

## International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 5, May 2017

# Study on Strength Properties of High Strength Concrete by Using Electric Arc Furnace Slag as Aggregate and Partially Replacing Cement With Nano Silica

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**ABSTRACT:** During the past few years, there is an increased interest in researchers to develop higher grades of concrete using industrial waste as a replacement for aggregate. Many factors like diminishing natural aggregate, increased industrial waste, economy have lead a path to find a better replacement material for natural aggregate. In the present study Electric Arc Furnace (EAF) slag, a steel industry waste is chosen and replaced for natural aggregate. High Strength Grade of Concrete M60 designed as per ACI 211.4R-08. The current work is conceded in three stages, In the first stage Coarse aggregate is substituted with EAF slag for the percentages of 20,40,60,80 and optimum strength properties were found. In the second stage, fine aggregate is substituted with EAF slag for the percentages of 20,40,60,80 and optimum strength properties were found. In the third stage, both coarse and fine aggregate are substituted for the proportion of optimum strength properties obtained in phase one and two, along with coarse and fine aggregate, cement is also replaced partially with nano silica for the percentages of 1,2,3 and optimum strength properties were found. Results specify that 40% replacement of coarse and 40% replacement of fine aggregate with EAF slag and cement with 2% nano silica gives extreme strength properties compared to reference concrete mix. Strength criteria alone do not satisfy the present requirement; durability criteria should also be satisfied, so as to meet the standards. In the present work chloride and sulphate content in the concrete were quantified as per the codes. From the experimental results it is concluded that chloride content is the primitive factor which is exceeding the limiting value, and should be taken care of, while sulphate contents in the concrete are within the permissible limits

**KEYWORDS:** Electric Arc Furnace Slag, Mechanical Properties, By-product.

### I.INTRODUCTION

The word concrete is originated from the Latin word "concretus".The most popular artificial material on Earth isn't steel, plastic, or aluminum — it's concrete. The word 'concrete' doesn't refer to a single material. It can be any number of substances that combine rocks or gravel with some kind of adhesive material. Concrete is a \$100 billion dollar industry. In fact, it's the most widely-used material on our planet after water. Ton for ton, humans use more concrete today than steel, wood, plastics, and aluminum combined.

The consumption of all type of aggregates has been increasing in recent years in most countries at a rate far exceeding that suggested by the growth rate of their economy or of their construction industries. Artificially manufactured aggregates are more expensive to produce, and the available source of natural aggregates may be at a considerable distance from the point of use, in which case, the cost of transporting is a disadvantage. The other factors to be considered are the continued and expanding extraction of natural aggregates accompanied by serious environmental

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Vol. 6, Issue 5, May 2017

problems. Often it leads to irremediable deterioration of the environment.

Concrete is a mixture of both coarse aggregate and fine aggregate are bonded with water. It exhibits great versatility and relative economy in filling wide range of needs which by other means has been made itself as competitive building material. With the advancement of technology and increased field of applications of concrete and mortars, the strength, workability, durability and other characteristics of the ordinary concrete need modifications to make it suitable for challenging needs for construction environment (Added to this is the necessity to combat the increasing cost and scarcity of natural aggregates). So there should be better alternate for natural aggregate to meet the challenges.

It is a widely used construction material for various types of structures due to its structural stability and strength. Increasing the construction challenges in combinations with the new innovations in materials and production techniques have provide new basis for producing standard concrete constructions.

There is rapid growth in the construction industry, at the same time economy and space is the constraint to make the structure efficient. Standard concrete is the better substitute to meet all the challenges, moreover Concrete is said to be of high strength if it is above 50 Mpa.

## Significance and Objectives

The objectives of the present experimental work is to find the better replacement for both coarse aggregate and fine aggregate. Based on the available literature review, Electric Arc Furnace Slag is chosen as a replacement material for natural aggregate. In the current work, coarse aggregate is substituted with EAF slag for the percentages of 20,40,60,80 and optimum mechanical properties were originated, then fine aggregate is substituted with EAF slag for the similar percentages of 20,40,60,80 and optimum mechanical properties were originated. Keeping those optimum percentage replacements constant, cement is replaced with Nano Silica there after mechanical properties were found.

Electric arc furnace slag is produced during the manufacture of crude steel by the electric arc furnace (EAF) process. In EAF Manufacturing Process, steel scrap is heated to a liquid state by means of electric current. During the melting process the fluxes combine with non-metallic scrap components and steel incompatible elements to form the liquid slag. As the slag has a lower density than steel, it floats on top of the molten bath of steel. The liquid slag is pass over at temperatures about 1600 °C and permitted to gradually air-cool creating crystalline slag. Electric arc furnace (EAF) slag is a strong, dense, none porous aggregate that is cubical in shape, has specific gravity above 2.92 which makes the concrete stronger and denser.

## II. LITERATURE REVIEW

Several authors have reported the use of Electric Arc Furnace Slag in various civil engineering applications.

**Idoia Arribas**<sup>[1]</sup> Analyzed the oxidizing electric arc furnace slag got after the production of carbon steel, afterward appropriate treatment, can and should be considered as an satisfactory fine and coarse aggregate for the preparation of good quality concrete. **Juan M. Manso**<sup>[2]</sup> describes the effort conceded out in laboratory to create concrete with good properties using oxidizing electric arc furnace (EAF) slag as fine and coarse aggregate. Studies and tests were accomplished on the durability of these concretes presenting an adequate behavior against aggressive environments. Finally, some leaching tests were conceded out in order to prove their environmental compatibility. **Satish Vitta**<sup>[3]</sup> had investigated the cementitious and pozzolanic behavior of electric arc furnace steel slag, both as received and treated has been studied in detail. The expected slag was totally crystalline and multiphase with Fine-substituted monticellite as the major phase. **Ye Qing**<sup>[4]</sup> have studied the influence of silica fume and nano silica individually on fresh concrete and hardened concrete and found that consistency and setting times were different for Nano Silica and Silica Fume. Nano Silica increases the bond strength and compressive strength. **Morteza Bastami**<sup>[5]</sup> studied the addition of Nano Silica was more effective than Silica Fume for increasing residual strengths. The addition of Nano Silica was more effective than SF for increasing residual compressive strength of heated specimens. The occurrence of Nano Silica enhanced the tensile strength of the concrete to avoid crack delay and strength decrease. **Ji**<sup>[9]</sup> Studied the water permeability resistant behaviour and micro structure of concrete with NS and observed that NS concrete has better water resistant permeability than ordinary concrete.

# International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 5, May 2017

## MATERIALS:

Dissimilar kinds of materials used in this work are cement, fly ash, EAF slag, Nano silica, super plasticizer, water. Physical and chemical properties of materials used in this investigation are mentioned below.

In this work ULTRATECH cement of Ordinary Portland Cement (OPC) 53 grade was used for all concrete mixes. The different tests are conducted on cement, they are

**Table -01 :Physical Properties of Cement**

Properties	Values obtained	Code used	Standard values
Initial setting time	48 min	IS 4031- 1988 part 5	Not be less than 30 min
Final setting time	300 min	IS 4031 -1988 part 5	Not be greater than 600 min
Fineness (%)	4.0	IS 4031 - 1996 part 1	Not be greater than 10 %
Compressive strength	56 N/mm <sup>2</sup>	IS 12269 -1987	Not be less than 53 N/mm <sup>2</sup>
Soundness	1mm	IS 4031 - 1988 part 3	Not be greater than 10 mm
Specific gravity	3.12	IS 2720 part 3	
Consistency	32%	IS 4031 - 1988 part 4	

## FINE AGGREGATE:

Fine Aggregate for the Investigational Program had been nearby found and followed to grading Zone II as per IS:383-1970<sup>[10]</sup>. Fine Aggregate sieved with 4.75 mm after which it was washed to remove dust.

## COARSE AGGREGATE:

Course aggregate was primarily sieved over 20 mm passing sieve to eliminate any particles greater and were tested as per Indian Standard Specifications IS: 383–1970.

**Table -02 :Physical Properties of Aggregate**

Characteristics	Specific Gravity	Fineness Modulus	Bulk Density ( Kg/m <sup>3</sup> )
Fine aggregate	2.66	3.10	1618
Coarse aggregate	2.85	6.29	1523

## SUPER PLASTICIZER:

Super plasticizer, **fosrostructuro - 202** based on poly carboxylic ether, complies with IS 9103-999 and ASTM C-494 was used

**Table - 03: Physical Properties of structuro - 202**

Specific gravity	1.065 g/cc
Appearance	Light yellow coloured liquid
pH	6.5
Chloride content	Nil to IS:456

## WATER:

In this project, casting and curing of specimens were done using potable water which shall be free from deleterious materials. Water plays an important role in concrete production (mix) in that it starts the reaction between the cement and the water. It helps in the hydration of the mix.

## International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 5, May 2017

### ELECTRIC ARC FURNACE SLAG & NANO SILICA:

**Table 04 : Physical Properties**

Characteristics	EAF SLAG	Nano Silica
Colour	Dark gray	Silver White
Specific Gravity	2.97	2.2
Size ( $\mu\text{m}$ )	<1 to 20	<1
Bulk Density ( $\text{Kg/m}^3$ )	3010	100-110
Surface Area ( $\text{m}^2/\text{gm}$ )	-	202
Chemical Composition	EAF SLAG %	Nano Silica %
CaO	26	-
SiO <sub>2</sub>	14	99.8
Al <sub>2</sub> O <sub>3</sub>	12	0.005
Fe <sub>2</sub> O <sub>3</sub>	35	0.001
MgO	5	-
Carbon content	2	0.06
Mno	6	-

### EXPERIMENTAL PROGRAM

In these investigations concrete mix design (M60) was designed based on ACI 211. 4R-2008<sup>[11]</sup>. this code presents a generally applicable method for selecting mixture proportion for high strength concrete and optimizing this mixture proportion on basis of trial batches. The method is limited to high strength concrete production using conventional materials and production techniques. Mix proportioning details are given below in

**Table- 05: Mix proportioning details**

	Cement (Kg/m <sup>3</sup> )	Silica Fume (Kg/m <sup>3</sup> )	Fine Aggregate (Kg/m <sup>3</sup> )	Coarse Aggregate (Kg/m <sup>3</sup> )	Water (lit/m <sup>3</sup> )	SP (lit/m <sup>3</sup> )	EAF SLAG as CA%	EAF SLAG as FA%	EAF SLAG as CA (Kg/m <sup>3</sup> )	EAF SLAG as FA (Kg/m <sup>3</sup> )
M0	542	54.2	711	1038	146.25	4.336	-	-	-	
M1	542	54.2	711	830.4	146.25	4.336	20		207.6	
M2	542	54.2	711	622.8	146.25	4.336	40		415.2	
M3	542	54.2	711	415.2	146.25	4.336	60		622.8	
M4	542	54.2	711	207.6	146.25	4.336	80		830.4	
M5	542	54.2	568.8	1038	146.25	4.336	-	20	-	142.2
M6	542	54.2	426.6	1038	146.25	4.336	-	40	-	284.4
M7	542	54.2	284.4	1038	146.25	4.336	-	60	-	426.6
M8	542	54.2	142.2	1038	146.25	4.336	-	80	-	568.8

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017

**Table 06: Mix proportion of standard concrete (M60) with 40% EAF SLAG, and for different % replacement of cement by NanoSiO<sub>2</sub>**

	Cement (Kg/m <sup>3</sup> )	Silica Fume (Kg/m <sup>3</sup> )	Fine Aggregate (Kg/m <sup>3</sup> )	Coarse Aggregate (Kg/m <sup>3</sup> )	Water (lit/m <sup>3</sup> )	SP (lit/m <sup>3</sup> )	EAF SLAG as Aggregate %	EAF SLAG as CA (Kg/m <sup>3</sup> )	EAF SLAG as FA (Kg/m <sup>3</sup> )	Nano SiO <sub>2</sub> %	Nano SiO <sub>2</sub> (Kg/m <sup>3</sup> )
M9	542	54.2	426.6	622.8	146.25	4.336	40	415.2	284.4	0	-
M10	536.58	54.2	426.6	622.8	146.25	4.336	40	415.2	284.4	1	5.42
M11	531.16	54.2	426.6	622.8	146.25	4.336	40	415.2	284.4	2	10.84
M12	525.74	54.2	426.6	622.8	146.25	4.336	40	415.2	284.4	3	16.26

### Preparation and Casting of Specimens

The different concrete specimens such as cubes (100mmX100mmX100mm) to evaluate the compressive strength of concrete, cylinders (100mm diameter and 200mm length) to determine split tensile strength and beams (100mmX100mmX500mm) to determine flexural strength were cast. All the specimens were arranged in accordance with IS: 516-1959<sup>[12]</sup>. All the moulds were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. A careful procedure was adopted in the batching, mixing and casting operations. Vibrations were stopped as soon as the cement slurry appeared on the top surface of the mould. The specimens were removed from moulds after 24 hours and cured in water till testing or as per requirement of the test.

### Testing

Cubes, cylinders and beams are tested for compressive strength and split tensile strength and flexural strength at 28 days. The cubes are tested underneath Compression Testing Machine (CTM) for compressive strength and split tensile strength and Universal Testing Machine (UTM) for Flexural strength

## III.RESULTS AND DISCUSSIONS

### COMPRESSIVE STRENGTH:

#### Compressive strength of STANDARD CONCRETE (M60) with partial replacement of coarse aggregate with EAF SLAG:

Compressive strength of M60 concrete with partial replacement of coarse aggregate by EAF SLAG is increased up to 40% replacement and with further increase in EAF SLAG the compressive strength decreases.

The maximum compressive strength of 77N/mm<sup>2</sup> is achieved for the concrete mix with 40% replacement of CA by EAF SLAG which is 10.8% more than that of reference mix for 28 days curing.

**Table 7: Compressive strength of M60 concrete for different % of EAF SLAG as Coarse Aggregate.**

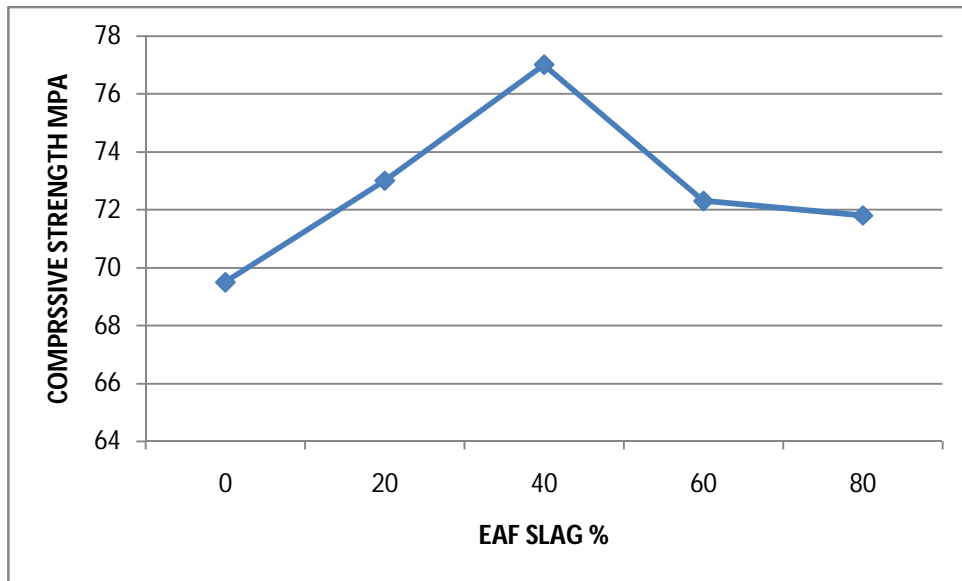
Concrete mixes	% replacement coarse aggregate with EAF SLAG	Compressive strength in N/mm <sup>2</sup> at 28 days
M0	0%	69.5
M1	20%	73
M2	40%	77
M3	60%	72.3
M4	80%	71.8

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017



**Fig 01:-** Variation of compressive strength of M60 concrete for different % of EAF SLAG as coarse aggregate.

**Compressive strength CONCRETE (M60) with partial replacement of fine aggregate with EAF SLAG:**

The maximum compressive strength of 78N/mm<sup>2</sup> is achieved for the concrete mix with 40% replacement of fine aggregate by EAF SLAG which is 12.2% more than that of reference mix for 28 days curing.

**Table 08: Compressive strength of M60 concrete for different % of EAF SLAG as CA**

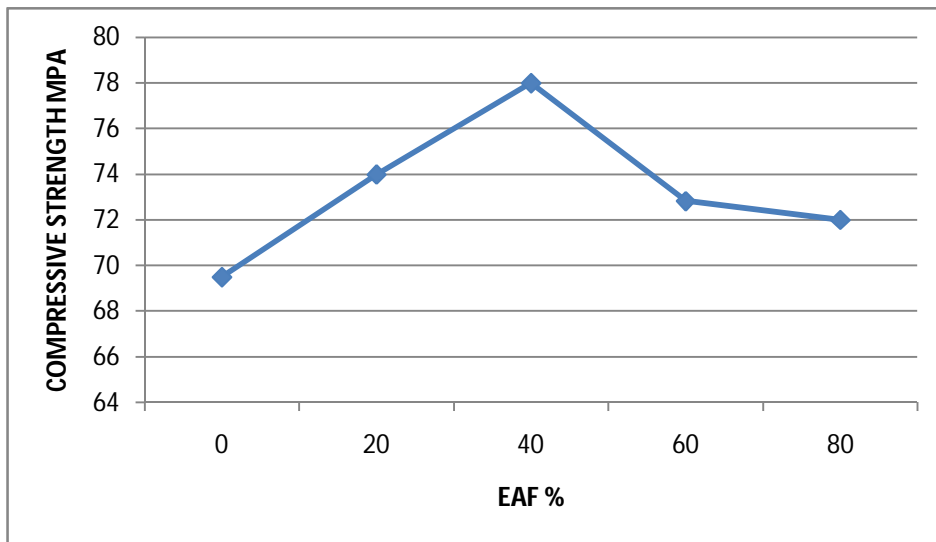
Concrete mixes	% replacement fine aggregate with EAF SLAG	Compressive strength in N/mm <sup>2</sup> at 28 days
M0	0%	69.5
M5	20%	74
M6	40%	78
M7	60%	72.83
M8	80%	72

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017



**Fig 02:-** Variation of compressive strength of M60 concrete for different % of EAF SLAG as fine aggregate.

### Compressive strength of CONCRETE(M60) with 40% EAF SLAG and partial replacement of cement with Nano SiO<sub>2</sub>:

The compressive strength of standard concrete (M60) with 40% EAF SLAG as both fine and coarse aggregate, and partial replacement cement with Nano SiO<sub>2</sub> is increased up to 2% replacement cement with Nano SiO<sub>2</sub> and further increase the Nano SiO<sub>2</sub> compressive strength decreases.

Maximum compressive strength is 81.8N/mm<sup>2</sup> is obtained for concrete mix with 2% replacement of cement by Nano SiO<sub>2</sub> which is 4.28% more than that of concrete mix without Nano SiO<sub>2</sub> for 28 days curing.

**Table 09: Compressive strength of CONCRETE(M60) with 40% EAF SLAG for different % of Nano SiO<sub>2</sub>.**

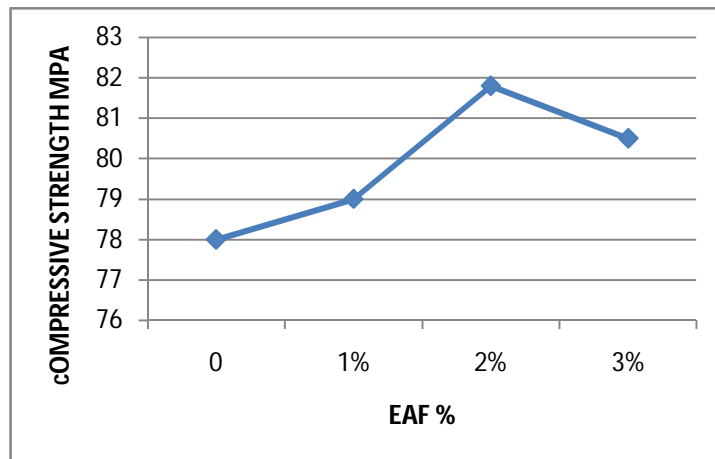
Concrete mixes	% replacement fine aggregate with EAF SLAG	Nano silica %	Compressive strength in N/mm <sup>2</sup> at 28 days
M9	40%	0	78
M10	40%	1%	79
M11	40%	2%	81.8
M12	40%	3%	80.5

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017



**Fig:03: Variations of compressive strength of STANDARD CONCRETE (M60) with 40% EAF SLAG for different % of Nano SiO<sub>2</sub>.**

### SPLIT TENSILE STRENGTH:

#### Split tensile strength of STANDARD CONCRETE (M60) with partial replacement of CA by EAF SLAG:

Split tensile strength of STANDARD CONCRETE (M60) with partial replacement of Sand by EAF SLAG is increases up to 40% replacement of CA and with further increase in EAF SLAG the split tensile strength decreases.

The maximum split tensile strength of 4.615 N/mm<sup>2</sup> is achieved for the concrete mix 40% replacement of sand by EAF SLAG which is 20.8 % more than that of reference mix for 28 days curing.

**Table 10: Split Tensile strength of M60 concrete for different % of EAF SLAG.**

Concrete mixes	% replacement coarse aggregate with EAF SLAG	Split Tensile strength in N/mm <sup>2</sup> at 28 days
M0	0%	3.50
M1	20%	4.660
M2	40%	4.77
M3	60%	4.03
M4	80%	3.860

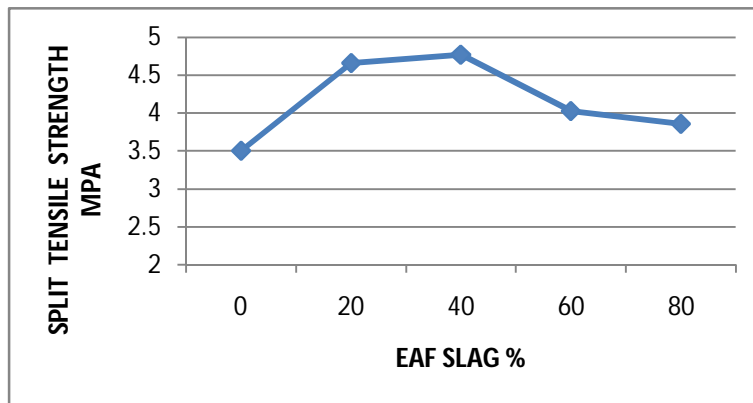


## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017



**Fig: 04 : Variations of split tensile strength of STANDARD CONCRETE (M60) with 40% EAF SLAG.**

**Split tensile strength of CONCRETE (M60) with partial replacement of fine aggregate by EAF SLAG:**

Split tensile strength of STANDARD CONCRETE (M60) with partial replacement of Sand by EAF SLAG is increases up to 40% replacement of FA and with further increase in EAF SLAG the split tensile strength decreases. The maximum split tensile strength of 4.774N/mm<sup>2</sup> is achieved for the concrete mix 40% replacement of sand by EAF SLAG which is 36.2 % more than that of reference mix for 28 days curing.

**Table 11: Split Tensile strength of M60 concrete for different % of EAF SLAG.**

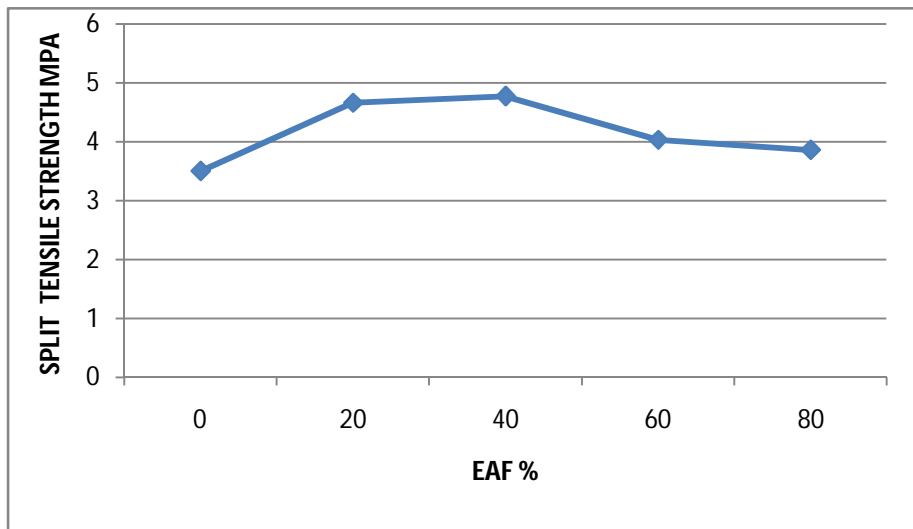
Concrete mixes	% replacement fine aggregate with EAF SLAG	Split tensile strength in N/mm <sup>2</sup> at 28 days
M0	0%	3.50
M5	20%	4.66
M6	40%	4.774
M7	60%	4.032
M8	80%	3.860

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017



**Fig 05:-**Variations of split tensile strength of STANDARD CONCRETE (M60) for different % of EAF SLAG as fine aggregate.

**Split tensile strength of CONCRETE (M60) with 40% EAF SLAG for different % of Nano Silica:**

The split tensile strength of standard concrete (M60) with 40% EAF SLAG and partial replacement cement by Nano SiO<sub>2</sub> is increases up to 2% replacement cement and further increase the split tensile strength decreases. Maximum split tensile strength 4.93 N/mm<sup>2</sup>.

**Table 12: Split Tensile strength of (M60) concrete with 40% EAF SLAG for different % of Nano SiO<sub>2</sub>.**

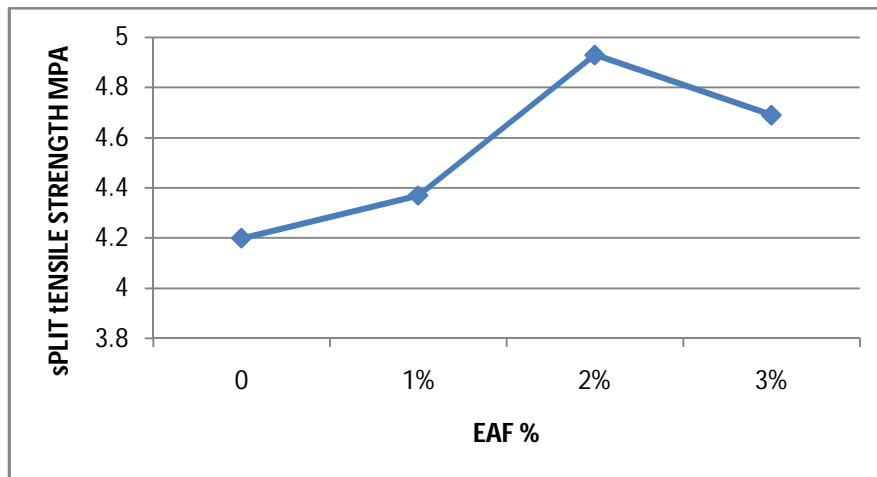
Concrete mixes	% replacement aggregate with EAF SLAG	Nano silica %	Split Tensile strength in N/mm <sup>2</sup> at 28 days
M9	40%	0	4.2
M10	40%	1%	4.37
M11	40%	2%	4.93
M12	40%	3%	4.69

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017



**Fig 06 :-Variations of split tensile strength for (M60) concrete with 40% EAF SLAG for different % of Nano SiO<sub>2</sub>.**

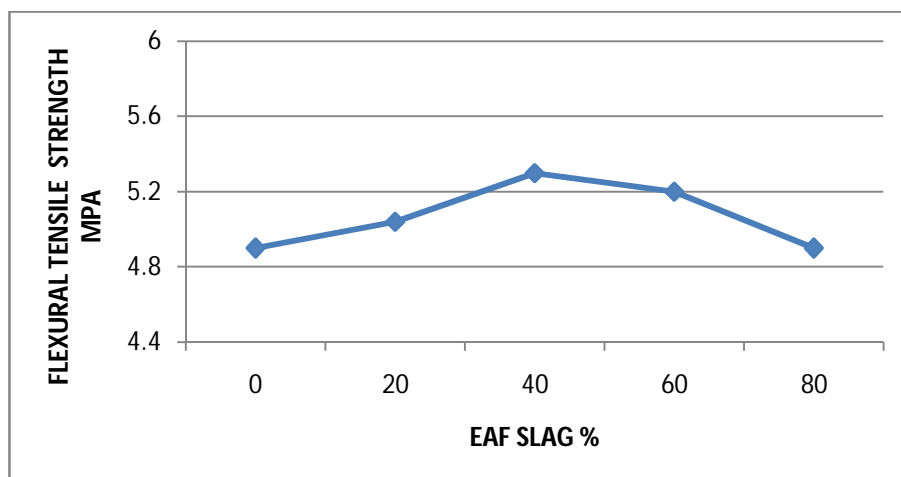
### FLEXURAL TENSILE STRENGTH:

#### Flexural tensile strength of STANDARD CONCRETE (M60) with partial replacement of CA by EAF SLAG:

Modulus of rupture strength of M60 concrete with partial replacement of CA by EAF SLAG is increases up to 40% replacement of CA and with further increase EAF SLAG the Flexural tensile strength decreases.

**Table 13: Flexural Tensile strength of M60 concrete for different % of EAF SLAG.**

Concrete mixes	%replacement of CA with EAF SLAG	Flexural tensile strength in N/mm <sup>2</sup> at 28 days
M0	0%	4.9
M1	20%	5.04
M2	40%	5.3
M3	60%	5.2
M4	80%	4.9



**Fig 07 :-Variations of flexural tensile strength for (M60) concrete with 40% EAF SLAG as Coarse Aggregate.**

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

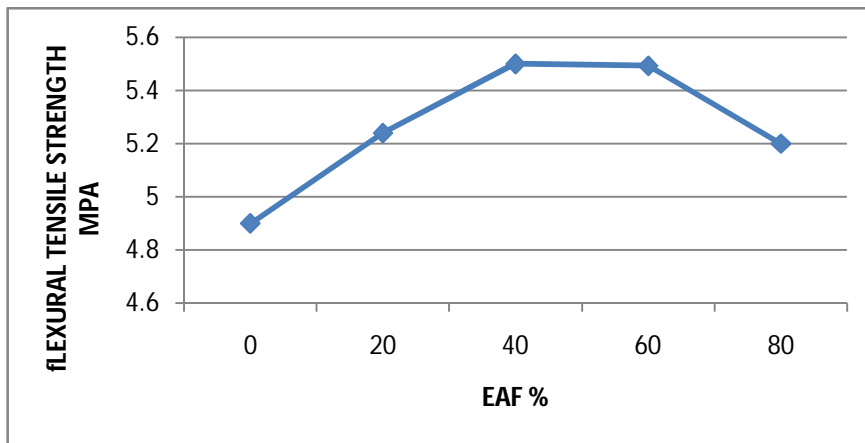
Vol. 6, Issue 5, May 2017

### Flexural tensile strength of CONCRETE (M60) with partial replacement of FA by EAF SLAG:

The maximum modulus of rupture strength of 5.5 N/mm<sup>2</sup> is achieved the concrete mix for 40% replacement of Sand by EAF SLAG which is 12.2 % more than that of reference mix for 28 days curing.

**Table 14: Flexural strength (M60) concrete for different % of EAF SLAG.**

Concrete mixes	% replacement fine aggregate with EAF SLAG	Flexural tensile strength in N/mm <sup>2</sup> at 28 days
M0	0%	4.90
M5	20%	5.240
M6	40%	5.50
M7	60%	5.49
M8	80%	5.20



**Fig 08 :-Variations of flexural strength of (M60) concrete for different % of EAF SLAG.**

### Flexural strength STANDARD CONCRETE (M60) with 40% EAF SLAG and partial replacement cement by Nano SiO<sub>2</sub>:

The modulus of rupture strength of standard concrete (M60) with 40% EAF SLAG, and partial replacement cement by Nano SiO<sub>2</sub> is increases up to 2% replacement cement and further increase the Nano SiO<sub>2</sub> Flexural strength decreases.

Maximum modulus of rupture strength is 6.36 N/mm<sup>2</sup> is obtained for concrete mix with 2% replacement of cement by NanoSiO<sub>2</sub> which is 16 % more than that of concrete mix without NanoSiO<sub>2</sub> for 28 days curing.

**Table 15: Flexural strength of (M60) concrete with 40% EAF SLAG For different % of NanoSiO<sub>2</sub>.**

Concrete mixes	% replacement fine aggregate with EAF SLAG	Nano silica %	Flexural Tensile strength in N/mm <sup>2</sup> at 28 days
M9	40%	0	5.4
M10	40%	1%	5.6
M11	40%	2%	6.3
M12	40%	3%	5.9

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 5, May 2017

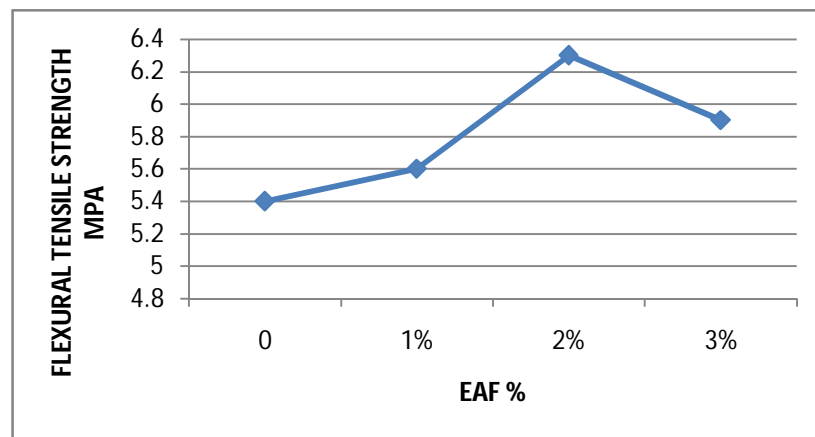


Fig 09 :-Variations of split tensile strength for (M60) concrete with 40% EAF SLAG for different % of Nano SiO<sub>2</sub>.

### IV.CONCLUSIONS

- The maximum compressive strength of 77 N/mm<sup>2</sup> is obtained ,when coarse aggregate is replaced 40% with EAF SLAG ,which is 10.8 % more compared to conventional concrete mix for 28 days curing.
- The maximum compressive strength of 78 N/mm<sup>2</sup> is obtained ,when fine aggregate is replaced 40% with EAF SLAG, which is 12.23 % more compared to conventional concrete mix for 28 days curing.
- The maximum compressivestrength of 81.8 N/mm<sup>2</sup> is obtained ,when coarse and fine aggregate is replaced 40% with EAF SLAG, and cement replacedpartially with 2% Nano Silica which is 4.28 % more compared to conventional concrete mix for 28 days curing.
- The maximum Split Tensile strength of 4.165N/mm<sup>2</sup> is obtained ,when coarse aggregate is replaced 40% with EAF SLAG, which is 20.8 % more compared to conventional concrete mix for 28 days curing.
- The maximum Split Tensile strength of 4.774N/mm<sup>2</sup> is obtained ,when fine aggregate is replaced 40% with EAF SLAG, which is 36 % more compared to conventional concrete mix for 28 days curing.
- The maximum Split Tensile strength of 4.93 N/mm<sup>2</sup> is obtained ,when coarse and fine aggregate is replaced 40% with EAF SLAG,and cement replaced partially with 2% Nano Silica, which is 3.44 % more compared to conventional concrete mix for 28 days curing.
- The maximum Flexural Tensile strength of 5.3N/mm<sup>2</sup> is obtained ,when fine aggregate is replaced 40% with EAF SLAG, which is 8.1 % more compared to conventional concrete mix for 28 days curing.
- The maximum Flexural Tensile strength of 5.5N/mm<sup>2</sup> is obtained ,when coarse aggregate is replaced 40% with EAF SLAG ,which is 12.2 % more compared to conventional concrete mix for 28 days curing.
- The maximum Flexural Tensile strength of 6.36N/mm<sup>2</sup> is obtained ,when coarse and fine aggregate is replaced 40% with EAF SLAG,and cement replaced partially with 2% Nano Silica, which is 16% more compared to conventional concrete mix for 28 days curing.
- Weight density of concrete is increasing, as the replacement percentage of EAF SLAG increases due to more weight density of EAF SLAG.

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Vol. 6, Issue 5, May 2017

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