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Experimental Study on Strength and Durability Properties of Steel Fibers & Glass Fibers using GGBS based Concrete

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Abstract: ***Concrete is the widely used construction material in civil engineering industry due to its massive properties like high structural strength and stability. The demand and cost of cement is growing day to day, so investigators are looking for supplementary materials with the main objective of reducing solid waste disposal problem, by using waste as supplementary by maintaining the same properties or by enhancing the properties by using selected materials. The study has been made to evaluate the effect on mechanical and durability properties of M25 grade concrete made with replacement of cement with Ground Granulate Blast Furnace Slag (GGBS), (0%, 10%, 20%, 30% and 40%) by weight and the addition of Steel fiber in different percentages (0%, 0.5%, 1%, 1.5% and 2%) and glass fiber in different percentages (0%, 0.1%, 0.2%, 0.3%, 0.4%). For each set of fibers, mechanical properties were studied by performing Compression test for Cubes, Flexural test for beams and Split Tensile test for cylinders and durability properties were studied by performing sulphate attack test cubes.***

Keywords: Concrete, Ground Granulated Blast Furnace Slag, Steel Fibre, Glass fibre, compressive strength, flexural strength and split tensile strength

1. Introduction

Concrete is probably the most extensively used construction material in the world. The main constituent in the conventional concrete is Portland cement. The amount of cement manufacture release approximately equal amount of carbon dioxide into the atmosphere. Cement production is consuming significant amount of natural resources. That has brought pressures to reduce cement consumption by the use of supplementary materials. The incorporation of supplementary cementatious material is Ground granulated blast furnace slag (GGBS) is a new mineral admixture, which improve mainly the mechanical properties of concrete and also reduce the cement consumption by replacing part of cement with these pozzolonic materials. Moreover only limited studies have been carried out in India on the use of slag for the development of high strength concrete with addition of steel fibers. GGBS is a superior material which resists salt corrosion & chemical reactions.

One method to improve the brittle behaviour of the concrete is the addition of small fibers in concrete with randomly distributed. Such reinforced concrete is called Fibre Reinforced Concrete (FRC). There are different types of fibers that can be used in FRC they are Steel fibers, Glass fibers, Synthetic fibers, Carbon fibres, Nylon fibre. In this study the addition of steel and glass fibers are added to concrete, leads to improvement in cracking and tensile strength.

2. Materials & Properties

2.1 Cement

Cement used in this experiment work is ordinary Portland cement of 53- grade available in the local market. The cement should be fresh and of uniform consistency. The specific gravity of the cement is 3.15. All properties of cement are tested by referring IS 12269 – 1987.

Table 1: Properties of cement

Sl. No.	*Property*	*Value*
1	Fineness test	7.4%
2	Setting time a)initial b)final	 40 min 270 min
3	Specific gravity	3.15
4	Soundness test	4.5 mm

2.2 Fine aggregates

Locally available sand conforming to grading zone II which is passing from 4.75 mm sieve and of specific gravity of 2.63 is used.

Table 2: Properties of fine aggregate

Sl. No.	*Property*	*Value*
1	Sieve analysis	Zone II
2	Specific gravity	2.67

2.3 Coarse aggregate

Locally available crushed stones conforming to graded aggregate of nominal size 20 mm as per IS: 383 – 1970. Specific gravity of course aggregate is 2.77.

Table 3: Properties of coarse aggregate

Sl. No.	*Property*	*Value*
1	Crushing value	14.36%
2	Impact value	2.7%
3	Abrasion value	11%
4	Specific gravity	2.7
5	Water absorption	0.5%

2.4 Water

Fresh potable water free from acid and organic substances was used for mixing and curing concrete.

2.5 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. Specific gravity of GGBS is 2.85.

Figure 1: GGBS

2.5.1 Chemical composition of GGBS

GGBS comprises mainly of CaO, SiO_2, Al_2O_3, MgO, it contains less than 1% crystalline silica, and contains less than 1 ppm water soluble chromium IV. It has the same main chemical constituents as ordinary Portland cement, but in different proportions.

Table 4: Chemical Composition of GGBS

Chemical Constituent	*Portland*	*GGBS*
CaO	65%	40%
SiO_2	20%	35%
AI_2O_3	5%	10%
MgO	2%	8%

Because of these chemical similarities, Ecocem GGBS can be replaced for Portland cement in concrete mixes by as much as up to 95% (EN 197-1 allows for up to 95% replacement).

2.5.2 Physical properties of GGBS

Table 5: Physical Properties of GGBS

Colour	Off-white powder
Bulk density (loose)	1.0–1.1 tonnes /m^3
Bulk density (vibrated)	1.2–1.3 tonnes /m^3
Relative density	2.85–2.95
Surface area	400–600 m^2/kg Blaine

2.6 Steel Fiber

Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fiber is often described by a convenient parameter called “aspect ratio”. The steel fiber type used here is hooked end with 35mm fiber length and 0.45mm diameter. The aspect ratio of the fiber is the ratio of its length to its diameter and generally the aspect ratio ranges from 30 to 150 and here the aspect ratio of the steel fiber is 80.

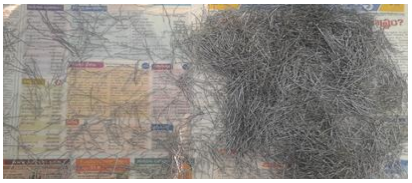


Figure 2: Steel fibre

The following value gives the effects of fibers on concrete

Table 6: Properties of steel fiber

Properties	*Improvement Over Ordinary Concrete*
Ductility	5 to 10 times
Impact resistance	100 to 200%
Cracking & flexural strength	80 to 120%
Shear strength	50 to 100%
Bearing strength	50 to 100%
Abrasion resistance	several times

2.7 Glass fiber

It is material made from extremely fine fibers of glass Fiberglass is a lightweight, extremely strong, and robust material. The glass fiber type used here is E glass with 50mm fiber length and 0.1mm diameter. The aspect ratio of the glass fiber is 500.

2.7.1 Composition of glass fiber

E-CR-glass (Electrical/Chemical Resistance; alumino-lime silicate with less than 1% w/w alkali oxides, with high acid resistance). E-glass ("E" because of initial **e**lectrical application), is alkali free, and was the first glass formulation used for continuous filament formation. It now makes up most of the fibreglass production in the world, and also is the single largest consumer of boron minerals globally. It is susceptible to chloride ion attack and is a poor choice for marine applications.

Table 7: Properties of glass fiber

Fiber type	*Tensile strength (MPa)*	*Comp. strength (MPa)*	*Density (g/cm^3)*	*Thermal expansion (µm/m·°C)*	*Softening T (°C)*
E-glass	3445	1080	2.58	5.4	846

Figure 3: Glass fiber

3. Experimental Work

Mix design for each set having different combinations are carried out by using IS:10262 – 2009method. The mix proportion obtained for normal M25 grade concrete is 1:1.87:3.2with a water-cement ratio of 0.42.

Table 8: Mix proportion

Grade	*Cement (kg/m^3)*	*Fine aggregate (kg/m^3)*	*Coarse aggregate (kg/m^3)*	*Water (Litres)*	*W/C ratio (kg/m^3)*
M25	364.9	685.3	1197.08	153.26	0.42
-	1	1.87	3.2	-	-

The experimental investigation consists of casting and testing of 9 sets along with control mix. Each set comprises of 18 cubes, 3 cylinders and 6 beams for determining compressive, tensile and flexural strengths respectively. By taking different percentage of GGBS, along with steel & Glass fibers individually as a partial replacement of cement will be replaced accordingly with the different percentages by weight of slag and different percentages by weight of steel fiber and Glass fiber. The concrete was filled in layers and compacted. The specimens were removed after 24 hours and submerged in water for curing. After a curing period of 7 and 28 days specimens were taken out and tested.

Figure 4(a): showing cubes compacted with concrete

Figure 4(b): showing cubes in curing

Tests and Results

A number of tests were carried out to determine the design mix properties of concrete in the laboratory. In the present work, the strength of the hardened concrete is determined. The strength criterion includes measurement of following parameters:

- Compressive Strength on cubes
- Flexural Strength
- Split Tensile Strength on Cylinders

2.7 Compression test

Compression test on cubes of size (150 x 150 x 150)mm was performed on compression testing machine. Optimized Results of Trial Mixes are as shown in tables from the results of trial mix, it is seen that the compressive strength of Concrete for all percentage remains nearly same with replacement of cement by GGBS ,G.F and S F and found maximum for 20%, 1.5% and 0.2% slag, S.F & G.F respectively replacement of cement. After testing the concrete (compressive strength) for M25 grade concrete separately for replacement of slag, steel and glass fiber by cement respectively finally combined percentage of slag & steel fiber mix in which maximum strength is obtained was used to get optimized strength.

Figure 6: Compressive testing of cubes

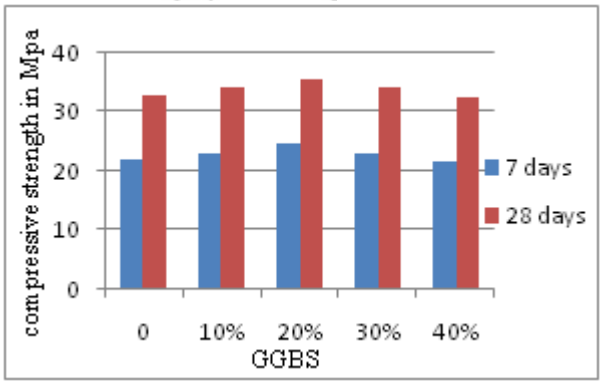
2.8 GGBS optimum percentages

The mix proportions with partial replacement of OPC with 0%, 10%, 20%, 30% and 40% of GGBS are calculated.

Table 9: Compressive strength for steel fiber

S. No	*% of GGBS*	*Compressive Strength (MPa)*	
		7 days strength	*28 days strength*
1	0	21.92	32.84
2	10	22.81	34.23
3	20	24.70	35.55
4	30	23.01	34.18
5	40	21.62	32.46

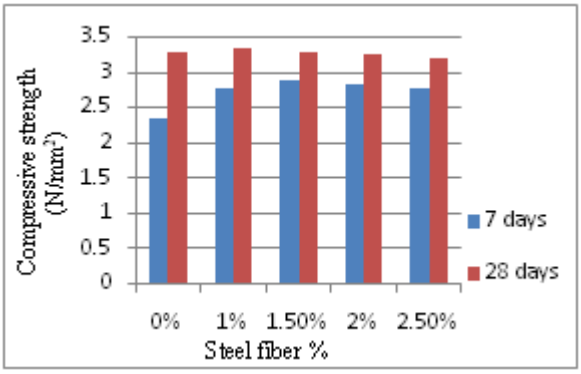
From the test results, the optimum percentage replacement of GBBS was found to be 20%. It is observed that the properties of can be maintained with GGBS as partial replacement of cement at 20%.



Graph 1: Compressive strength of GGBS for 7 & 28 days

Table 10: Compressive strength for steel fiber

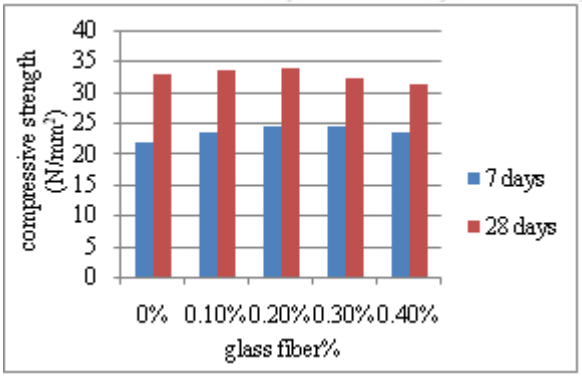
Sl .No	*GGBS %*	*% Of Steel fiber*	*7 days (N/mm^2)*	*28 days (N/mm^2)*
1	20	0	21.92	32.88
2	20	1	23.73	33.54
3	20	1.5	25.56	33.96
4	20	2	24.68	32.24
5	20	2.5	23.72	31.43



Graph 2: Compressive strength of steel fiber for 7 & 28 days

TABLE 11: Compressive strength for glass fiber

S.No	*GGBS %*	*% Of glass fiber*	*7 days (N/mm²)*	*28days (N/mm²)*
1	20	0	21.92	32.88
2	20	0.1	23.43	33.42
3	20	0.2	24.23	33.89
4	20	0.3	24.48	32.12
5	20	0.4	23.34	31.23



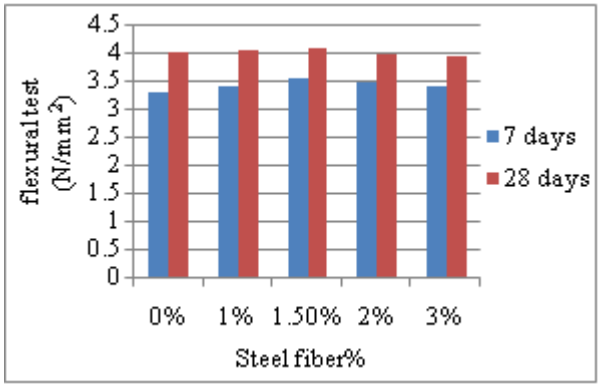
Graph 3: compressive strength for glass fibre for 7 & 28 days

4.3 Flexural test

Flexural test was performed on beams of (500×100×100)mm size by placing them on universal find out the flexural strength. After testing the concrete (flexural strength) for M25 grade concrete separately for replacement of slag, glass& steel fiber by cement respectively finally combined percentage of slag & steel fiber mix, slag & glass fiber mix in which maximum strength is obtained was used to get optimized strength.

Table 12: Flexural test for steel fiber

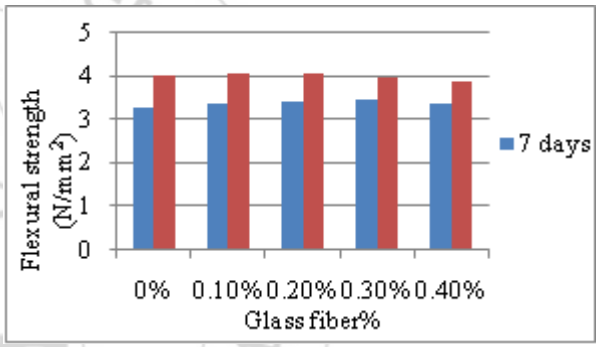
S.NO	*GGBS %*	*% OF STEEL FIBER*	*7 days (N/mm²)*	*28 days (N/mm²)*
1	20	0	3.27	4.01
2	20	1	3.41	4.05
3	20	1.5	3.54	4.08
4	20	2	3.48	3.97
5	20	2.5	3.41	3.92



Graph 4: flexure test for steel fiber for 7 & 28 days

Table 13: Fleural test for glass fiber

S.NO	*GGBS %*	*% OF GLASS FIBER*	*7 days (N/mm²)*	*28days (N/mm²)*
1	20	0	3.27	4.01
2	20	0.1	3.38	4.06
3	20	0.2	3.44	4.07
4	20	0.3	3.46	3.96
5	20	0.4	3.38	3.91



Graph 5: Flexural strength for 7 & 28 days

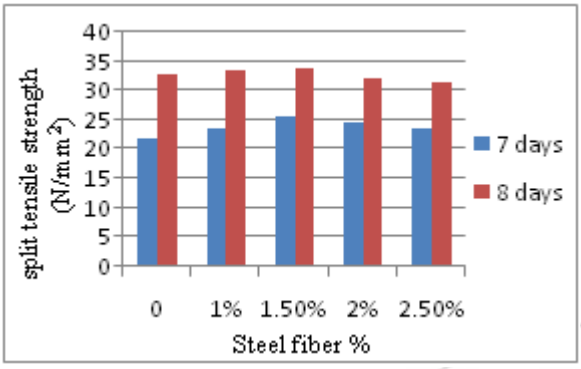
2.9 Split Tensile Test

Split tensile was performed on cylinders 150mm dia. and 300mm height on compression testing machine. The failure load was recorded to find out split tensile strength. After testing the concrete (split tensile strength) for M25 grade concrete separately for replacement of slag, glass & steel fiber by cement respectively finally combined percentage of slag & steel fiber mix, slag & glass fiber mix in which maximum strength is obtained was used to get optimized strength.

Figure 7: Tensile test on cylinders

Table 14: Split tensile test for steel fiber

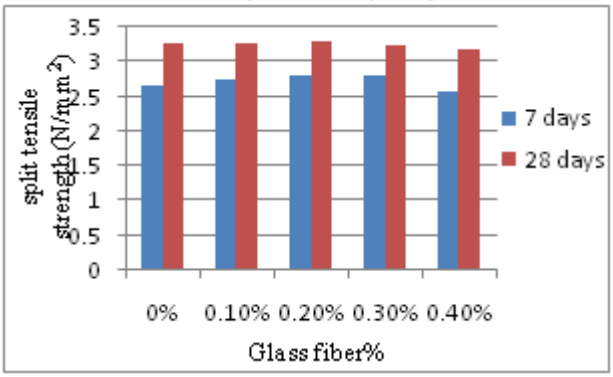
S.No	GGBS %	% Of Steel fiber	7 days (N/mm^2)	28 days (N/mm^2)
1	20	0	2.34	3.26
2	20	1	2.77	3.33
3	20	1.5	2.88	3.28
4	20	2	2.83	3.23
5	20	2.5	2.77	3.19



Graph 6: Split tensile test for steel fiber for 7 & 28 days

Table 15: Split tensile test for glass fiber

S. No	GGBS %	% Of Glass fiber	7 days (N/mm^2)	28days (N/mm^2)
1	20	0	2.66	3.26
2	20	0.1	2.75	3.28
3	20	0.2	2.81	3.31
4	20	0.3	2.82	3.23
5	20	0.4	2.57	3.18



Graph 7: Split tensile strength for 7 & 28 days

4. Conclusion

- The optimum quantity for partial replacement of cement by ground granulated blast furnace slag is 20%
- The optimum quantity for extension of steel fibred is 1.5%
- The optimum quantity for extension of glass fiber is 0.2%
- The percentage of increase in compressive strength for M25 grade for partial replacement of cement by GGBS (20%) + extension of steel fibred (1.5%)+extension of glass fiber is (0.2%) for 7 &28 days of curing.
- The percentage of increase in flexural strength for M25 grade for partial replacement of cement by GGBS (20%) + addition of steel fibred (1.5%)+extension of glass fiber is(0.2%) for 7 & 28 days of curing.
- The percentage of increase in split tensile strength for M25 grade for partial replacement of cement by GGBS (20%) + addition of steel fibred (1.5%) +extension of glass fiber is(0.2%) for 7& 28 days of curing.
- Test results display that higher fiber content has conduct around increased compressive strength, flexural strength, abrasion resistance, and fiber crack-control effect. Hence the addition of steel& glass fiber within FRC is more helpful for the flexural strength than the compressive strength.

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