Triple Blending of Cement Concrete with Micro Silica and Ground Granulated Blast Furnace Slag

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Abstract - *Cement industry may be one amongst the key sources of environmental pollution so the reduction of cement demand should be improved. Micro Silica (MS) and Ground granulated blast furnace slag (GGBS) are the by-products of industries and it ought to be reused to scale back the waste pollution. Therefore the present study is directed towards developing a better understanding on the combined performance of MS and GGBS on the strength properties of Ternary concrete over an Ordinary concrete. This work primarily deals with the strength characteristics such as Compressive, Split Tensile and Flexural Strength. Total 12 Different concrete mixtures were cast and tested with different cement replacement levels (5%, 10% and 15%) of Micro Silica with GGBS as addition (20%, 30%, 40% and 50%). Compressive ,Split Tensile and Flexural Strength of Ternary Blended Concrete At the ages of 7, 28, 60 and 90 days for various combinations of Micro Silica and GGBS..All Mixes were studied at water cement ratio of 0.55.*

The experimental results shows that, the strength properties of ternary blended concrete increase with increase in cement replacement levels of Micro Silica and GGBS (40%),the addition of Micro Silica and GGBS does not improve the strength properties of compressive, Split Tensile and Flexural.

Keywords—*Compressive Strength, Split Tensile and Flexural Strength, Ordinary Portland cement and Ternary Concrete, Micro Silica and GGBS.*

1. Introduction

Concrete is a mixture of naturally, cheaply and easily available ingredients as cement, sand, aggregate and water. Cement is occupied second place as most used material in the world after water. The rapid production of cement creates big problems to environment. First environment problem is emission of CO_2 during the production process of the cement. The CO_2 emission is very harmful which creates big changes in environment. According to the estimation, 1 tonne of carbon dioxide is released to the atmosphere when 1 tonne of ordinary Portland is manufactured. As there is no alternative building material which totally replace the cement. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Substantial energy and cost savings can result when industrial by products are used as a partial replacement of cement. Fly ash, Ground Granulated Blast furnace Slag, Rice husk ash, High Reactive Meta kaolin, silica fume are some of the pozzolanic materials which can be used in concrete as partial replacement of cement [1] Micro Silica is extremely fine with particle size less than 1 micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles. Silica fume has specific surface area of about 20,000 m2/kg against 230 to 300 m2/kg.Micro Silica has become one of the necessary ingredients for making high strength and high performance concrete. In India, silica fume has been used very rarely. Nuclear Power Corporation was one of the first to use silica fume concrete in their Kaiga and Kota nuclear power projects.Micro Silica was also used for one of the flyovers at Mumbai where, for the first time in India 75 MPa concrete was used (1999). Silica fume is also now specified for the construction of proposed Bandra-Worli sea link project at Mumbai. Silica fume, also referred to as micro silica or condensed silica fume, is another materialthat is used as an artificial pozzolanic admixture.It is a product resulting from reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy.

Ground granulated blast-furnace slag is a nonmetallic product consisting essentially of silicates and aluminates of calcium and other bases. The molten slag is rapidly chilled by quenching in water to form a glassy sand like granulated material. The granulated material when further ground to less than 45 micron will have specific surface of about 400 to 600 sq m/kg (Blaine). The performance of slag largely depends on the chemical composition, glass content and fineness of grinding. There are two methods for making Blast Furnace Slag Cement. In the first method blast furnace slag is interground with cement clinker along with gypsum.In the second method blast furnace slag is separately ground and then mixed with the cement. The replacement of cement with GGBS will reduce the unit water content necessary to obtain the same slump..This reduction of unit water content will be more pronounced with increase in slag content and also on the fineness of slag. This is because of the surface configuration and particle shape of slag being different than cement particle. In addition, water used for mixing is not immediately lost, as the surface hydration of slag is slightly slower than that of cement. The engineering benefits from the use of mineral admixtures in concrete result partly from their particle size distribution characteristics, and partly from the pozzolanic and cementitious reactivity. When OPC is replaced by GGBS the rate of gain of strength of concrete is slower at early age, and this limits its use in concrete where early age strength is desirable. To overcome this problem Micro silica is employed with GGBS in ternary concrete and it increases early strength of concrete by formation of secondary C-S-H gel at early stages due to fat pozzolanic reaction.

2.Literature Review

Deepa A Sinha [2], was aimed to investigate the properties of ternary blended concrete incorporating Micro silica, metakaolin, and GGBS. The properties investigated include workability, compressive strength and. flexural strength. They replaced cement by ternary blend of Fly ash, metakaolin, Micro silica, GGBS up to 30% to determine the workability, compressive strength and flexural strength. The study reveals that out of all pozzolonic material Micro Silica gives highest strength in flexure after 28 and 90 days. Micro Silica gives highest compressive strength after 90 days. Metakaolin gives highest compressive strength after 28 days.S.Bhanja, B.Sengupta [3] reported that the compressive, as well as the tensile, strengths increased with silica fume incorporation, and the results indicate that the optimum replacement percentage is not a constant one but depends on the water–cementitious material (w/c) ratio of the mix. Compared with split tensile strengths, flexural strengths have exhibited greater improvements. Based on the test results, relationships between the 28-day flexural and split tensile strengths with the compressive strength of silica fume concrete have been developed using statistical methods. V. Bhikshma, K. Nitturkarb and Y. Venkates [4], Described the mechanical properties of high-strength concrete of grades M40 and M50, at 28 days characteristic strength with different replacement levels of cement with silica fume or micro silica of grade 920-D are considered. Cement replacement up to 12% with silica fume leads to increase in compressive strength, splitting tensile strength and flexural strength, for both M40 and M50 grades. Beyond 12% there is a decrease in compressive strength, tensile strength and flexural strength for 28 days curing period. They found that the compressive strength, splitting tensile strength and flexural strength of M40 grade concrete is increased by 16.37%, 36.06% and 16.40% respectively, and for M50 grade concrete 20.20%, 20.63% and 15.61% respectively over controlled concrete. Dilip Kumar Singha Roy, Amitava Sil [5], was investigated the strength parameters of concrete made with partial replacement of cement by SF. Properties of hardened concrete viz Ultimate Compressive strength, Flexural strength, Splitting Tensile strength has been determined for different mix combinations of materials and these values are compared with the corresponding values of conventional concrete. The investigation has been aimed at to bring awareness amongst the practicing civil engineers regarding advantages of these new concrete mixes. The maximum 7 days cube compressive strength observed as 17.85 N/mm2 split tensile is found to be 3.61 N/mm2 at 10% cement replaced by SF (38.58% more than that of normal concrete). The maximum 28 days flexural strength of SF concrete is found to be 4.93 N/mm2. for 10% replacement of cement with silica fume and the values are higher (by 19.6% and 16.82% respectively) where as split tensile strength and flexural strength of the SF concrete (3.61N/mm2 and 4.93N/mm2 respectively) are increased by about 38.58% and 21.13% respectively over those (2.6 N/mm2 and 4.07 N/mm2 respectively) of the normal concrete when 10% of cement is replaced by SF... D.Audinarayana, Seshadri sekhar, T & Srinivasa Rao.[6], studied the performance of ternary blended concrete by replacing the OPC with Micro silica and Fly ash. It reveals the combination of micro silica and fly ash leads to increase in compressive strength, split tensile, flexural strength as compared to ordinary concrete irrespective to of water to binder ratios. The percentage increase of compressive strength of ternary concrete of is 10 to 30%, 15 to 27% in split tensile strength and 10 to 30% in flexural strength when compared with ordinary concrete. S.Vijaya Bhaskar Reddy, P.Srinivasa Rao[7] was investigated the optimization of a Ternary Blended Cementitious system based on Ordinary Portland Cement (OPC)/ GGBS / Micro Silica for the development of Ternary Concrete. Compressive Strength of Ternary Blended Concrete at the ages of 7, 28, 60, 90 days for various combinations of Micro Silica and GGBS mixes. Micro Silica of 0%, 5%, and 10% and15% along with GGBS was replaced by 20%, 30% 40% and 50%. All the mixes were studied at water cement ratio of 0.45. The study reveals that, the compressive strength of ternary concrete increases gradually until GGBS content reaches to 30%, and there after it falls even increase of GGBS content al all curing times, and it is found that the micro silica improves the early age strength of concrete with GGBS by refining the properties of hardened concrete continuously as it matures.

3. Objectives of the study

- To determine combined effect of Micro silica and GGBS on compressive, split and flexural strengths of Ternary concrete.
- To use pozzolanic materials such as Micro silica and GGBS in concrete by partial replacement of cement
- To utilize Industrial byproducts and find out the economical and performance evaluation of concrete mix.
- To create healthy environment world-wide by using industrial byproducts wisely.
- To provide economical construction material

4. Research Significance

This research provides information concerning the behavior of Micro Silica and GGBS for triple blended concrete under compressive, split tensile and flexural strength. Though enhancement in the strength properties of ternary blended concrete through mineral admixtures like Fly ash, metakaolin, etc., but there exists little understanding of Micro silica and GGBS combinations and the information is still scanty. The contribution of silica fume to the strength of concrete is yet to be fully quantified. Although the literature is rich in reporting on silica fume concrete, most of the research works are centered on the compressive strength, and technical data on tensile strength is quite limited.

5. Experimental Programme

The experimental programme was planned to produce a Ternary Blended Concrete with reduced cement content by adding different percentages of Micro Silica and GGBS. The material used and the experimental procedure for mixing, casting and testing of specimens are described in the following section. Total 312 (12+144,8+96 and 4+48) specimens were casted to determine compressive, split tensile and flexural strength of ordinary Portland cement and Ternary Blended Concrete at the age of 7, 28, 60 and 90 days.

5.1 Materials

5.1.1 Cement: Ordinary Portland cement of 53 grade having specific gravity of 3.15 was used. The Cement used has been tested for various proportions as per IS 4031-1988 and found to be confirming to various specifications of 12269-1987.

5.1.2 Micro Silica: Micro Silica -920D **[8]** as a mineral admixture in dry dandified form was obtained from "ELKEM South Asia (P) Ltd., Navi Mumbai confirming to ATSM-C (1240-2000) having specific gravity 2.2 and fineness 20000 m^2/kg.

5.1.3 GGBS: GGBFS was collected from JSW-HYD **[9].** Confirming to IS: 12089 – 1987. (Specific gravity: 2.87 Fineness: m^2/kg.**)**

5.1.4 Fine Aggregate*:* Locally available river sand confirming to zone II of table 4 of BIS: 383-1970 (specific gravity: 2.6 and fineness modulus 3.17 and bulk density 1793 kg/m^3) was used as fine aggregate.

5.1.5 Coarse Aggregate*:* Locally available quarried and crushed granite stones confirming to graded aggregate of nominal size between 20mm and 4.75mm as per table 2 of BIS:383-1970 (specific gravity: 2.9, fineness modulus:6.87,bulk density:1603kg/m^3)

Water: Clean drinking water available in the college campus was used for mixing and curing of concrete confirming to IS 456-2000.

5.2 Mix Proportions

5.2.1. Control concrete: Mix design is carried out as per guide line given in IS: 10262-2009, which yielded a proportion of 1:2.40:3.373 with water cement ratio of 0.55. is used as the reference mix. Control mixtures were prepared for medium workability without using super plasticizer. The mix proportioning control concrete is given in **Table 1.**

5.2.2. Ternary concrete mixes*:* For each curing period, Twelve Ternary Mixes (OPC+Micro Silica+GGBS) were made with cement replacement. One Ordinary mix was established with OPC only.. The compositions of Ternary concretes are given in **Table 2.**

Table 1: Mix proportion (kg/m^3) for controlled concrete

Cement	Water	FA[a]	CA[b]
324	178	785	1093
1.000	0.550	2.400	3.373
11.352	6.243	27.471	38.255

[a] Fine Aggregate , [b] Coarse Aggregate

Table 2: Ternary concrete mix proportioning (kg/m^3) and Quantity of ingredients

Mix ID	Ternary concrete (TC) (C%+MS%+GGBS %)	Cement	MS	GGBS	FA	CA	Water (liters)
CC[a]	C100%+MS 0%+GGBS 0%	324	0	0	785	1093	178
TM 1[b]	C75%+MS 5%+GGBS 20%	243	16.2	64.8	785	1093	178
TM 2	C65%+MS 5%+GGBS 30%	210.6	16.2	97.2	785	1093	178
TM 3	C55%+MS 5%+GGBS 40%	178.2	16.2	129.6	785	1093	178
TM 4	C45%+MS 5%+GGBS 50%	145.8	16.2	162	785	1093	178
TM 5	C70%+MS 10%+GGBS 20%	226.8	32.4	64.8	785	1093	178
TM 6	C60%+MS 10%+GGBS 30%	194.4	32.4	97.2	785	1093	178
TM 7	C40%+MS 10%+GGBS 40%	162	32.4	129.6	785	1093	178
TM 8	C40%+MS 10%+GGBS 50%	129.6	32.4	162	785	1093	178
TM 9	C65%+MS 15%+GGBS 20%	210.6	48.6	64.8	785	1093	178
TM 10	C55%+MS 15%+GGBS 30%	178.2	48.6	97.2	785	1093	178
TM 11	C45%+MS 15%+GGBS 40%	145.8	48.6	129.6	785	1093	178
TM 12	C35%+MS15%+GGBS 50%	113.4	48.6	162	785	1093	178

[a] Controlled concrete, [b] Ternary mix

5.3 Mixing, Casting, and curing of specimens.

5.3.1 Mixing: A Designed mix ratio of 1: 2.40: 3.373 was used for the ternary concrete. Batching was by weight and a constant water/cement ratio of 0.55 used. Mixing was done manually on smooth concrete pavement.

5.3.2 Casting: For casting the cubes, cylinders and beams, standard cast iron metal moulds was used. Whole casting procedure is confirmed to Indian Standard: 10086-1882. The following specimens were prepared for both controlled concrete (CC) and ternary concrete (TC) to perform tests at 7, 28, 60 and 90 day of curing.

i) 150x150x150 mm cubes (12 for CC and 114 for TC) for compressive strength as per IS 516-1999
ii) 150 x300mm. cylinders (8 for CC and 96 for TC) for split tensile strength as per IS 5816-1999
iii) 100x100x500 mm beams(4 for CC and 48 for TC) for flexural test as per IS516-1959

5.3.3 Curing: After casting, the moulded specimens are stored in the laboratory free from vibration, in moist air and at room temperature for 24 hours. After this period, the specimens are removed from the moulds and immediately submerged in the clean fresh water of curing tank. The curing water is removed after every 3 days. The specimens are cured for 7, 28, 60and 90 days.

5.4. Testing of Specimens: At the age of 7, 28, 60 and 90 days, the specimens were taken out of water and allowed to dry under shade and then tested for strengths at room temperature.

5.4.1. Compressive strength: Cube compression tests were performed on standard cubes of size 150 x 150 x 150 mm after 7, 28, 60 and 90 days curing as per IS:516-1959 **[10]**. As shown in **Fig.3** and the test results are presented in **Table 3**

Compressive strength of specimen was calculated by the expression:

$$f_{cu}= P_c/A \quad (1)$$

Where,

P_c= Failure load in compression, KN

A = Loaded area of cube, mm^2

5.4.2. Split Tensile Strength: The test was carried out on cylinder by splitting them along the middle plane parallel to the edges by applying the compressive load to opposite edges as per IS: 5816-1956 **[11]**. As shown in **Fig. 4.** Test results shown in **Table 4.**

The split tensile strength of cylinder was determined by expression:

$$f_t=2P_t/\ LD \quad (2)$$

Where,

f_t = Tensile strength, MPa

P_t = Load at failure, N

L = length of cylinder, mm

D = Diameter of cylinder, mm

5.4.3. Flexural strength test: Flexural strength test were performed on beam specimens according to IS: 516-1959**[12].** Standard beams of size 100mmx100mmx500mm were supported symmetrically over a span of 400 mm and subjected to two points loading till failure of the specimen. After failure the distance (a) between the crack and nearest support is measured. The flexural strength of the specimen is expressed as the modulus of rupture. Test results are presented in the **Table 5.**

The flexural strength of beam was calculated by the following expressions:

$f_{cr}=PL/bd^2$ (when 'a' is greater than13.3 cm) (3)

$f_{cr}=3Pa/bd^2$ (when 'a' is in between 11.0cm and13.3cm) (4)

Where,

f_{cr} = Flexural strength, MPa

a = distance between the line of fracture and the nearest support,

b = width of beam, mm

d = depth of beam, mm

P = Central load, KN

Fig. 1. Mineral Admixtures

Fig. 5. Arrangement of cubes

Fig. 2. Blending of SCMs

Fig. 6. Compression Test

Fig.3. Casting.

Fig.7. Arrangement of Cylinders

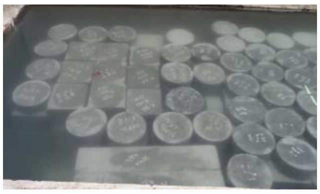

Fig. 4 .Curing Tank

Fig. 8. Split Tensile Test

Fig.9. Arrangements of Beams

Fig. 10. Flexural Test

Fig.11 over view of Specimens

Table.3: Compressive Strength Test Results

MI	7-D	28 -D	60-D	90-D
RM1	24.64	35.20	36.52	37.35
TM1	23.83	36.81	38.48	40.50
TM2	**23.65**	**39.02**	**41.09**	**42.98**
TM3	23.43	38.13	39.92	41.60
TM4	23.15	37.51	39.23	40.81
TM5	25.89	39.2	40.90	42.08
TM6	**25.46**	**42.6**	**44.86**	**47.68**
TM7	25.18	40.91	42.95	45.30
TM8	25.08	37.89	39.72	41.36
TM9	26.70	33.83	35.26	36.21
TM10	**26.41**	**38**	**40.05**	**41.78**
TM11	**26.01**	33.54	34.94	36.16
TM12	25.92	33	34.34	35.20

Where D means Days

Table.4: Split Tensile Strength Test Results

Mix Id	Ternary concrete (TC) (C%+MS%+GGBS %)	7 Days	28 Days	60 Days	90 Days
RM1	C100%+MS 0%+GGBS 0%	2.48	3.2	3.28	3.33
TM1	C75%+MS 5%+GGBS 20%	2.44	3.36	3.45	3.53
TM2	**C65%+MS 5%+GGBS 30%**	**2.4**	**3.43**	**3.56**	**3.68**
TM3	C55%+MS 5%+GGBS 40%	2.38	3.38	3.5	3.6
TM4	C45%+MS 5%+GGBS 50%	2.36	3.34	3.44	3.54
TM5	C70%+MS 10%+GGBS 20%	2.56	3.44	3.55	3.62
TM6	**C60%+MS 10%+GGBS 30%**	**2.53**	**3.7**	**3.87**	**4.05**
TM7	C50%+MS 10%+GGBS 40%	2.51	3.59	3.72	3.83
TM8	C40%+MS 10%+GGBS 50%	2.5	3.56	3.68	3.8
TM9	C65%+MS 15%+GGBS 20%	2.61	3.1	3.19	3.25
TM10	**C55%+MS 15%+GGBS 30%**	**2.59**	**3.37**	**3.5**	**3.6**
TM11	C45%+MS 15%+GGBS 40%	2.57	3.08	3.17	3.25
TM12	C35%+MS15%+GGBS 50%	2.56	3.04	3.13	3.19

Table.5: Flexural Strength Test Results

Mix Id	Ternary concrete (TC) (C%+MS%+GGBS %)	7-D	28-D	60-D	90-D
RM	C100%+MS 0%+GGBS 0%	3.58	4.54	4.65	4.72
TM1	C75%+MS 5%+GGBS 20%	3.5	4.67	4.82	4.98
TM2	**C65%+MS 5%+GGBS 30%**	**3.48**	**4.86**	**5.03**	**5.19**
TM3	C55%+MS 5%+GGBS 40%	3.46	4.79	4.94	5.07
TM4	C45%+MS 5%+GGBS 50%	3.44	4.73	4.88	5.01
TM5	C70%+MS 10%+GGBS 20%	3.7	4.88	5.02	5.11
TM6	**C60%+MS 10%+GGBS 30%**	**3.66**	**5.18**	**5.4**	**5.57**
TM7	C50%+MS 10%+GGBS 40%	3.63	5.05	5.21	5.37
TM8	C40%+MS 10%+GGBS 50%	3.62	4.77	4.92	5.05
TM9	C65%+MS 15%+GGBS 20%	3.78	4.42	4.54	4.62
TM10	**C55%+MS 15%+GGBS 30%**	**3.75**	**4.78**	**4.95**	**5.09**
TM11	C45%+MS 15%+GGBS 40%	3.71	4.39	4.51	4.62
TM12	C35%+MS15%+GGBS 50%	3.7	4.35	4.46	4.54

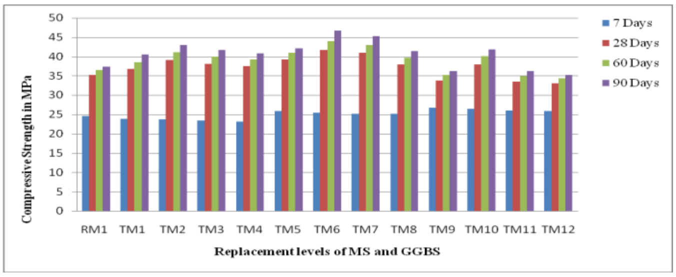

Fig.12. Compressive Strength of TBC w.r.t Normal Concrete with Micro Silica (5%, 10% and 15%) and different % of GGBS (20%-50%)

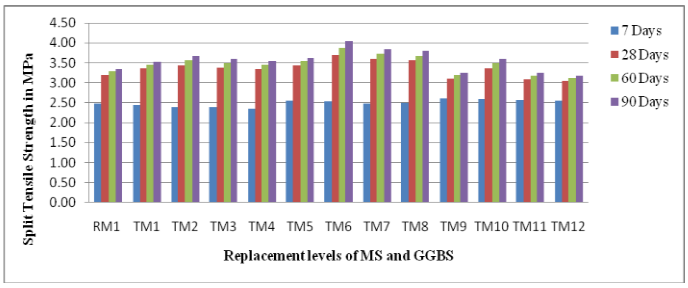

Fig.13. Split Tensile Strength of TBC w.r.t Normal Concrete with Micro Silica (5%, 10% and 15%) and different % of GGBS (20%-50%)

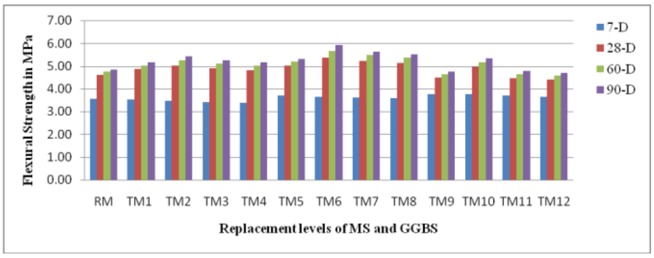

Fig.14. Flexural Strength of TBC w.r.t Normal Concrete with Micro Silica (5%, 10% and 15%) and different % of GGBS (20%-50%)

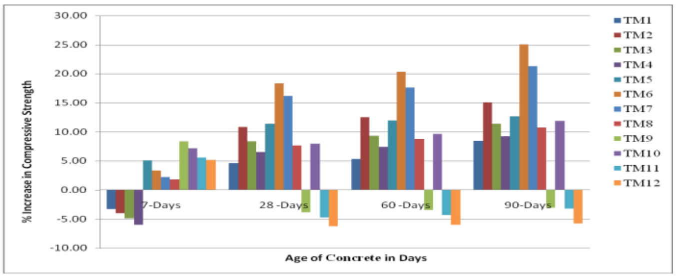

Fig.15. % Increase in Compressive Strength of TBC w.r.t Normal Concrete with Micro Silica (5%, 10% and 15%) and different % of GGBS (20%-50%)

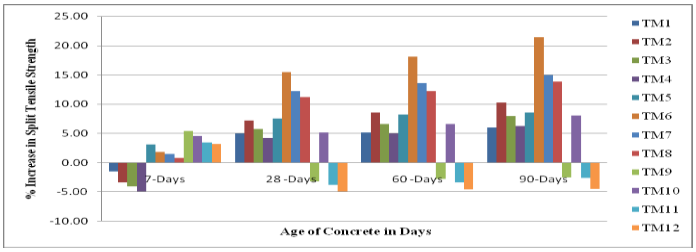

Fig.16. % Increase in Split Tensile Strength of TBC w.r.t Normal Concrete with Micro Silica (5%, 10% and 15%) and different % of GGBS (20%-50%)

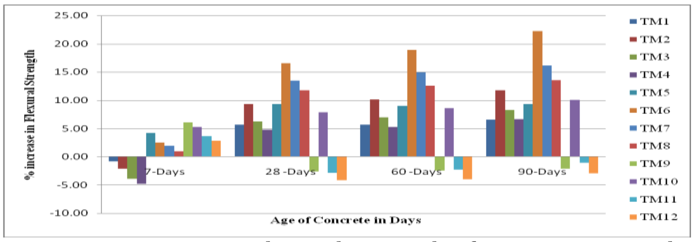

Fig.17. % Increase in Flexural Strength of TBC w.r.t Normal Concrete with Micro Silica (5%, 10% and 15%) and different % of GGBS (20%-50%)

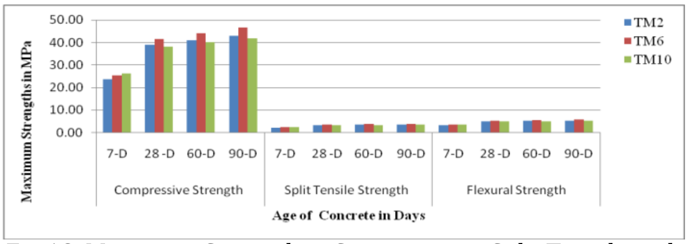

Fig.18. Maximum Strength in Compression, Split Tensile and Flexural.

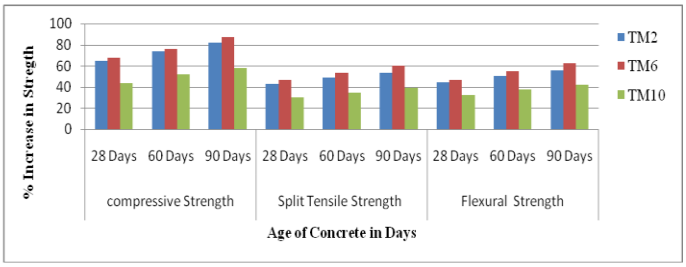

Fig.19 Maximum Percentage Increase in Compression, Split Tensile and Flexural (7 Days Compared to all Curing Days)

6. Results and Discussion

6.1 Fresh Concrete properties:

6.1.1 Mix Characteristics: While observing the characteristics of fresh concrete, Micro Silica and its super fine particles, causes the ternary mixtures to be Sticky and Cohesive, when compared to control concrete mixtures and also noticed that, the Cohesiveness increases with increase in Micro Silica content and which leads to more paste volume, and Contributes to a reduction in bleeding. All the Mixtures have exhibited satisfactory characteristics regarding bleeding and Segregation. Content reaches to 30% and it decreased even the GGBS Content increased. Also observed that, workability of Ternary Concrete Mixtures were decreased with the increase of Micro silica content .All Mixtures were prepared by maintaining medium workability.

6.2 Hardened concrete properties

Compressive, Split and Flexural strengths of control concrete and ternary concrete mixtures were determined at 7, 28, 60 and 90 days of curing. The average of three samples was taken for every testing age.

6.2.1 Compressive strength development

Fig.12 shows the early age (7days) strength of ternary concrete varies with respect to the percentage levels of Micro silica (MS) and GGBS and also noticed that, the compressive strength of ternary concrete is lower than that of control concrete at Micro silica 5% as constant, for all replacement levels of GGBS. At MS 10% as constant, slightly increase in strength of ternary concrete was observed from the Table 3. But there is a considerable increase in strength of Ternary concrete at MS 15% as constant, for all percentage levels of GGBS. The reason for this phenomenon is, the GGBS in the ternary concrete, which delays the early age strength due to slow pozzolanic reaction. Inclusion of Micro silica in cement system, increase the strength of ternary concrete at early stage significantly [12].

Conversely it is observed that, the 28 day compressive strength of ternary concrete increases gradually until GGBS content reaches to 30% and there after it falls even increase of GGBS, with MS 5% as constant. Same trend was observed with MS 10% as constant. But it is noticed that, the strength of Ternary concrete is lower than that of control concrete with MS 15% as constant. The same trend was observed even at 90 days curing also.

6.2.2 Split tensile strength

Fig.13 shows the variation of split tensile strength with Micro silica and GGBS replacement percentages as well as curing days. It is observed that Micro silica incorporation increases early age strength and GGBS increases the strength with respect to curing days. A close observation of Fig.12 exhibits the strength gain is almost similar with that of compressive strength at all curing days. And also noticed that very high percentages of Micro silica do not significantly increase the split tensile strengths, and increase is almost insignificant beyond 10%. As shown in Table: 4

6.2.3 Flexural strength

Fig.13 shows the variation of flexural tensile strength with Micro silica and GGBS replacement percentages as well as curing days. Micro silica seems to have more pronounced effect on the flexural strength than the split tensile strength. The flexural strengths almost follows the same tend as the compressive strength does at all curing days.

6.3 Optimum Ternary Mixes Combinations

From the **Table 3** It is noticed that the maximum cube compressive strength (26.70MPa) was obtained by ternary mix TM9 (15%MS+20%GGBS+65% OPC) at 7 day curing. And also observed that the ternary mix TM6 (10%MS+30%GGBS+60%OPC) attained. Maximum cube compressive strength (41.65MPa) at 28 days testing, Maximum cube compressive strength (43.65MPa) at 60 days testing. Even at 90 days curing, the same combination i.e. TM6 shows maximum cube compressive strength (47.52MPa)

From the **Table 4** It is noticed that the maximum Split Tensile (2.61MPa) was obtained by ternary mix TM9 (15%MS+20%GGBS+65% OPC) at 7 day curing. And also noticed that the ternary mix TM6 (10%MS+30%GGBS+60%OPC) attained maximum cube compressive strength (3.70MPa) at 28 days testing. Even at 60 and 90 days curing the same combination i.e. TM6 shows maximum cube compressive strength (3.87 and 4.05MPa)

From the **Table 5** It is noticed that the maximum Flexural Strength (3.78MPa) was obtained by ternary mix TM9 (15%MS+20%GGBS+65% OPC) at 7 day curing. And also noticed that the ternary mix TM6 (10%MS+30%GGBS+60%OPC) attained maximum cube compressive strength (5.18MPa) at 28 days testing. Even at 60 and 90 days curing the same combination i.e. TM6 shows maximum cube compressive strength (5.40 and 5.57MPa).

6.3.1 Percentage Increase in Compressive strength with respect to binder content

The analysis of experimental data showed that, the addition of Micro silica and GGBS enhanced the strength properties of ternary mixtures, which was on par with that of control concrete mixtures.

Fig.15 shows that, The 7 day's compressive strength of ternary mix (TM9) is 8.36% higher than the controlled concrete mix. The 28 days, maximum compressive strength of ternary mix (TM6) is 18.32% higher than the controlled concrete. At 60 and 90 days curing, the maximum compressive strength was 20.37% and 25.09% higher than controlled concrete, and it is again by ternary mix (TM6).for *water cement ratio* 0.55

6.3.2 Percentage Increase in Split Tensile strength with respect respect to binder content

Fig.16 shows that, the maximum Split Tensile strength of ternary mix (TM9) is 5.39% at 7 Days. The 28, 60 and 90 days curing, had 15.7%, 18.10 and 21.44% respectively.

6.3.3 Percentage Increase in Flexural strength with respect respect to binder content.

Fig.17 shows that, the maximum Flexural strength of ternary mix (TM9) is 5.45% at 7 Days. The 28, 60 and 90 days curing, had 14.26%, 16.05% and 17.97% respectively.

6.4 Percentage gain in Compressive, Split Tensile and Flexural strength with respect curing days

Fig.19 shows that, the maximum compressive strength of ternary mix (TM6) at 28, 60 and 90 days curing, had 67.32% ,76.19% and 87.24% respectively over 7 days compressive strength for *water cement ratio* 0.55

Fig.19 shows that, the maximum Split Tensile strength of ternary mix (TM6) at 28, 60 and 90 days curing, had 46.27%, 53.34 and 60.32% respectively over 7 days compressive strength for *water cement ratio* 0.55

Fig.19 shows that, the maximum Flexural strength of ternary mix (TM6) at 28, 60 and 90 days curing, had 46.84%

,55.06% and 62.19% respectively over 7 days compressive strength for *water cement ratio* 0.55

7 Conclusions

Extensive experimentation was carried out to determine the combined effect of Micro silica and GGBS on compressive, split tensile and flexural strengths of concrete at water-cement ratio 0.55, and cement replacement of 0% to 65%. The following conclusions can be derived from the present study.

1. The incorporation of Micro silica in concrete resulting in significant improvement in the early age strength of concrete. The optimum 7days strength has been obtained by 15% micro silica, but it is reduced to 10% at 28 day strength.
2. The early age strength of concrete with GGBS was lower than the control concrete. However, as the curing period is extended, the strength increases. The reason is that the pozzolanic reaction is slow and the formation of calcium hydroxide requires time.
3. The strength properties of concrete increases as the GGBS content increased up to an optimum point. Therefore it can be concluded that, there is an optimum level for the efficient use of GGBS content, which yields the highest strength. The optimum level of GGBS content for maximizing strengths is at about 30% of total binder content.
4. Addition of GGBS in concrete, beyond 30% does not improve the strength. And it can be concluded that, after certain limit, the GGBS, which could not enter into reaction, but behaves like fine aggregate. It indicates that, GGBS cannot be used efficiently as a binder, but rather as filler in the concrete.
5. The 7day compressive strength ternary concrete is maximum at 35% replacement of OPC by MS and GGBS. And it is 8.36% higher than control concrete. Whereas 28, 60 days and 90 days compressive strength is maximum at 30%, it is 21.02%, 22.84 and 24.56 respectively.
6. The percentage increase in compressive strength of ternary concrete is 67.32%,76.20% and 87.27% when compared to 7 day strength
7. Split tensile strength of ternary concrete is maximum at 35% replacement of OPC by MS and GGBS, which 5.39% higher than control concrete at 7 day curing. But it is 15.47%, 18.10% and 21.44 % higher than control concrete at 30% replacement of cement at 28days, 60 Days and 90 days respectively.
8. The percentage increase in split tensile strength of ternary concrete is 46.28%,53.35% and 60.33% when compared to 7 day strength
9. The 7 day Flexural strength of ternary concrete is maximum at 35% replacement of cement, and it is 6.05% higher than control concrete. Whereas 28 days ,60 Days and 90 days strength was obtained at 30% replacement, which are 16.52%,18.91% and 22.24% respectively.
10. The percentage increase in Flexural strength of ternary concrete is 46.85,55.07% and 62.19% when compared to 7 day strength

From the above investigation, an effective and efficient ternary concrete can produce by using mineral admixture (Micro silica and GGBS). In ternary blended concrete Micro silica acts filler and GGBS controls workability. Therefore, this combination is more effective in improving the properties of ternary blended concrete. It was observed that the combination of Micro silica and GGBS not only enhances the Compressive, Split tensile and Flexural strengths but also many other beneficial properties like durability, better crack resistance, low permeability, cost effectiveness etc. therefore the Triple blended concrete is quite suitable for high performance concrete.

Recommendations

From the above cited test results, the authors recommending the use of Micro silica and GGBS in the ternary concrete mix TM6 (C60%+MS10%+GGBS30%) to get economical and durable concrete.

Acknowledgments

The experimental work was carried out at the laboratories of Concrete and High way Materials, in CMR Technical Campus, Hyderabad. We would like to thank to Elkem South Asia pvt.ltd. Mumbai and JSW Steel Pvt. Ltd. for providing the Micro silica and GGBS.

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