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IJIEMR Transactions, online available on 20th July 2020. Link :http://www.ijiemr.org/downloads.php?vol=Volume-09&issue=ISSUE-07

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Volume 09, Issue 07, Pages: 46-56

Paper Authors

GOWTHAMI PEDADA[1*], BHARGAVI PEDADA[2] ,B.V.SHIVA KUMAR[3**]**

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A STUDY ON STEEL FIBRE REINFORCED CONCRETE USING MICRO SILICA

GOWTHAMI PEDADA[1*], BHARGAVI PEDADA[2**] ,B.V.SHIVA KUMAR[3**]
[1,2,3] Department of CIVIL, Welfare engineering College, Visakhapatnam, Andhra Pradesh, India.
[1]pedada.gowthami4@gmail.com , [2]bhargavi.pedada@gmail.com,[3] shivakumar.bandaru@gmail.com

Abstract: The principle of sustainable development and green building has penetrated the construction industry at an accelerating rate in recent years. In this regard, the idea of using by-product such as Micro Silica as partial replacement of cement in concrete, due to its great environment effect and became popular for producing infrastructures. However, concrete has low tensile strength, low flexural strength, low ductility and low energy absorption. Therefore to improve its strength, toughness and ductility, fibres are used in concrete. Fibre reinforced concrete is a composite material consisting of cement based matrix with an ordered or random distribution of fibres. This paper features an experimental study on concrete mixes of different proportions with Micro Silica and steelhooked end fibre of 1% by weight of cement with an aspect ratio of 30 are prepared and tested after curing and the effect of these materials on the strength of concrete is studied by replacing the cement by Micro silica with 0%, 5%, 10%, 15% & 20%. Here the grade of concrete is M30. The experimental investigation is carried out to find Compressive Strength, Flexural Strength and Split Tensile Strength for 7 days and 28 days and cubes were tested for alternate wetting and drying for 56 days and obtained optimum percentage is 15% replacement of Micro Silica.

1. Introduction

Concrete plays a vital role in the development of infrastructure globally and its applications are very significant in this advancing world. The basic ingredients of traditional concrete are cement, fine aggregate and coarse aggregate, where in the cement is generally Portland cement and fine aggregate is usually river sand are used. During the past few years cement and concrete technology has attained a lot of achievements. One of those is incorporation of industrial by products as filler or additive in cement and concrete production with technical, economical and environmental advantages. Industrial by products are the waste materials produced in the industries besides the main product so they are generally cheaper materials. Use of waste and byproducts in concrete will lead to green environment. Despite this fact, concrete production is one of the concerns worldwide that impact the environment with major impact being global warming due to CO_2 emission during production of cement. It was found that 0.8 tons of carbon dioxide gas is released into the atmosphere with the manufacture of 1 ton of cement.

Micro Silica is a mineral admixture which composes of very fine glassy spheres of silicon dioxide (SiO_2). Most of the Micro Silica particles are less than 1 micron in diameter and generally 50 to 100 times finer than average cement or fly ash particles.

Silica fume is a byproduct in the carbothermic reduction reaction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric arc furnaces in the production of silicon and ferrosilicon alloys. Micro Silica, also known as Silica fume is fine amorphous silica. Added to concrete, it reacts with the cement hydration products which dramatically improve the concrete strengths, durability and impermeability, allowing concrete to be used in a very

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efficient way like never used before. Silica fume can be used in a variety of cementitious products such as concrete, grouts, and mortars as well as in elastomeric, polymer, refractory, ceramic and rubber applications. Silica Fume is used in concrete to improve its properties. It has been found that Silica Fume improves Compressive strength, bond strength, and abrasion resistance; reduces permeability; and therefore helps in protecting reinforcing steel from corrosion. Steel Fibre in Concrete: Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle fracture of the concrete. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibres to the concrete would act as crack arrester and would substantially improve its compressive and flexural strength properties.

2. Literature Review

However the studies on steel fibre reinforced concrete using micro silica are limited especially in case of alternate wetting and drying.

Few of them are given byMohammad Ali et al. (2017),SivakumarAnandan et al.(2017),Muhammad Abed Attiya (2017), R. Sri Pragadeesh et al. (2017), Dilipkumar et al. (2016), SaiyadWaquar Husain (2015), Anandan et al. (2014).

Since concrete is generally the exterior component, it must resist severe physical and chemical attacks. Concrete becomes vulnerable to frequent exposure to wind, sun, rain, snow, and high concentrations of chloride solutions. Some combinations of these types of attacks are cyclic in nature such as freezing and thawing cycles, or wetting and drying cycles. Extensive research has been done on concrete exposed to freezing and thawing cycles, and the physical mechanisms governing this type of attack are well understood. It is known that cyclic wetting and drying allows for deeper penetration of aggressive ions and can lead to corrosion rates 20 times higher than exposure to a continuous salt fog. Cyclic wetting and drying causes continuous moisture movement through concrete pores. This cyclic effect accelerates durability problems because it subjects the concrete to the motion and accumulation of ha& materials, such as sulphates, alkalis, acids, and chlorides. Cyclic wetting and drying is a problem for RC structures exposed to chlorides and its effects are most severe in mainly three locations:

- Marine structures, particularly in the splash and tidal zones.
- In parking garages exposed to deicer salts.
- Highway structures, such as bridges and other elevated roadways for instance the Gardner expressway.

3. Methodology

The methodology adopted comprised of both preliminary and experimental investigations carried out using the study material and these are presented as follows:

a) Preliminary Investigations

For the preliminary investigations, micro silica and cement was subjected to physical and chemical analyses to determine whether they are in compliance with the standard used. The experimental program was designed to investigate silica fume as partial cement replacement in concrete. The replacement levels of cement by silica fume are selected as 5%, 10%, 15 and 20% and 1% steel fibre for

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the M30 grade of concrete. Cubes, Beams and Cylinders were casted with M30 grade concrete with different replacement levels of cement from 0 to 20% with silica fume and the specimens were put in curing tank for 7 and 28 days after 28 days cubes and compressive strength were determined and recorded down accordingly. The other materials used are listed as follow:

3.1 Cement

Portland cement is the most common type of cement used in general around the world, used as a basic ingredient of concrete, mortar. The raw materials required for the manufacturing of Portland cement are calcareous materials such as limestone or chalk, and argillaceous material such as shale or clay. It is a fine powder produced by heating materials to 1450^0 C in a kiln and the process is called calcination. Ordinary Portland cement of grade 53 conforming to IS: 12269-1983 was used in this investigation. The cement to be used for concrete making should be fresh and should have uniform colour. It should not contain any lumps and should be free from foreign matter.

3.2 Coarse aggregate

Aggregates whose particle size is retained on IS sieve of size 4.75 mm are termed as coarse aggregates. The coarse aggregate used in this investigation are obtained from local crushing unit. The size of aggregate used in this investigation is 20 mm and 10 mm. The aggregates are free from dust before used in concrete.

3.3 Fine aggregate

Aggregates passing through 4.75mm and retained on 150µ sieve are termed as fine aggregates. The fine aggregate conforming to zone-II according to IS: 383-1970 were used in the mix design. The sand obtained for the investigation is nearby river course.

3.4 Water

Water which is used for making concrete should be clear, potable fresh water with pH value (7 to 8) which is free from organic substances, durability and concentrations of acids. Water containing less than 2000 milligrams per litre of total dissolved solids can generally used for making concrete. Although high concentration is not always harmful they may affect certain cements adversely and should be avoided where possible.

3.5 Micro Silica

Silica fume, also known as Micro Silica, is an amorphous (no crystalline) polymorph of silicon dioxide. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. Silica fume is an ultrafine airborne material with spherical particles less than 1 µm in diameter, the average being about 0.1 µm. This makes it approximately 100 times smaller than the average cement particle. The unit weight, or bulk density, of silica fume depends on the metal from which it is produced. Its unit weight usually varies from 130 to 430 kg/m^3. The specific gravity of silica fume is generally in the range of 2.20 to 2.5. Based on this test the specific surface of silica fume typically ranges from 15,000 to 30,000 m^2/kg.

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Fig: 3.1 Micro Silica

3.6 Steel Fibres

The steel fibre used in this investigation is a hook end type fibre. The length of the fibre used in this experiment is 30mm and the diameter of the fibre is 1mm and the l/d ratio is 30.

Fig: 3.2 Steel Fibres

b) Preparation of Specimens

It was proposed to investigate the properties of concrete, cast with partial replacement of cement with 0%, 5%, 10%, 15% and 20% of Micro Silica In this experimental work, physical properties of materials used in the experimental work were determined. M30 grade of concrete was mixed and cured in potable water and sea water.

The test moulds were kept ready before preparing the mix. Moulds were cleaned and oiled on all contacts surfaces. The concrete is filled into moulds in three layers and then compacted with tamping rod. The top surface of concrete is struck off to level with a trowel. The number and date of casting was put on the top surface of the cubes, cylinders and beams.

- **Mix Proportioning**

Mix Proportioning by weight was used and the mix ratio was0.4*: 1: 1.72: 3.04*
Micro silica were used to replace OPC at dosage levels of 0%,5%, 10%, 15% and 20% by weight of the binder. The mix proportions were calculated and presented in table2.1

Materials	**Mix Proportion (Kg)**				
	Control 0%	MS 5%	MS 10%	MS 15%	MS 20%
Cement	400	380	360	340	320
Micro Silica	0	20	40	60	80
Total Water	160	160	160	160	160
Fine Aggregate	687.5	687.5	687.5	687.5	687.5
Coarse Aggregate	1219	1219	1219	1219	1219
SP 430	2.8	2.8	2.8	2.8	2.8

Table:3.1 Mix Proportion of concrete in $1m^3$ of concrete

c) Testing of Specimen

- **Compression Strength Test**

Compression test is most common test conducted on hardened concrete, partly because it is an easy test to perform, and partly because most of the desirable characteristics properties of concrete are qualitatively related to its compressive strength. Compression test was conducted on 150mm×150mm×150mm cubes. The compression tests were carried out at 7days, 28days & 56 days.

Cube compressive strength

$$= \frac{\text{Load}}{\text{Area of cross section}}$$

➢ Split Tensile Strength Test

The cylinder specimen is of the size 150 mm diameters and 300mm height was cast to determine the split tensile strength of concrete. The test is carried out by placing a cylindrical specimen horizontally between the loading surfaces of compression testing machine and the load is applied until failure of cylinder, along its longitudinal direction. The cylinder specimens are tested at 7 days and 28 days. The average of three specimens was reported as the split tensile strength provided the individual variation is not more than 15% of average value.

$$\text{Split tensile strength} = \frac{2\times P}{\pi\times D\times L}$$

Where

P = compressive load on the cylinder.

L=length of the cylinder.

D=diameter of the cylinder

➢ Flexural Strength Test

In the flexural strength test theoretical maximum tensile stress reached at the bottom fibres of the test beam is known as the modulus of rupture. When concrete is subjected to bending stress, compressive as well as tensile stresses are developed at top and bottom fibres respectively. The strength shown by the concrete against bending is known as flexural strength. If the largest nominal size of aggregate does not exceed 20mm, the dimension of specimen may be 150mm×150mm×700mm.

$$f_b = \frac{PL}{bd^2}$$

Fig 3.3 Flexural strength test setup

➢ Alternate Wetting and Drying

There were series of cyclic wetting and drying performed, in a day one cycle was done i.e, Drying and Wetting. During the day time at 6 A.M cubes were kept out for drying for 12 hours. Later the cubes were kept for wetting in marine water at 6 P.M for 12 hours. *The cycles were done for 30 days and later compressive strength test was done on the cubes*

Cube compressive strength

$$= \frac{\text{Load}}{\text{Area of cross section}}$$

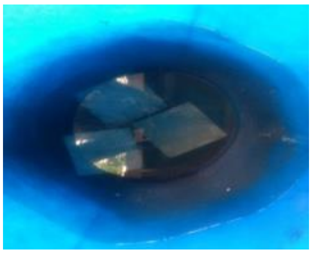

Fig 3.4 Alternate Wetting and Drying

➢ Modulus of elasticity

Modulus of elasticity is carried out in order to determine the tendency of an object to deform along an axis when opposing forces are applied along that axis. For calculating the modulus of elasticity of concrete, test was conducted on 150mm x 300mm cylinder specimens on Compression testing machine of capacity 200T. The test was performed as per Indian standard specifications BIS: 516-1959. Three concrete cube specimens

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were broken first to determine the ultimate compressive strength of the concrete.

Fig 3.5 Compression testing setup

4. Results And Discussions

4.1 Results of fresh concrete

Slump cone test

The variation of slump values for all the mixes is measured. The values of slump are given below in the table.

Percentage of replacement of micro silica	Percentage of steel fibre	Slump value (mm)
0	-	61
5	1	50
10	1	53
15	1	55
20	1	56

Table: 4.1 Variation of Slump

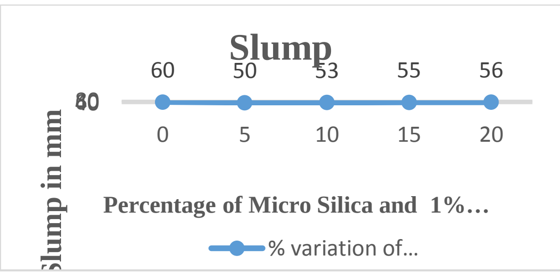

Fig. 4.1 Slump Vs. % of replacement

4.2 Hardened concrete properties

4.2.1Compressive strength

Percentage of Micro Silica replaced and 1% steel fibre	Compressive strength of concrete in MPa	
	7 days	28 days
0	33.16	41.33
5	34.8	43.82
10	37.92	45.33
15	40.12	48.24
20	38.93	46.07

Table: 4.2 Compressive strength results

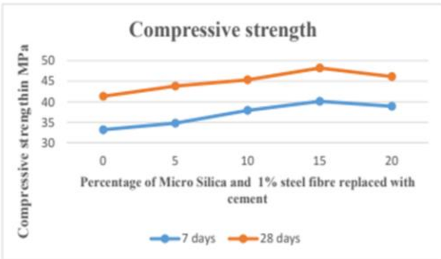

Fig.4.2 Compressive strength Vs. Age

4.2.2 Split tensile strength

The split tensile strength results at 0% and 15% at 7 and 28 days are tabulated

Percentage of Micro Silica replaced and 1% steel fibre	Flexural strength of concrete in MPa	
	7 days	28 days
0	5.11	5.87
15	6.01	7.18

Table: 4.3 Split tensile strength results

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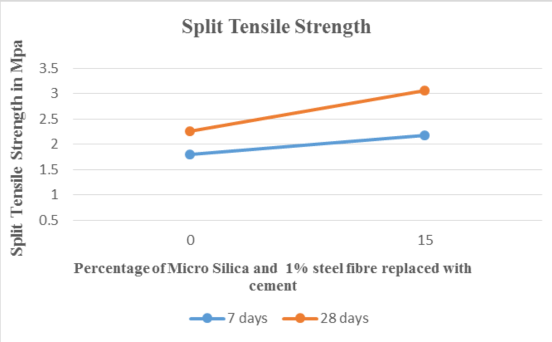

Fig. 4.3 Split tensile strength Vs. Age

4.2.3 Flexural strength

The flexural strength results at 0% and 15% at 7, 28 days are tabulated

Percentage of Micro Silica replaced and 1% steel fibre	Splitting tensile of concrete in MPa	
	7 days	28 days
0	1.79	2.26
15	2.17	3.06

Table: 4.4 Flexural strength results

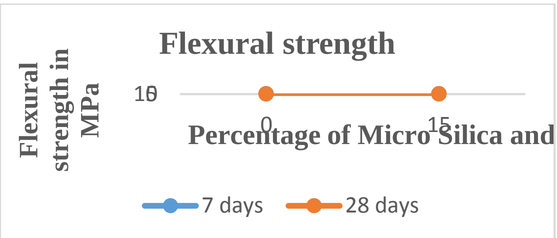

Fig. 4.4 Flexural strength Vs. Age

4.2.4 Alternate Wetting and Drying

Percentage of Micro Silica replaced and 1% steel fibre	Compressive strength of Alternate Wetting and Drying for every 12 hours MPa
0	49.48
15	57.77

Table: 4.5 Alternate Wetting and Drying results

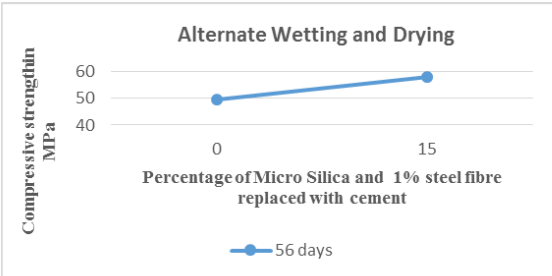

Fig.4.5 Alternate Wetting and Drying Vs. Age

4.2.5 Modulus of elasticity

The selected mix is considered and the cylinders of 150mmx300mm are cast with replacement of cement with 0% and 15% of micro silica in concrete. The values of young's modulus (E_c) are calculated from the stress-strain curves of nominal concrete and concrete with micro silica replacement are shown in the table 3.6.

Ec-Theoretical = $5000\sqrt{fck}$ = 27386.12 N/mm2

Ec-Practical (Secant modulus) =21568.43 N/mm2

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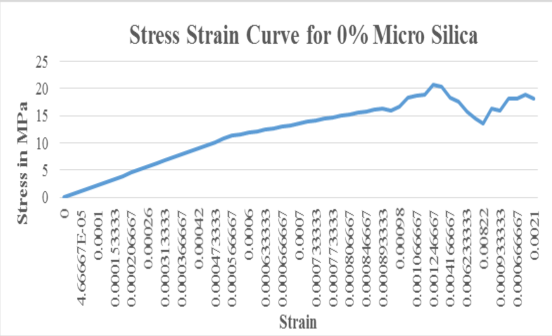

Fig. 4.6 Stress –Strain curve for 0% replacement of Micro Silica

Observations

- ➢ The ultimate strength of nominal mix cylinder obtained is 365 kN.
- ➢ The maximum strain observed at peak stress (20.665) is 0.00124
- ➢ Secant modulus calculated is 21568.43N/mm^2.

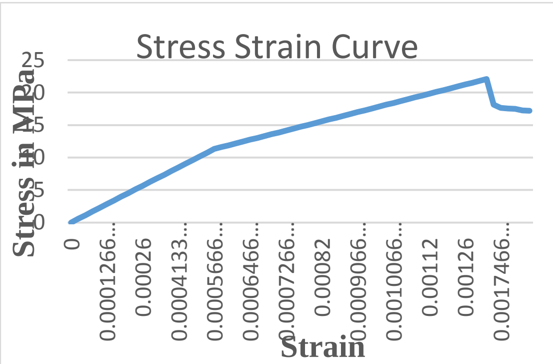

Fig.4.7 Stress –Strain curve for 15% replacement of Micro Silica

E_c-Theoretical = $5000\sqrt{f_{ck}}$= 27386.12 N/mm2

E_c-Practical (Secant modulus) = 19846.76452N/mm^2

Observations

- ➢ The ultimate strength of nominal mix cylinder obtained is 390 kN.
- ➢ The maximum strain observed at peak stress (22.0806 MPa) is 0.00136.
- ➢ Secant modulus calculated is19846.76N/mm^2

Percentage of replacement	f_{ck} (N/mm^2)	Ec theoretical (N/mm^2) Ec = $5000\sqrt{f_{ck}}$	Ec-practical (N/mm^2)
0	30	27386.12	21568.43
15	30	27386.12	19846.76

Table: 4.6 E_c-values of 0% and 15% replacement of Micro Silica

4. Conclusion and Future Prospects

On the basis of experimental studies carried out and the analysis of test results, the conclusions are drawn as follows.

- ➢ As the percentage replacement of cement with Micro Silica increases, compressive, split tensile and flexural strength increases, reach a maximum value and then decrease.
- ➢ The slump cone test results showed a decrease in the slump value when compared with reference mix due to presence of steel fibres and again there is increase in slump due to increase in Micro Silica content.
- ➢ Maximum increase in compressive strength obtained at 0.4 w/c ratio with 15% Micro Silica is 48.0 N/mm2 which is 16.13% more than the reference mix at the age of 28 days.

- Maximum increase in compressive strength obtained at 0.4 w/c ratio with 15% Micro Silica is 57.77 N/mm2 which is 16.78% more than the reference mix at the age of 56 days for alternate wetting and drying.
- Maximum increase in split tensile strength obtained at 0.4 w/c ratio with 15% Micro Silica is 3.06N/mm2 which is 35.3% more than the reference mix at the age of 28 days.
- Maximum increase in flexural strength obtained at 0.4 w/c ratio with 15% Micro Silica is 71.88N/mm2 which is 22.34% more than the reference mix at the age of 28 days.
- Young's Modulus for reference mix was almost equal to theoretical value and for optimum mix, it was less than the theoretical value.
- The compressive, split tensile and flexural strength results were found optimum at 15% replacement of Micro Silica.

Future Prospects:

- Further study can be done by increasing the cycles of alternate wetting and drying.
- In the present study only M30 grade has been considered. The other grades of concrete like M40 and M50 also need investigation.
- Further study can be done by providing reinforcement to the proposed mix.

In the present study alternate wetting and drying is done in laboratory with sea water it can be done near the sea shore.

6. Acknowledgments

Happy to acknowledge that the co-author and guide to support for preparing the paper. And a lot of thanks to the all authors and websites to provide me that the valuable contents and information for our reference.

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