AN EXPERIMENTAL STUDY ON PERFORMANCE OF TERNARY BLENDED HIGH STRENGTH HYBRID FIBRE REINFORCED CONCRETE

B.TEJA[1], T. Jeevan Kumar[2] P. Bala Krishna[3]

[1]Student, KMM Engineering College
[2] Assistant Professor, Dept. of Civil Engineering, KMM Engineering College
[3]Assistant Professor, Head of the Dept. of Civil Engineering, KMM Engineering College

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Abstract - Over the past several decades, extensive research work is in progress throughout the globe in concrete technology in finding alternative materials which can partially or fully replace ordinary Portland cement (OPC) and which can also meet the requirements of strength and durability aspects. Amongst the many alternative materials tried as partial cement replacement materials, the strength, workability and durability performance of industrial by products like flyash, blast furnace slag, silica fume, metakaolin, rice husk ash, etc., now termed as complimentary cementitious materials (CCM) are quite promising. Subsequently, these have led to the development of binary, ternary and tertiary blended concretes depending on the number of CCM and their combinations used as partial cement replacement materials. In the present experimental investigation a mix design high strength concrete of M60 is tried using triple blending technique with ternary blend of ground granulated blast furnace slag(GGBS) and Metakaolin (MK) as partial replacement by weight of cement at various blended percentages ranging between 0% – 30% with steel and glass fibers having aspect ratio of 80 and 150. The various proportions of fibers are added at 0.5%, 1.0%, 1.5% and 2% as total fiber percentages. The results of fiber reinforced specimens with various percentages of ternary blend are compared with control specimens to study the behavior of FRC properties with various percentages of the blends as partial replacement by weight of cement.

***Key Words*: Compressive strength, Fine aggregate, Fibers, Flexural Strength, concrete.**

1. INTRODUCTION

Concrete is the mostly used material in various types of construction, from the flooring of a hut to a multi storied high rise structure from pathway to an airport runway, from an underground tunnel and deep sea platform to high-rise chimneys and TV Towers. In the last millennium concrete has demanding requirements both in terms of technical performance and economy while greatly varying from architectural masterpieces to the simplest of utilities. It is the most widely used construction materials. It is difficult to point out another material of construction which is as versatile as concrete. High strength concrete is used extensively throughout the world like in the oil, gas, nuclear and power industries are among the major uses. The application of such concrete is increasing day by day due to their superior structural performance, environmental friendliness and energy conserving implications. Apart from the usual risk of fire, these concretes are exposed to high temperatures and pressures for considerable periods of times in the above mentioned industries. Applications of mineral admixtures such as silica fume, metakaolin and ground granulated blast furnace slag in concrete are effective easy to future increase the strength and make durable for high strength concrete.

1.1 TRIPLE BLENDED CONCRETE

Triple blended concretes belong to that strata of concretes where the strength and durability characteristics are maximized to the highest extent possible, in comparison to various other types of concretes, by subtle tailoring of its chemical composition, fineness and particle size distribution. Greater varieties are introduced by the incorporation of additives like pozzolana, granulated slag or inert fillers. These lead to different „specification‟ of cements in national and international standards. In simple words, triple blended cement is characterized by part replacement of cement with mineral admixtures/additives such as pozzolanic admixtures (fly ash, silica fume, granulated slag etc.) or inert fillers. The corresponding concrete is termed as triple blended concrete. These admixtures are found to enhance the physical, chemical and mechanical properties of the concrete i.e. in terms of its strength parameters (compressive and flexural) as well as durability parameters.

1.2 FIBRE REINFORCED CONCRETE

Concrete has become so popular and indispensable, as aforementioned, due to its inherent characteristics and advantages. The use of reinforcement in concrete brought a revolution in the application of concrete. However generally, despite this, compared to other building materials such as metals and polymers, concrete is significantly more brittle and exhibits a poor tensile strength. Based on fracture toughness values, steel, in the form of reinforcement, is at least 100 times more resistant to crack growth than concrete. Concrete in service thus cracks easily, and this cracking creates easy access routes for deleterious agents resulting in early saturation, freeze-thaw damage, scaling, discoloration and steel corrosion. The concerns with the inferior fracture toughness of concrete are mitiagated to a large extent by reinforcing it with fibres of various materials. The resulting material with a random distribution of short, discontinuous fibres is termed fibre reinforced concrete (FRC).

2. POZZOLANAS

Pozzolans are defined as siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. The quantification of the capacity of a pozzolan to react with calcium hydroxide and water is given by measuring its pozzolanic activity Pozzolana are naturally-occurring pozzolans of volcanic origin.

3. METAKAOLIN (MK)

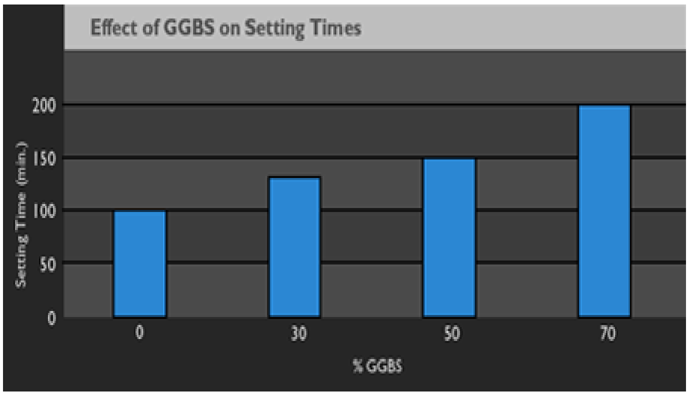
The raw material input in the manufacture of metakaolin is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. It is thought that the term kaolin is derived from the Chinese Kaoline ,which translates loosely to white hill and has been related to the name of a mountain in China. Kaolinite is the mineralogical term that is applicable to kaolin clays

Table 1 Physical properties of Metakaolin

Specific gravity	2.4 to 2.6
Physical form	Powder
Colour	Off white, Gray to Buff
Brightness	80-85 HunterL
BET	15m2/gram
Specific surface	8-15 m2/g

4. SETTING TIME

The setting time of concrete is influenced by many factors, in particular temperature and water/cement ratio. With GGBS, the setting time will be extended slightly, perhaps by about 30 minutes. The effect will be more pronounced at high levels of GGBS and/or low temperatures. An extended setting time is advantageous in that the concrete will remain workable longer and there will be less risk of cold joints. This is particularly useful in warm weather.



5. CRIMPED STEEL FIBERS

In the present investigation Ultratech Ordinary Portland Concrete is the most widely used structural material in the world is prone to cracking for a variety of reasons. These reasons may be attributed to structural, environmental or even economics factors, but most of the cracks are formed due to the inherent weakness of the material to resist tensile forces. When concrete shrinks, and it is restrained, it will crack. Steel fiber reinforcement offers solution to the problem of cracking by making concrete tougher and more ductile. R & D and field trials over three decades have proved that addition of steel fibers to conventional plan or reinforced and pre-stressed concrete member at the time of mixing / production in parts strength, performance and durability of concrete.

Table -2: Physical properties of CRIMPED STEEL FIBERS

Description	Range of ultimate tensile strength (Mpa)	Minimum ultimate strength as per ASTM-A820 (Mpa)
Steel fibers (0.45 to 1.00mm diameter)	840 to 1250	345

6. GLASS FIBRE

The glass fibres used are from Owens Corning located at Thimmapur, Telangana with modulus of elasticity 72 GPa, Filament diameter 140 microns, specific gravity 2.68, length 15 mm and aspect ratio of 150.

a) Reduction in bleeding is observed by addition of glass fibres in the glass fibre concrete mixes;

b) A reduction in bleeding improves the surface integrity of concrete, improves its homogeneity and reduces the probability of cracks;

c) The percentage increase of compressive strength of various grades of glass fibre concrete mixes compared with 28 days compressive strength is observed from 20 to 25% and

d) The percentage increase of flexural and split tensile strength of various grades of glass fibre concrete mixes compared with 28 days is observed from 15 to 20%.

7. SUPER PLASTICIZER

The super plasticizer used in this experiment is SP430 DIS. It is manufactured by FOSROC. Super plasticizers are new class of generic materials which when added to the concrete causes increase in the workability. They consists mainly of naphthalene or melamine sulphonates, usually condensed in the presence of formaldehyde. Super plastised concrete is a conventional concrete containing a chemical admixture of super plasticizing agent. It enhances workability state to make reduction in water cement ratio of super plasticized concrete, while maintaining workability of concrete. The use of super plasticizers in ready mixed concrete and construction reduces the possibility of deterioration of concrete for its appearance and density. On the other hand, it makes the placing of concrete more economical by increasing productivity at the construction site.

Conplast SP430 Superplasticising admixture:

7.1 Description

Conplast SP430 is based on SulphonatedNapthalene Polymersand supplied as a brown liquid instantly dispersible in water.Conplast SP430 has been specially formulated to give highwater reductions upto 25% without loss of workability or toproduce high quality concrete of reduced permeability.

7.2 Properties

- **Specific gravity** 1.220 to 1.225 at 30^{0}C
- **Chloride content** Nil

Air entrainment Approx. 1% additional airis entrained

- **Compatibility**: Can be used with all types of cements excepthigh alumina cement. Conplast SP430 is compatible with other types of Fosroc admixtures when added seperately to the mix.Site trials should be carried out to optimise dosages.
- **Workability** : Can be used to produce flowing concrete thatrequires no compaction. Some minor adjustments may berequired to produce high workable mix without segregation.
- **Cohesion** : Cohesion is improved due to dispersion of cementparticles thus minimising segregation and improving surface finish.
- **Compressive strength** : Early strength is increased upto 20%if water reduction is taken advantage of. Generally, there isimprovement in strength upto 20% depending upon W/C ratioand other mix parameters.
- **Durability** : Reduction in W/C ratio enables increase in densityand impermeability thus enhancing durability of concrete.

8. MIX DESIGN OF M60 GRADE CONCRETE

8.1 DESIGN STIPULATION

Target strength = 60 Mpa
Max size of aggregate used = 20 mm

Data Obtained from test results of material:

Specific gravity of cement = 3.12
Specific gravity of fine aggregate (F.A) = 2.59
Specific gravity of Coarse aggregate (C.A) = 2.77
Bulk Density of fine aggregate = 1627 Kg/m^3
Bulk Density of coarse aggregate = 1460 Kg/m^3

Step-1
Calculation for weight of Coarse Aggregate:

From ACI 211.4R Table 4.3.3 Fractional volume of oven dry C.A for 20 mm size aggregate is 0.712m^3
Weight of C.A = 0.712*1460 = 1158.424 Kg/m^3

Step-2
Calculation for Quantity of Water:

From ACI 211.4R Table 4.3.4
Assuming Slump as 50 to 75mm and for C.A size 20mm the Mixing water = 132.66 ml
Void content of FA for this mixing water = 35%
Void content of FA (V)
V = {1-(Dry unit wt / specific gravity of FA*1000)}*100
= [1-(1627/2.59*1000)]*100
= 37.18%

Adjustment in mixing water = (V-35)* 4.55
= (37.18 – 35)*4.55
= +0.099 ml
Total water required = 132.66 + 0.099 = 132.765ml

Step-3
Calculation for weight of cement

From ACI 211.4R Table 4.3.5(b)
Take W / C ratio = 0.29
Weight of cement = 132.765 / 0.29 = 457.81 kg/m^3

Step-4
Calculation for weight of Fine Aggregate:

Cement = 457.81 / 3.12*1000= 0.1467
Water = 132.765 / 1*1000= 0.1327
CA = 1158.424 / 2.77*1000= 0.4182
Entrapped Air = 4 / 100= 0.040
Total = 0.7286 m^3
Volume of Fine Aggregate= 1-0.7286=0.2714
Weight of Fine Aggregate= 0.2714*2.59*1000= 702.926 kg/m^3

Step-5
Super plasticizer:

Adjustments for water
For 1% = (1 / 100)*457.81*1.22 = 5.585 ml

Step-6
Correction for water:

Weight of water (For 01%) =132.765– 5.585 =127.18kg/m^3

Requirement of materials per Cubic meter

Cement = 457.81 Kg/m^3
Fine Aggregate = 702.926 Kg/m^3
Coarse Aggregate = 1158.424 Kg/m^3
Water = 127.18 Kg/ m^3
Super plasticizers = 5.585 / m^3

So the final ratio becomes
Cement: Fine aggregate (kg/m^3): Coarse aggregate (kg/m^3): Water (l/m^3): Super plasticizer (l/m^3).

1: 1.535 :2.53 :0.28 :1

9. SCOPE AND PRESENT STUDY

In the present experimental investigation a mix design high strength concrete of M60 using American Concrete Institute (ACI) method is tried using triple blending technique with ternary blend of ground granulated blast furnace slag(GGBS) and Metakaolin (MK) as partial replacement by weight of cement at various blending percentages ranging between 0% – 30% with additional steel and glass fibers having aspect ratio of 80 and 150. The various proportions of fibers are added at 0.5%, 1.0%, 1.5% and 2% as total fiber percentages.The results of fiber reinforced specimens with various percentages of ternary blend are compared with control specimens to study the behavior ofFRC properties with various percentages of the blends as partial replacement by weight of cement. Also by using this technique of ternary blended concrete high strength concrete is produced at reasonable price than that of conventional concrete.

10. EXPERIMENTAL INVESTIGATION

Mix	Cement (%)	Fibers (%)	Metakaolin (%)	GGBS (%)
M0G0	100	0	0	0
M0G30	70	0	0	30
M5G25	70	0	5	25
M10G20	70	0	10	20
M15G15	70	0	15	15
M20G10	70	0	20	10
M25G5	70	0	25	5
M30G0	70	0	30	0
M10G20F0.5	70	0.5	10	20
M10G20F1	70	1	10	20
M10G20F1.5	70	1.5	10	20
M10G20F2	70	2	10	20

M=Metakolin ; G=GGBS ; F = Steel Fiber and Glass Fiber

SPECIMENS REQUIRED:

- Combinations : 12
- No of samples per combination : 9 (6 cubes & 3 cylinders)
- Total no of samples : 9*12=108

10.1 TEST RESULTS OF M60 WITH DIFFERENT REPLACEMENTS

10.2M60 GRADE CONCRETE WITH M0 G0 F0:

Table 3 Compressive strength of cubes M0 G0 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	37.34	34.36	67.77	64.82
2	34.66		64.511	
3	31.12		62.17	

Table 4 Tensile strength of cylinders M0 G0 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	5.2	5.23
	2	5.8	
	3	4.7	

10.3 M60 GRADE CONCRETE WITH M0 G30 F0:

Table 5 Compressive strength of cubes M0 G30 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	57.38	56.86	75.33	73.21
2	54.62		70.98	
3	58.58		73.33	

Table 6 Tensile strength of cylinders M0 G30 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	5.42	5.13
	2	4.41	
	3	5.55	

10.4 M60 GRADE CONCRETE WITH M5 G25 F0:

Table 7 Compressive strength of cubes M5 G25 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	62.44	61.91	72.98	75.30
2	59.69		73.07	
3	63.60		79.87	

Table 8 Tensile strength of cylinders M5 G25 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	5.96	5.64
	2	4.92	
	3	6.03	

10.5 M60 GRADE CONCRETE WITH M10 G20 F0:

Table 9 Compressive strength of cubesM10 G20 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	64.84	64.24	76.22	77.17
2	62		74.93	
3	65.87		80.36	

Table 10 Tensile strength of cylinders M10 G20 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	6.28	5.94
	2	5.23	
	3	6.31	

10.6 M60 GRADE CONCRETE WITH M15 G15 F0

Table 11 Compressive strength of cubesM15 G15 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	63.78	65.20	76.76	79.64
2	62.98		77.42	
3	68.84		84.76	

Table 12 Tensile strength of cylinders M15 G15 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	7.03	6.65
	2	5.94	
	3	6.99	

10.7 M60 GRADE CONCRETE WITH M20 G10 F0:

Table 13 Compressive strength of cubesM20 G10 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	64.23	63.13	78.62	79.23
2	64.15		77.85	
3	61		81.23	

Table 14 Tensile strength of cylinders M20 G10 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	5.12	6.26
	2	6.73	
	3	6.94	

10.8 M60 GRADE CONCRETE WITH M25 G5 F0

Table 15 Compressive strength of cubesM25 G5 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	70	69.35	82.31	81.79
2	67.11		79.56	
3	70.93		83.51	

Table 16 Tensile strength of cylinders M25 G5 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28-days	1	7.20	6.81
	2	6.10	
	3	7.13	

10.9 M60 GRADE CONCRETE WITH M30 G0 F0

Table 17 Compressive strength of cubesM30 G0 F0

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	67	65.68	78.13	77.64
2	63.13		75.65	
3	66.92		79.15	

Table 18 Tensile strength of cylinders M30 G0 F0

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28-days	1	6.49	6.51
	2	6.13	
	3	6.92	

10.9.1M60 GRADE CONCRETE WITH M10 G20 F0.5:

Table 19 Compressive strength of cubesM10 G20 F0.5

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	63.60	64.41	76.44	76.40
2	62.18		74.18	
3	67.47		78.58	

Table 20 Tensile strength of cylinders M10 G20 F0.5

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	6.51	6.87
	2	7.56	
	3	6.54	

10.9.2 M60 GRADE CONCRETE WITH M10 G20 F1:

Table 21 Compressive strength of cubesM10 G20 F1

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	68.84	68.46	80.67	78.81
2	66.22		76.58	
3	70.31		79.20	

Table 22 Tensile strength of cylinders M10 G20 F1

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28-days	1	7.19	7.11
	2	6.39	
	3	7.74	

10.9.3 M60 GRADE CONCRETE WITH M10 G20 F1.5:

Table 23 Compressive strength of cubesM10 G20 F1.5

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	68.53	71.79	76.53	79.56
2	69.56		77.33	
3	77.29		84.80	

Table 24 Tensile strength of cubesM10 G20 F1.5

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	7.87	8.20
	2	7.48	
	3	9.24	

10.9.4 M60 GRADE CONCRETE WITH M10 G20 F2

Table 25 Compressive strength of cubesM10 G20 F2

S. No	Compressive Strength in MPa			
	7-days of curing	Average of 7-days	28-days of curing	Average of 28-days
1	69.42	68.31	76.53	79.57
2	66.09		77.33	
3	69.42		84.84	

Table 26 Tensile strength of cylinders M10 G20 F2

Age of cubes cured	Cylinder no	Split tensile strength in MPa	Average tensile strength in (MPa)
28- days	1	7.48	8.24
	2	7.53	
	3	9.7	

11. DISCUSSION OF RESULTS

The present experimental investigation on the strength properties of triple blended hybrid fibres reinforced mixes has been carried out. The results obtained are shown by tables.

The values of 7days and 28days compressive strength and 28days split tensile strength for various percentages of Metakaolin and GGBS are used as a replacement to cement in M60 grade concrete mix used in present investigation Different steel fibres and glass fibres are combined in percentages like 0%, 0.5%,1%, 1.5% & 2% were used in each case respectively.

12. CONCLUSIONS

The following conclusions may be drawn based on the observation made in the present experimental study on performance evaluation of ternary blended hybrid fiber reinforced concrete.

- Higher dosages of superplasticizer are required for high strength concrete mixes particularly when mineral admixtures and fibres were employed to maintain workability.
- For this combination of 10% Metakaolin with 20% GGBS the compressive strength has shown an increase from 19.06 to 22.76 % with various percentages of fibre
- 20% GGBS generates marginal increase in strength. To compensate for the loss of strength when higher percentages of GGBS is used Metakaolin is added
- As the percentage of steel and glass fibre are increased there is marginal increase in the compressive strength for all the combinations
- For this combination of 10% Metakaolin with 20% GGBS the tensile strength has shown an increase from 13.54 to 57.42 % with various percentages of fibre
- As the percentage of steel and glass fibre are increased there is higher increase in the tensile strength. For a mix with 2% fibers the tensile strength obtained was 8.24MPa. The tensile strength of the reference mix without any mineral admixtures and without fibre was obtained as 5.23MPa.
- By cost analysis it is found that the triple blended high strength hybrid reinforced concrete for Metakaolin+GGBS (0+30%) showed a decrease in cost by 16.52% without compromising the strength compared to normal mix and addition of fibers were not economical.
- M60 with GGBS replacing 30% of cement is considered optimum mix and adding certain fibres would help in improving durability properties.
- An optimum high strength concrete mix possessing optimum strength properties can be obtained resorting to triple blending.

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