The type of fracture of the specimen and the compressive strength were recorded.

Calculations:

$$f_c = P_{max}/A$$

Where

f_c = compressive strength.

P_{max} = the maximum load that the cube sustained. A = the cross sectional area of the cube.

Figure 4.6.2(A): Compressive strength testing machine

Splitting Tensile Strength of Concrete:

The splitting tensile strength of the concrete specimens was tested at 7 and 28 days. The dimensions of the cylindrical specimens are of diameter 100mm and the height of the cylindrical specimen is 200mm were moulded at the same time as the compressive strength specimens and the specimens were cured in curing tank. Three specimens were tested at eachage, on a Compressive testing machine of capacity 2000KN . The splitting tensile strength can be obtained from the following equation

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$f_t = 2P/$

Where

f_t = splitting tensile strength (MPa)

P = maximum applied load (N)

l = length (mm)

d = diameter (mm)

For this research the length (l) was equal 200mm and the diameter (d) of was taken as 100mm.Three specimens were tested at 7 and 28 days for each experimental mixture.

Figure 4.6.2(B): Split tensile strength testing machine

EXPERIMENTAL RESULTS

Compressive strength test for the Optimisation of Steel slag aggregate:

To determine the optimum replacement level of the steel slag aggregate as the coarse aggregate, Compressive strength test is conducted to the cubical specimens of age 7days and 28 days after curing in curing tank.

Mix ID	% Replacement of steel slag	Compressive strength (Mpa)
CC	0	27.9
SLA10%	10	31.4
SLA20%	20	33.8
SLA30%	30	32.1
SLA40%	40	33.8
SLA50%	50	38.5
SLA60%	60	26.9
SLA70%	70	24.2
SLA80%	80	21.8
SLA90%	90	19.9
SLA100%	100	19.2

Table 5.3.1 : Compressive strength at 7 days

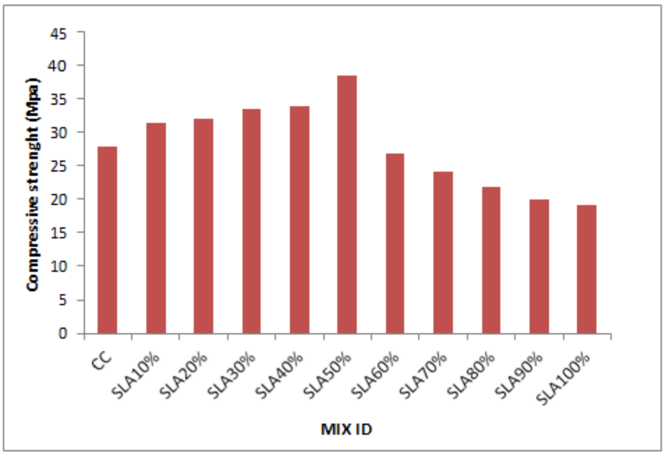

Figure 5.3.1: Compressive strength of SSAC at 7 days

Table 5.3.2: Compressive strength at 28 days

Mix ID	% Replacement of steel slag	compressive strength (Mpa)
CC	0	38.1
SLA10%	10	33.6
SLA20%	20	34.1
SLA30%	30	34.3
SLA40%	40	36.4
SLA50%	50	40.3
SLA60%	60	33.1
SLA70%	70	31.6
SLA80%	80	26.9
SLA90%	90	23.7
SLA100%	100	21.6

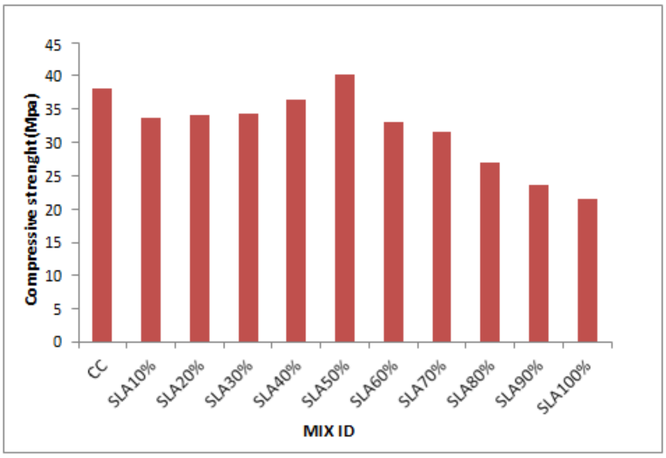

Figure 5.3.2: Compressive strength of SSAC at 28 days

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From the above table 5.3.2 and figure 5.3.2 it was found that the optimum level for the replacement of the steel slag was 50% and the compressive strength of the steel slag aggregate concrete decreased gradually when the replacement level was above 50%.The maximum compressive strength for the SSAC was 40.3 MPa for the SLA50% mix at 28 days. To the Optimum replacement level of the steel slag as the replacement of the coarse aggregate, the steel fibres are added at different volume fractions such as 0.50%, 1.00% and 1.50% to gain the strength properties of concrete.
The compressive strength test, Split tensile strength test, Young‟s modulus test, Flexural strength test and the deflection variation for RCC beams is carried out on the different shapes and sizes of specimens.

Compressive strength of SSAC with steel fibres at 7 & 28 days:

The compressive test is carried out on the cube shaped specimens of the steel slag aggregate concrete with steel fibres at different volume fractions.

Table 5.3.3: Compressive strength of steel slag aggregate concrete at 7 & 28 days

S. No	Mix ID	7 days	28 days
1	SLA50%SF0.5%	42.4	47.3
2	SLA50%SF1.0%	43.6	50.1
3	SLA50%SF1.5%	49.7	53.6

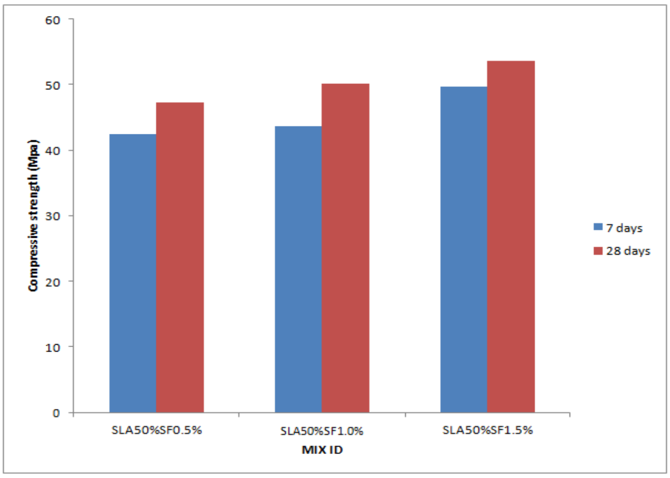

Figure 5.3.3: Compressive strength of SSAC at 7 and 28 days

The above table 5.3.3 and figure 5.3.3 shows that the compressive strength of the steel slag aggregate concrete increases with the increase in the volume fraction % of the steel fibres. It is found that the ideal Compressive strength of the slag aggregate concrete was 53.6Mpa for SLA50%SF1.5% concrete mix.

Splitting Tensile Strength

The splitting tensile strength of the concrete specimens was determined at 28 days. As previously mentioned the specimens were moulded at the same time as the compressive strength specimens. Cylinders were moulded with a diameter of 100 mm and a length of 200 mm. Table 5.5 displays the average splitting tensile strength of the samples at 28 days. The ideal splitting tensile strength of concrete specimens at the end of 28 days was approximately about 6Mpa attained for 1.5 Vf.
Table 5.4: Split tensile strength of slag aggregate concrete at different volume fractions of steel fibres at 28days:

S. No	Mix ID	Split tensile strength (Mpa)
1	SLA50%SF0.5%	4.15
2	SLA50%SF1.0%	5.22
3	SLA50%SF1.5%	5.98

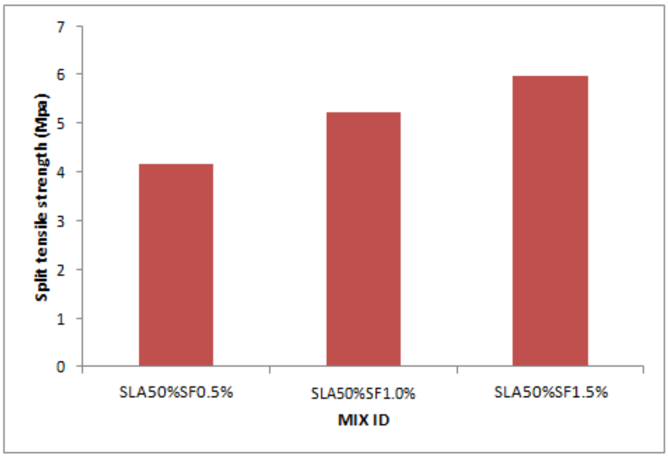

Figure 5.4: Split tensile strength of SSAC at 28 days

From the table 5.4 and the figure 5.4 it was observed that the split tensile strength of the steel slag aggregate concrete increases with the increase in the volume

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fraction of the steel fibres. It is found that the maximum split tensile strength of the steel slag aggregate concrete was 5.98 Mpa for SLA50%SF1.5% concrete mix.

Flexural strength:

Beam specimens were prepared having dimensions of 500mmX100mmX100mm to determine the flexural strength of slag aggregate concrete. The flexural strength was found at the end of 28 days on a hydraulic testing machine

Table 5.5: Flexural strength of slag aggregate concrete at different volume fractions of steel fibres at 28days:

S. No	Mix ID	Flexural strength(Mpa)
1	SLA50%SF0.5%	6.29
2	SLA50%SF1.0%	7.41
3	SLA50%SF1.5%	7.62

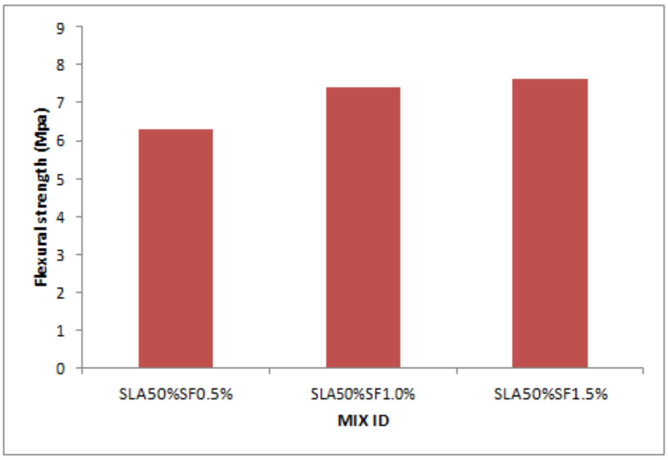

Figure 5.5: Flexural strength of the SSAC at 28 days

From the table 5.5 and graph 5.5 it was observed that the flexural strength of the steel slag aggregate concrete increases with the increase in the volume fraction % of the steel fibres. It is found that the maximum flexural strength of the steel slag aggregate concrete was 7.62 Mpa for SLA50%SF1.5% concrete mix.

CONCLUSIONS

The main objective of this study was to study the behaviour of concrete and changes in the properties of concrete with steel slag aggregates by replacing the use of natural aggregates. Steel slag is a by-product and using it as aggregates in concrete will might prove an economical and environmentally friendly solution. The demand for aggregates is increasing rapidly and so as the demand of concrete. Thus, it is becoming more important to find suitable alternatives for aggregates in the future. A through literature review was conducted to study and investigate the properties of steel slag aggregates. The results showed that it has properties similar to natural aggregates and it would not cause any harm if incorporated into concrete. A comparison was made between concrete having natural coarse aggregates and concrete with various percentages of steel slag aggregates replaced by volume. The results of this research were encouraging, since they show that using steel slag as coarse aggregates in concrete has no negative effects on the short term properties of hardened concrete.

The results of the research program can be summarized as follows:

1.From the compressive strength findings optimum replacement level of the steel slag aggregate was found to be 50%.

2.Steel slag aggregate concrete attains the maximum compressive strength of 40.3 MPa which was slightly higher than the control concrete.

3.When steel slag was used as coarse aggregate replacement the compressive strength of the steel slag aggregate concrete was increased by 6% when compared to control concrete.

4.The slight improvement in strength may be due to shape, size and surface texture of steel slag aggregates, which provide better adhesion between the particles and cement matrix.

5.When the steel fibres were added to the optimum replacement level of steel slag to produce steel slag aggregate concrete, it was observed that the compressive strength reached 52.1MPa for SLA50%1.5%.

6.Maximum flexural strength of the steel slag aggregate concrete was 7.62 MPa for the SLA50%SF1.5% mix.

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7.Young‟s modulus value for the steel slag aggregate concrete was found to be 26.27GPa for SLA50%SF1.5% mix.
8.Split tensile strength of the steel slag aggregate concrete was found to be 5.98 MPa for the SLA50%sSF1.5% mix.
9.It was observed that the increase in the volume fraction of steel fibres increases the compressive strength, split tensile, Young‟s modulus and flexural strength of the steel slag aggregate concrete.
10.The initial cracking load of the RC beams of slag aggregate concrete delayed with the increase in the volume fraction of steel fibres when compared to the control concrete beam.
11.The ultimate load bearing capacity of the RC beams increased at the percent fo34% with the increase in the volume fraction of the steel fibres when compared with the control concrete beam.

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