

# Mechanical Properties of Concrete [M60] With Electric Arc Furnace Slag as Aggregate and Partially Replacing Cement with Nano Silica

N.Sandeep<sup>1</sup> & Dr. T.Chandra Shekara Reddy<sup>2</sup>

M.Tech Student, G.Pulla Reddy College of Engineering, Kurnool, Andhra Pradesh, India<sup>1</sup>

Professor, G.Pulla Reddy College of Engineering, Kurnool, Andhra Pradesh, India<sup>2</sup>

**ABSTRACT:** Electric Arc furnace slag, a steel industry by-product can be a better replacement for natural aggregate in concrete. As availability of natural aggregate is diminishing day by day, Electric Arc furnace slag answers all the needs of better replacement for natural aggregate. The strength properties of M60 grade concrete were studied with different percentages of replacement of fine aggregate and coarse aggregate by Electric Arc Furnace Slag. The standard concrete grade M60 is designed as per ACI 211. 4R-08. Work is carried out in 3 phases, in the first phase and second phase, Coarse aggregate and fine aggregate is replaced with Electric Arc Furnace slag for 20%, 40%, 60%, 80% respectively. The optimum percentage of Electric Arc Furnace slag in concrete corresponding to maximum mechanical properties was identified. Keeping this optimum percentage of Electric Arc Furnace slag as constant, cement is replaced with Nano Silica for 1%, 2%, 3%. The maximum increase in strength properties compared to conventional concrete was achieved at 2% replacement of Nano Silica. Test results indicate that replacement of 40% Electric Arc Furnace slag as coarse and fine aggregate and 2% Nano Silica as cement replacement gives maximum mechanical properties on comparison with conventional concrete.

**KEYWORDS:** Electric Arc Furnace Slag, Mechanical Properties, Nano Silica.

## I. INTRODUCTION

Due to the rapid growth of industrialization, a huge quantity of waste is generated which is being disposed. One of the major challenges with the environmental awareness and scarcity is availability of natural aggregates. 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. In spite of the rapid development in concrete technology in recent years, concrete with compressive strength higher than 40-60 MPa is a tough task. 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 objective 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. Thus, significance of the present work is to prove that EAF slag is the better replacement for natural 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 2, February 2017

## II. LITERATURE REVIEW.

**Idoia Arribas**<sup>[1]</sup> Studied the oxidizing electric arc furnace slag obtained after the manufacture of carbon steel, after suitable treatment, can and should be considered as an acceptable fine and coarse aggregate for the preparation of good quality concrete. **Juan M. Manso**<sup>[2]</sup> describes the work carried out in laboratory to produce concrete with good properties using oxidizing electric arc furnace (EAF) slag as fine and coarse aggregate. Studies and tests were performed on the durability of these concretes showing an acceptable behavior against aggressive environments. Finally, some leaching tests were carried out in order to verify their environmental compatibility. **Flora Faleschini**<sup>[3]</sup> Studied the use of by-products of steel industry (particularly EAF slag) instead of natural aggregates in high performance concrete. Concrete mixtures with different cement dosages and w/c ratios have been produced with natural fine aggregate and full replacement of coarse aggregate with EAF slag. **Mauthoor Sumayya**<sup>[4]</sup> done research work, which was conducted as a preliminary study to assess the feasibility of using slag from electric arc furnace (EAF) as aggregate in concrete. The physical as well as chemical properties of both types of EAF slags namely black and dense slag (BDS) and light and porous slag (LPS) were assessed. **Saveria Monosi**<sup>[5]</sup> Investigated in an interesting way to use EAFs, could be replaced as natural aggregates for manufacturing ordinary concretes with it. In order to avoid an excessive amount in specific weight, a partial replacement is recommended.

## III. MATERIALS AND MIX PROPORTIONS

### ELECTRIC ARC FURNACE SLAG & NANO SILICA: 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          | -             |

## IV. 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 material sand production techniques. Mix proportioning details are given below in table 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 2, February 2017

**Table- 05: Mix proportioning details**

|    | Cement<br>(Kg/m <sup>3</sup> ) | Silica Fume<br>(Kg/m <sup>3</sup> ) | Fine<br>Aggregate<br>(Kg/m <sup>3</sup> ) | Coarse<br>Aggregate<br>(Kg/m <sup>3</sup> ) | Water<br>(lit/m <sup>3</sup> ) | SP<br>(lit/m <sup>3</sup> ) | EAF<br>SLAG<br>as CA% | EAF<br>SLAG<br>as FA% | EAF<br>SLAG<br>as CA<br>(Kg/m <sup>3</sup> ) | EAF<br>SLAG<br>as FA<br>(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  |

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

|     | Cement<br>(Kg/m <sup>3</sup> ) | Silica Fume<br>(Kg/m <sup>3</sup> ) | Fine<br>Aggregate<br>(Kg/m <sup>3</sup> ) | Coarse<br>Aggregate<br>(Kg/m <sup>3</sup> ) | Water<br>(lit/m <sup>3</sup> ) | SP<br>(lit/m <sup>3</sup> ) | EAF SLAG<br>as<br>Aggregate % | EAF<br>SLAG<br>as CA<br>(Kg/m <sup>3</sup> ) | EAF<br>SLAG<br>as FA<br>(Kg/m <sup>3</sup> ) | Nano<br>SiO <sub>2</sub> % | Nano<br>SiO <sub>2</sub><br>(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 determine compressive strength, cylinders (100mm diameter and 200mm length) to determine split tensile strength and beams (100mmX100mmX500mm) to determine flexural strength were cast. All the specimens were prepared in accordance with Indian Standard Specifications IS: 516-1959<sup>[21]</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

# 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 2, February 2017

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. They are tested under Compression Testing Machine (CTM) for compressive strength and split tensile strength and Universal Testing Machine (UTM) for Flexural strength

## V. RESULTS AND DISCUSSIONS

### COMPRESSIVE STRENGTH:

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

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   |

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.

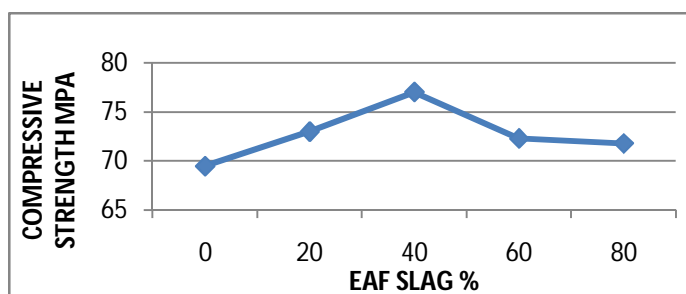


Fig 01:- Variation of compressive strength of M60 concrete for different % of EAF SLAG as coarse aggregate.

### 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.

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

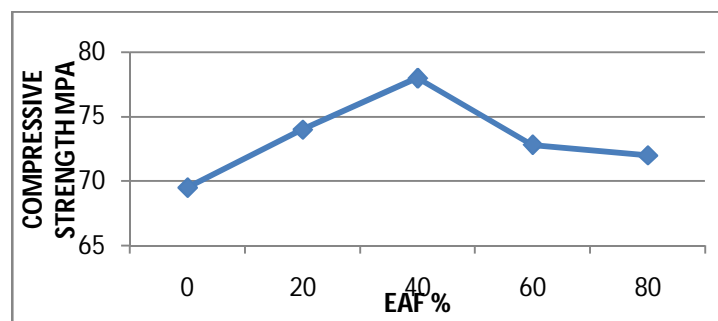
(An ISO 3297: 2007 Certified Organization)

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

Vol. 6, Issue 2, February 2017

**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   |



**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>.**

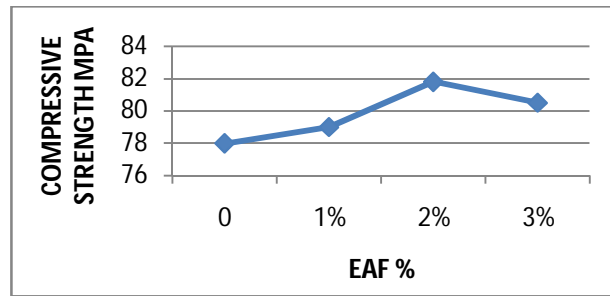
| Concrete mixes | % replacement fine aggregate with EAF SLAG | Nano silica % | Compressive strength in N/mm <sup>2</sup> at 28 days |
|----------------|--|---------------|--|
| M9             | 40%  | 0             | 78   |
| M10            | 40%  | 1%            | 79   |
| M11            | 40%  | 2%            | 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 2, February 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:

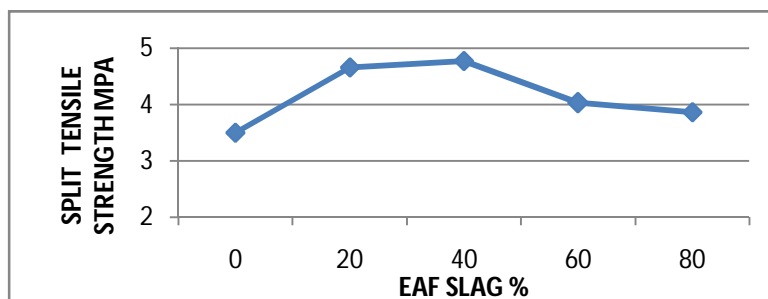
#### Split tensile strength of STANDARD CONCRETE (M60) with partial replacement of CA by EAF SLAG:

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  |



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

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

(An ISO 3297: 2007 Certified Organization)

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

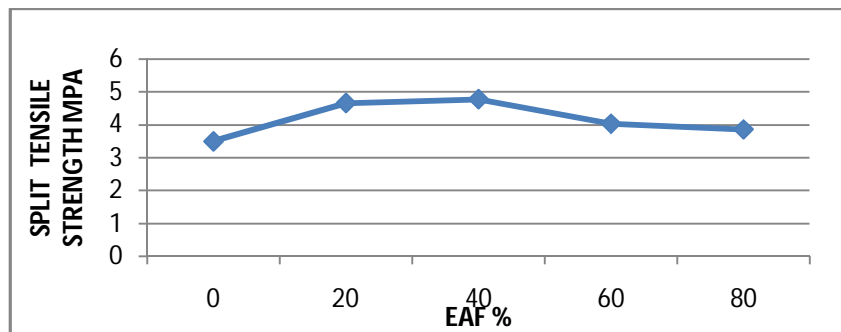
Vol. 6, Issue 2, February 2017

### 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  |



**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> is obtained for concrete mix with 2% replacement of cement with Nano Silica which is 3.44 % more than that of concrete mix without SiO<sub>2</sub> for 28 days curing.

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

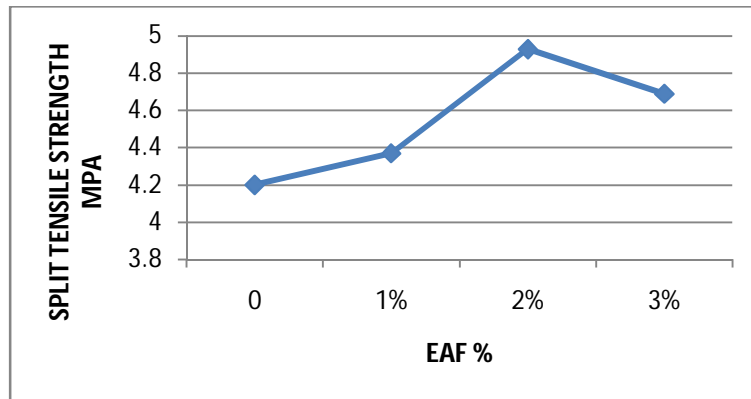
| Concrete mixes | % replacement aggregate with EAF SLAG | Nano silica % | Split Tensile strength in N/mm <sup>2</sup> at 28 days |
|----------------|---------------------------------------|---------------|--|
| M9             | 40%                                   | 0             | 4.2  |
| M10            | 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 2, February 2017



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

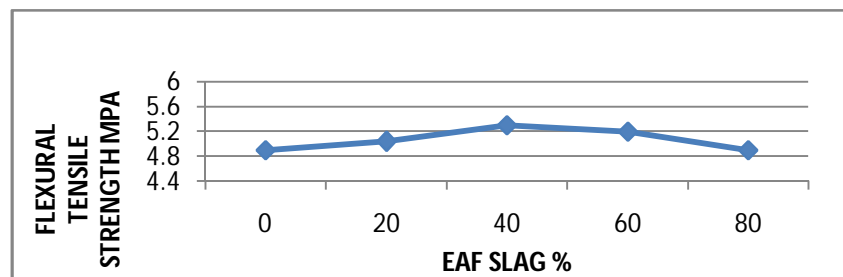
### FLEXURAL TENSILE STRENGTH:

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

Modulus of rupture 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. The maximum modulus of rupture strength of 5.3 N/mm<sup>2</sup> is achieved the concrete mix for 40% replacement of Sand by EAF SLAG which is 8.1 % more than that of reference mix for 28 days curing

**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 2, February 2017

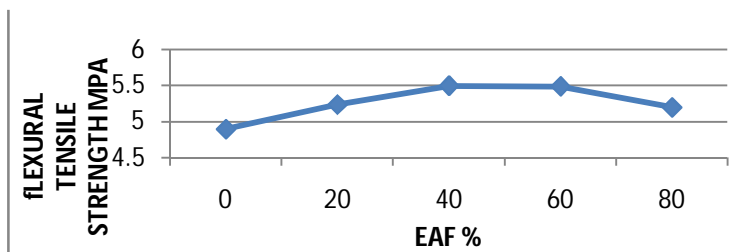
### Flexural tensile strength of CONCRETE M60) with partial replacement of FA by EAF SLAG:

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

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 2, February 2017

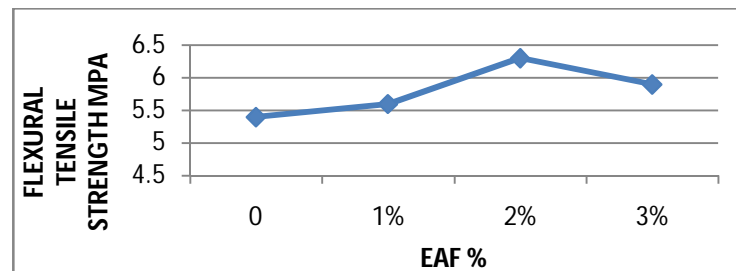


Fig 09 :- Variations of split tensile strength for (M60) concrete with 40% EAF SLAG for different % of Nano SiO<sub>2</sub>.

### VI. CONCLUSIONS

- The maximum compressive strength of 81.8 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 4.28 % 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 6.36 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 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.

### REFERENCES

1. Idoia Arribas, Amaia Santamaría, Estela Ruiz, Vanesa OrtegaLópez, Juan M. Manso “Electric arc furnace slag and its use in hydraulic concrete” Construction and Building Materials 90 (2015) 68–79.
2. Saveria Monosi, Maria Letizia Ruello, Daniela Sani PII: S0958-9465(15)30037-8DOI: 10.1016/j.cemconcomp.2015.10.004 Reference: CECO 255
3. Flora Faleschini , M. Alejandro Fernández Ruíz , Mariano Angelo Zanini ,Katya Brunelli,Carlo Pellegrino , Enrique Hernández Montes “High performance concrete with electric arc furnace slag as aggregate: Mechanical and durability properties” Construction and Building Materials 101 (2015) 113–121)
4. Mauthoor Sumayya , Mohee Romeelab, Kowlessar Prakash “Characterisation of electric arc furnace slags as concrete aggregate in a small island developing state: A preliminary study” Construction and Building Materials 105 (2016) 459–464.
5. Morteza Bastamia Mazyar Baghbadranib, Farhad Aslani “Performance of nano-Silica modified high strength concrete at elevated temperatures” Construction and Building Materials 68 (2014) 402–408.