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AN EXPERIMENTAL STUDY ON TERNARY BLENDED HIGH STRENGTH HYBRID FRC

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ABSTRACT

Recently, research on investigating alternative material as cement substitute becomes a massive issue in construction industry. Previous research proved that utilizing cement contribute bad environment effect due to high CO2 emitted during its production Hence, reducing cement use by replacing or substituting it with other eco green material will be an enable solution for a better future.

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.

Keywords: Triple blended concrete, Metakaolin, GGBS, Crimped steel fibers, Glass fibers, Triple blended high strength concrete Super plasticizers (Conplast SP430)

INTRODUCTION

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 [1-8].

Triple blended concrete

- This presentation investigates the use of triple-blend cementitious mixtures with silica fume, now widely used in the production of high performance concrete.
- These high performance triple-blend mixtures are often comprised of Portland cement + fly ash + silica fume, or Portland cement + GGBS + silica fume.
- It is concluded that a triple-blend approach to high performance concrete mix design can enable cost savings, increased performance and improved sustainability.

Triple blended concretes belong to that stratum 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 characterised by part replacement of cement with mineral

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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.

Triple blended high strength concrete

The American Concrete Institute defines high strength concrete as a type of concrete generally with a specified compressive strength of 6000psi (41 MPa) or greater.

At the commencement of a concrete construction, the exposure conditions generally decide the type of cement. Based of load-carrying capacity, required strength grade of concrete and strength class of cement are decided. Thus, in order to meet all these requirements, incorporation of high strength concrete into a new effective concept of triple blended concretes is considered a needful solution. The objective of doing so is to optimize the thrust in strength and durability parameters achieved by both triple blended cements as well as high strength concrete to obtain what is known as triple blended high strength concrete.

MATERIALS AND METHODOLOGY

Materials

Cement

Cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together. Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete.

Table 2.1: Chemical composition of cement

Calcium oxide (CaO)	59 – 64%
Silica oxide (SiO_2)	19 – 24%
Aluminum oxide (Al_2O_3)	3 – 6%
Ferric oxide (Fe_2O_3)	1 – 4%
Magnesia (MgO)	0.5 – 4%

Coarse aggregate (CA)

The material whose particles are retained on IS sieve no 4.75mm is termed as coarse aggregate. The size of coarse aggregate is 20mm, crushed and angular in shape. The aggregates are free from dust before used in the concrete.

Fine aggregates (FA)

Natural Sand of particle size less than IS sieve 4.75mm is taken. Sand may be obtained from rivers, lakes but when used in concrete mix, it should be properly washed and tested to ascertain that total percentage of clay silt and other organic matters doesn’t exceed the specified limit.

Metakaolin (MK)

The raw material input in the manufacture of MK is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain.MK when used as a partial replacement substance for cement in concrete, it reacts with $Ca(OH)_2$ one of the by-products of hydration reaction of cement and results in additional C-S-H gel which results in increased strength. MK is obtained by thermal activation of kaolin clay. To obtain an adequate thermal activation, the temperature range should be established between 600 to 750ºC. Chemical formula of MK is $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. Calcium hydroxide is one of the by-products of hydration reaction of cement. When cement is partially replaced with MK, it reacts with calcium hydroxide and results in extra C-S-H gel. C-S-H gel is the sole cause for strength development in cement and cement based concrete.

Cement + Water = C-S-H gel + Ca $(OH)_2$

Ca $(OH)_2$+ MK = C-S-H gel

Figure 3.3: Metakaolin

Table 2.2: Physical Properties of Metakaolin

Specific gravity	2.4 – 2.6
Physical form	Powder
Colour	Off white, grey to buff
Brightness	80 – 85 hunterl
Bet	15 m^2/g
Specific surface	8 – 15 m^2/g

Table 2.3: Chemical properties of MK

Particles	FA % by mass	MK % by mass
SiO2	35.91	31
Al2O3	16.02	53.5
CaO	14.43	1.1
Fe2O3	12.34	6.58
K2O	1.28	5.79
MgO	9.09	0.12
Na2O	5.87	0.04
TiO2	0.66	0.919

GGBS:Ground-granulated blast-furnace slag

GGBS is obtained by quenching molten iron slag, a by-product of iron and steel making from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder.

It has been utilized for many years as an additional cementitious material in Portland cement concretes, either as a mineral admixture or as a component of blended cement. GGBS typically replaces 35–65% Portland cement in concrete. The use of GGBS as a partial replacement of ordinary Portland cement improves strength and durability of concrete by creating a denser matrix and thereby increasing the service life of concrete structures. It has a higher proportion of the strength-enhancing Calcium Silicate Hydrates (CSH) than concrete made with Portland cement only, and a reduced content of free lime, which does not contribute to concrete strength.

Setting times will increase with increasing GGBS content, although factors such as curing temperature and w/c ratio also need to be considered. The longer setting time has the advantage of allowing concrete to be worked for longer periods: thus time delays, including delays in transport, between mixing and using concrete are less critical. It also reduces the risk of cold joints in larger concrete pours.

GGBS

Crimped steel fibers

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.

The fibers are factory – crimped to improve bonding characteristics with concrete and are available in diameters ranging from 0.45mm to 1.00m and length from 25mm to 60mm and aspect ratios are from 40 to 130.

When steel fibers are added to concrete, the results are tougher, more durable and superior concrete than when reinforced with conventional steel bars and mesh. The steel fibers are uniformly dispersed inside the entire mass of concrete creating a new breed of construction material steel fibers reinforced concrete.

- Fatigue and impact resistance increased
- Wear and tear resistance increased

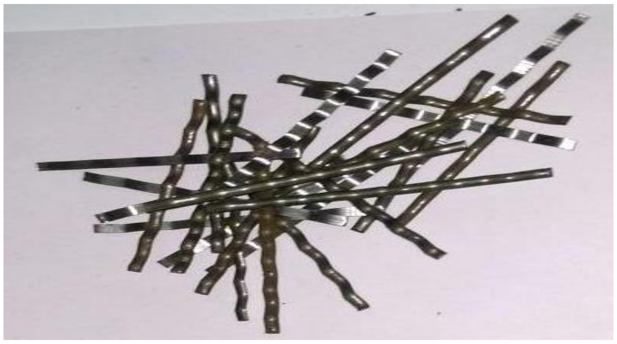


Figure 2.5: Crimped steel fibers

Glass fibers

The glass fibers used has 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 fibers which improves the surface integrity of concrete, homogeneity and reduces the probability of cracks.
- The percentage increase of compressive strength of various grades of glass fiber concrete mixes compared with 28 days compressive strength is observed from 20 to 25% and

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

Figure2.6: Glass fibers

Super plasticizers

Super plasticizers are new class of generic materials which when added to the concrete causes increase in the workability. The super plasticizer used in this experiment is SP430 DIS. It is manufactured by FOSROC. Conplast SP430 is based on SulphonatedNapthalene Polymers and supplied as a brown liquid instantly dispersible in water. Conplast SP430 has been specially formulated to give high water reductions upto 25% without loss of workability or to produce high quality concrete of reduced permeability. They consist mainly of naphthalene or melamine sulphonates, usually condensed in the presence of formaldehyde. Super plasticised concrete is a conventional concrete containing a chemical admixture of super plasticizing agent.

Properties

- Specific gravity 1.220 to 1.225 at 300C.
- Chloride content nil.

Uses

- To produce high strength, high grade concrete M30 and above by substantial reduction in water resulting in low permeability and high early strength.
- To produce high workability concrete requiring little or no vibration during placing.

APPLICATION INSTRUCTIONS

Dosage

The optimum dosage is best determined by site trials with the concrete mix which enables the effects of workability, strength gain or cement reduction to be measured. Site trials with Conplast SP430 should always be compared with mix containing no admixture. As a guide, the rate of addition is generally in the range of 0.5 - 2.0 litres /100 kg cement.

Over dosing

An over dose of double the recommended amount of Conplast SP430, will result in very high workability and some retardation of setting time will occur. However, the ultimate compressive strength will not be impaired.

Figure 2.7: Super plasticizer

MIX DESIGN OF M60 GRADE CONCRETE

Results and tests

Preliminary tests

In the first stage of the project work, the theoretical investigation and literature review are carried out and the following results are obtained.

a. The specific gravity of the cement = 3.12
b. The specific gravity of the fine aggregate = 2.59
c. The specific gravity of the coarse aggregate = 2.77
d. The Specific gravity of the MK = 3.2
e. The Specific gravity of the GGBS = 2.77
f. Fineness modulus of the fine aggregate = 2.93
g. Fineness modulus of the coarse aggregate = 6.99
h. Water-cement ratio = 0.29
i. Weight of cement = 457.8 kg/m^3
j. Weight of fine aggregates = 702.926 kg/m^3
k. Weight of coarse aggregates = 1158.424 kg/m^3
l. Quantity of water = 127.18 kg/m^3
m. Quantity of super plasticizer = 5.585 kg/m^3

Final ratio of mix proportion for M60 grade concrete is obtained as **1: 1.535: 2.53**

Test results of Cubes

The tests on cubes were conducted for its compressive strength at 7 days and 28 days curing. The average strength of cubes are recorded for each proportions of Metakaolin to GGBS along with super plasticiser and conventional M60 concrete.

Compressive Strength of Cubes

The Compressive strengths of the concrete cube mixes using 0% to 30% replacement of cement with MK and GGBS, sand with fibers are compared with conventional concrete of grade M60.

Casting of concrete samples

There are total no of 12 concrete combinations.

1. M0G0F0
2. M0G30F0
3. M5G25F0
4. M10G20F0
5. M15F15F0
6. M20F10F0
7. M25G5F0
8. M30G0F0
9. M10G20F0.5
10. M10G20F1
11. M10G20F1.5
12. M10G20F2

Table 4.9: Concrete mix combinations

S.no	Sample representation	Cement %	Fibre %	Metakaolin %	GGBS %
S1	M0G0F0	100	0	0	0
S2	M0G30F0	70	0	0	30
S3	M5G25F0	70	0	5	25

S4	M10G20F0	70	0	10	20
S5	M15G15F0	70	0	15	15
S6	M20G10F0	70	0	20	10
S7	M25G5F0	70	0	25	5
S8	M30G0F0	70	0	30	0
S9	M10G20F0.5	70	0.5	10	20
S10	M10G20F1	70	1	10	20
S11	M10G20F1.5	70	1.5	10	20
S12	M10G20F2	70	2	10	20

Compressive strength of concrete samples

Table 1: Compressive Strength Result of Cubes

Sample	Average 7-days Compressive strength (MPa)	Percentage increase or decrease	Average 28-days Compressive Strength (MPa)	Percentage increase or decrease
S1	44.37		64.82	
S2	56.86	+28.14	73.21	+12.95
S3	61.91	+39.52	75.30	+16.17
S4	64.24	+44.76	77.17	+19.05
S5	65.20	+46.94	79.64	+22.87
S6	63.13	+42.26	79.23	+22.24
S7	69.35	+56.28	81.79	+26.19
S8	65.68	+48.02	77.64	+19.78

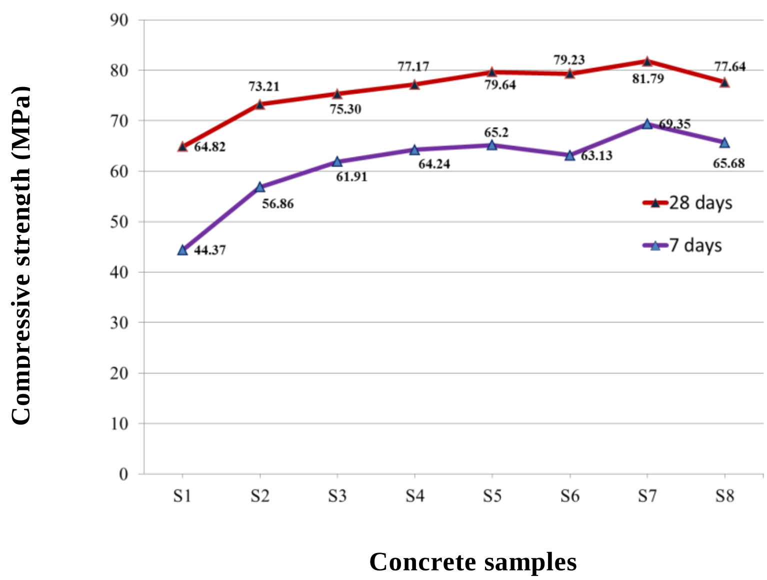


Figure: Compressive strength of concrete samples

Comparison of Compressive strength between conventional concrete (cc) and TBFRC

Table 2: Comparison of strength between CC and TBFRC

Sample	Average 7-days Compressive strength (MPa)	Percentage increase or decrease	Average 28-days Compressive Strength (MPa)	Percentage increase or decrease
S1	44.37		64.82	
S9	64.41	+45.17	76.40	+17.87
S10	68.46	+54.28	78.81	+21.59
S11	71.79	+61.79	79.56	+22.73
S12	68.31	+53.95	79.57	+22.76

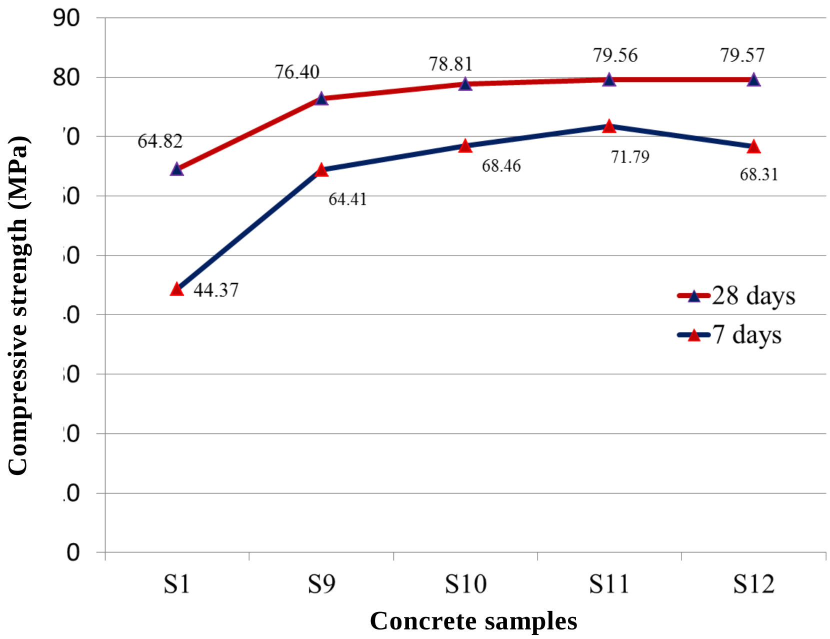


Figure 2 : Comparison of compressive strength between CC and TBFRC

Comparison of Compressive strength between TBC and TBFRC

Table 3: Comparison of strength between TBC nad TBFRC

Sample	Average 7-days Compressive strength (MPa)	Percentage increase or decrease	Average 28-days Compressive Strength (MPa)	Percentage increase or decrease
S4	64.24		77.17	
S9	64.41	+0.26	76.40	-0.99
S10	68.46	+6.56	78.81	+2.12
S11	71.79	+11.75	79.56	+3.09
S12	68.31	+6.33	79.57	+3.10

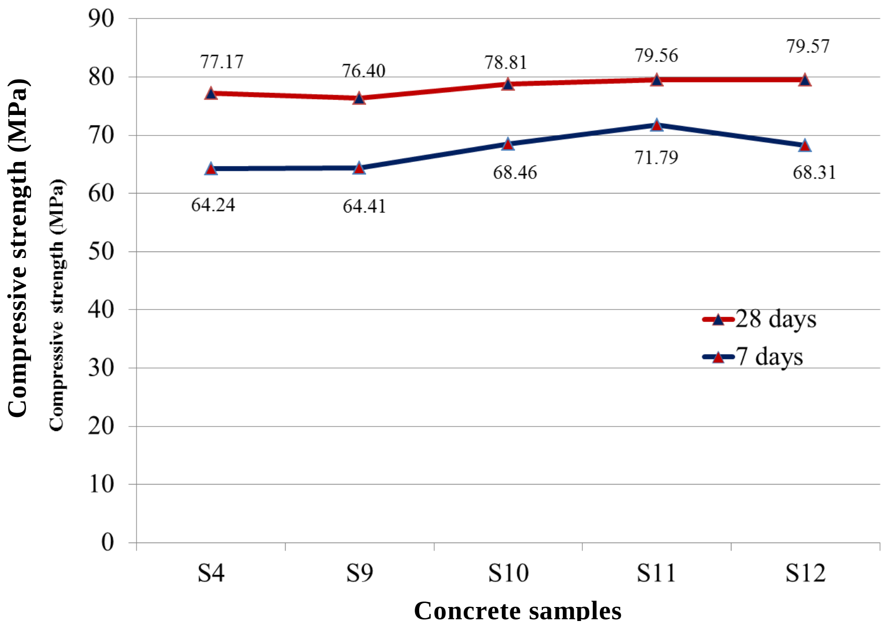


Figure 3: Comparison of compressive strength between TBC and TBFRC

Test results of Cylinders

The test on cylinders was conducted for its split tensile strength at 28 days curing. The average strength of cylinders was recorded for each category of cement replacement concrete with Metakaolin, GGBS, steel fibers and glass fibers along with super palsticiser and M60 conventional concrete.

Split tensile Strength of Cylinders

The Split tensile strengths of the concrete cylinder mixes using 0 % to 30 % replacement of cement with MK and GGBS in increments of 5, and 0% to 2% replacement with fibers are compared with conventional concrete of grade M60.

Split tensile strength of concrete samples

Table 4: Split tensile strength results of concrete samples

Sample	Average 28 days Split Tensile Strength (MPa)	Percentage increase or decrease
S1	5.23	
S2	5.10	-2.05
S3	5.64	7.68
S4	5.94	13.54
S5	6.65	27.14
S6	6.26	19.68
S7	6.81	30.12
S8	6.51	24.46

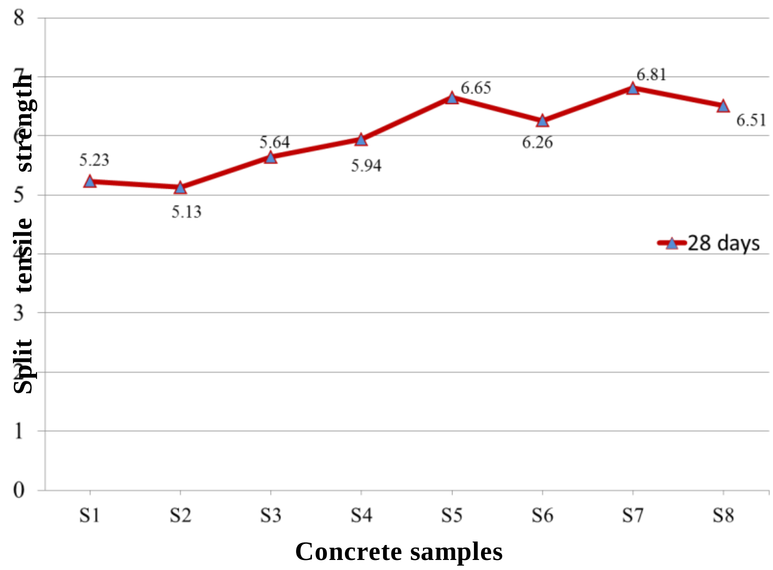
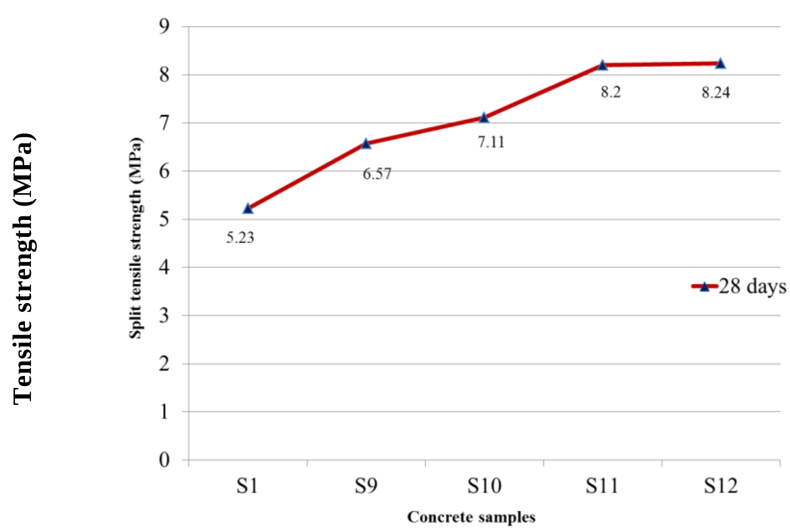


Figure 4: Split tensile strength of concrete mixes

Comparison of tensile strength between CC and TBC

Table 5: Comparison of tensile strength between CC and TBC

Sample	Average 28 days Split Tensile Strength (MPa)	Percentage increase or decrease
S1	5.23	
S9	6.57	+17.86
S10	7.11	+35.79
S11	8.20	+56.61
S12	8.24	+57.42



Concrete samples

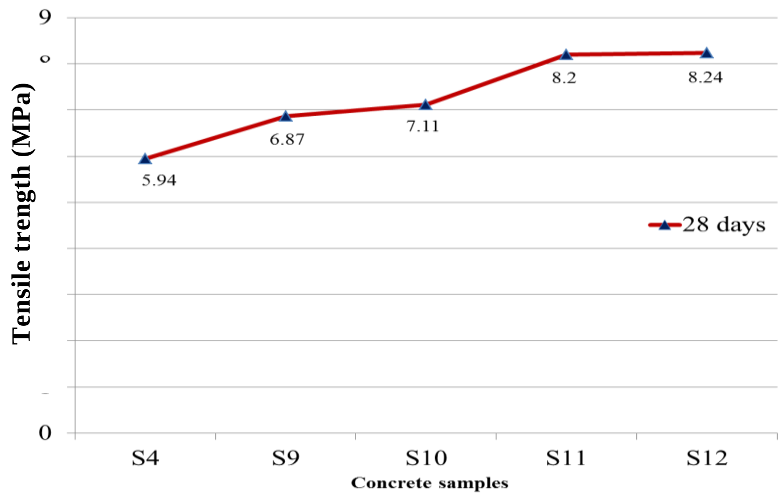
Figure Comparison of tensile strength between CC and TBC

Comparison of tensile strength between TBC and TBFRC

Table .6: Comparison of tensile strength between TBC and TBFRC

Sample	Average 28 days Split Tensile Strength (MPa)	Percentage increase or decrease
S4	5.94	
S9	6.87	+15.6
S10	7.11	+19.6
S11	8.20	+38.04
S12	8.24	+38.72

* TBC – Teranry blended concrete
* TBFRC – Ternary blended fiber reinforced concrete



Concrete samples

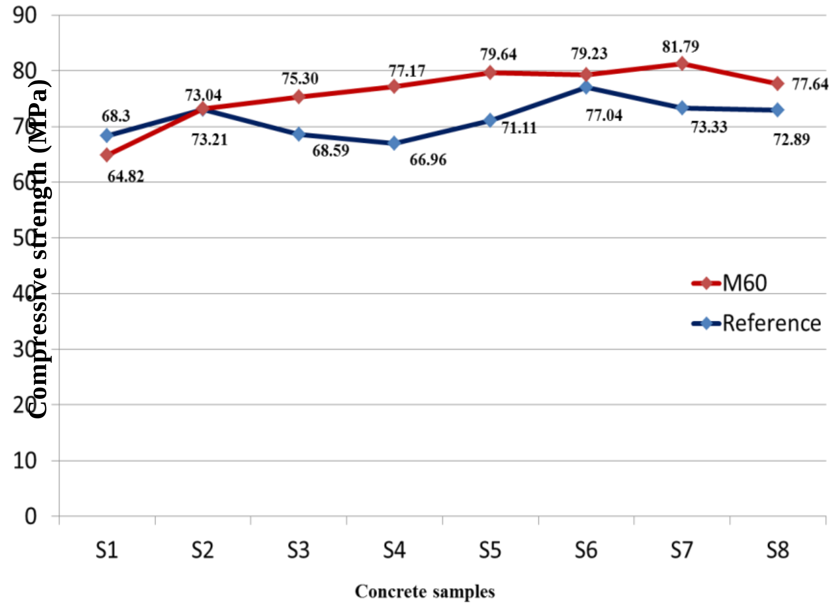
Figure 6: Comparison of tensile strength of TBC and TBFRC

Comparison of results with reference ternary blended concrete M60

The compressive strength results which are obtained for the present experimental ternary blended fiber reinforced concrete M60 are compared with reference ternary blended concrete M60. Table shows compressive strength results of M60 and reference M60 grade concrete for 28 days curing. The admixtures used in reference concrete are fly ash, alccofine. The experimental concrete shows better results than reference M60 concrete since the strength gaining capacity of the admixtures used in reference concrete is lower when compared to admixtures which are used in the present experimental study.

Table 7: Comparison of compressive strength results with reference M60 concrete

1	68.3	64.82
2	73.04	73.21
3	68.59	75.30
4	66.96	77.17
5	71.11	79.64
6	77.04	79.23
7	73.33	81.79
8	72.89	77.64



Concrete

Figure 7: Comparison of compressive strength results with reference concrete

Stress strain curves

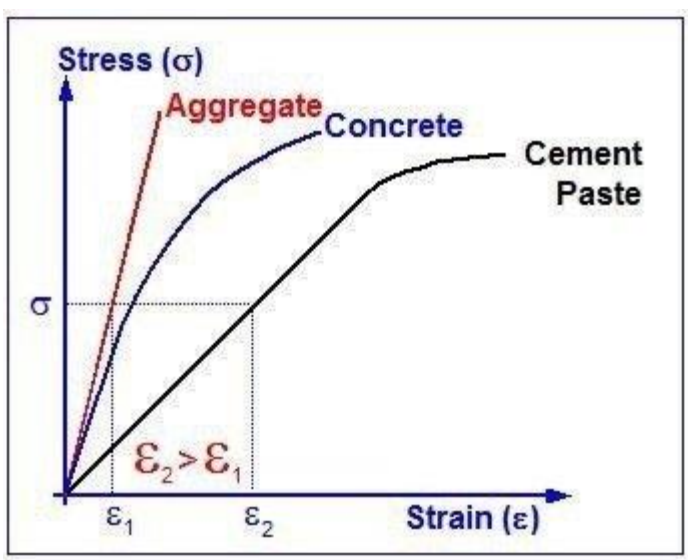


Figure 8: Stress-strain curve of concrete (ref: web source)

Comparison between conventional concrete (CC) and Sample 2

Here comparison of stress strain curves is done between conventional concrete and partially cement replaced concrete by 30% ggbs.

Table 9: Stress-strain values of cc and sample 2

Mix	**Stress (MPa)**	**Strain**
Conventional concrete (cc)	0	0
	64.82	0.00167
	0	0
S 2	73.21	0.00189

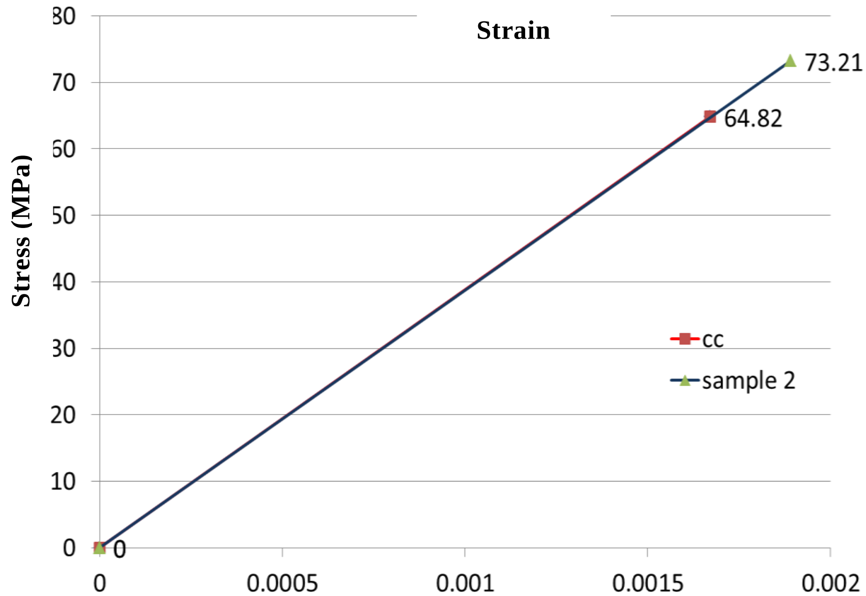


Figure 9: Comparison of stress strain curve between CC and Sample 2

From figure, it is observed that the maximum stress value for conventional concrete is 64.82 (MPa) and for sample 2 is 73.21 (MPa). The stress increases to 12.9% when cement is placed with 30% GGBS.

Comparison between Conventional concrete (CC) and Sample 5

Here comparison of stress stain curve is given between conventional concrete and sample 5 which is partially cement replaced concrete by 10% metakaolin and 20% ggbs.

Table 10: Stress strain values of cc and sample 5

Mix	**Stress (MPa)**	**Strain**
Conventional concrete (cc)	0	0
	64.32	0.00167
	0	0
S 5	77.17	0.00199

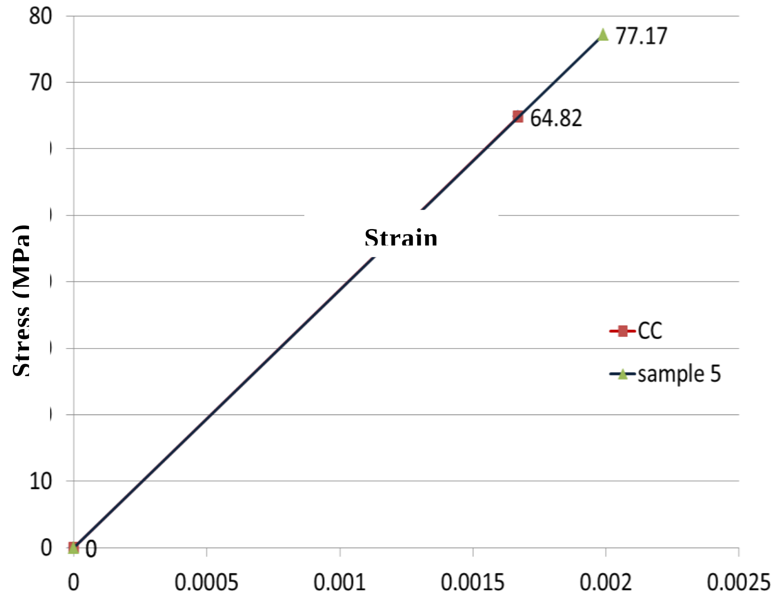


Figure .10: comparison of stress-strain curve between CC and Sample 5

From figure 5.10, the maximum stress value for conventional concrete is 64.82 (MPa) and sample 5 is 77.17 (MPa). The stress increases to 19% when cement is replaced with 20% GGBS and 10% MK.

Comparison between CC and Sample 12

Table 11: Stress-strain values of CC and S 12

Mix	Stress (MPa)	Strain
CC	0	0
	64.82	0.00167
S 12	0	0
	79.57	0.00205

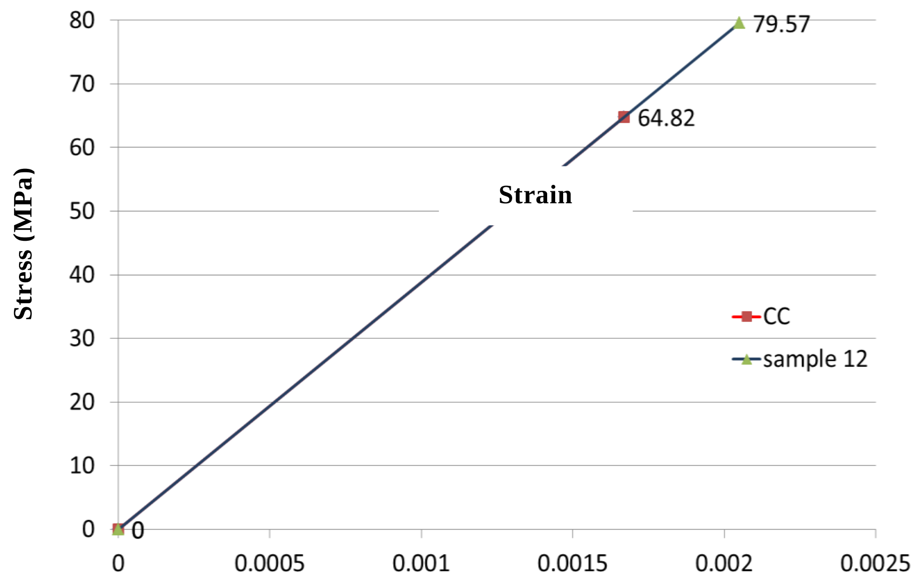


Figure11: Comparison of stress-strain curve between CC and Sample 12

The maximum stress value for conventional concrete is 64.82 (MPa) and for sample 12 is 79.57 (MPa). The stress increases to 22.7% when cement is replaced with 10% MK, 20% GGBS, 2% steel and glass fibers.

CONCLUSION

The strength of ternary blended fiber reinforced concrete has been determined in this study. Ternary blended fiber reinforced concrete is obtained by replacing cement with Metakaolin, GGBS, crimped steel fibers, glass fibers with various percentages. 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 super plasticizer are required for high strength concrete mixes particularly when mineral admixtures and fibers were employed to maintain workability.
- For the combination of 10% MK with 20% GGBS the compressive strength has shown an increase from 19.06 to 22.76 % with various percentages of fiber
- For this combination of 10% MK with 20% GGBS the tensile strength has shown an increase from 13.54 to 57.42 % with various percentages of fiber
- 20% GGBS generates marginal increase in strength. To compensate for the loss of strength when higher percentages of GGBS is used MK is added
- As the percentage of steel and glass fiber is increased there is marginal increase in compressive strength and higher increase in the tensile strength. For a mix with 2% fibers the tensile strength obtained was 8.24 MPa. The tensile strength of the reference mix without any mineral admixtures and without fiber was obtained as 5.23 MPa.
- M60 with GGBS replacing 30% of cement is considered optimum mix and adding certain fibers 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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