VOL. 14, NO. 9, MAY 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EXPERIMENTAL STUDY ON HIGH PERFORMANCE CONCRETE WITH GGBS AND HYBRID FIBRES

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ABSTRACT

In this Study, the effects of High Performance Concrete (HPC) with ground granulated blast furnace slag (GGBS) and hybrid fibres are studied. The optimal mix of GGBS replacement to cement is found from initial test results. The optimal mix is further tested by adding fibres to it. Hooked end steel fibres having aspect ratio 50 and type-S finely chopped glass fibres having flexural modulus 1.51 GPa are combined in various levels. Steel fibres help in improving the mechanical strength of concrete whereas glass fibres help in improving durability. The fibre combination percentages are (0.25%Glass, 0.5%Steel), (0.25%Steel, 0.5%Glass) and (0.5%Steel, 0.5%Glass). The various test results are compared to conventional concrete. It can be concluded from obtained results that GGBS replacement to cement doesn't decrease the concrete strength and fibres provide additional strength. The compression and tensile strength were maximum for mix containing 0.5% steel fibres and 0.5% glass fibres content. Testing of RC beams showed that fibre addition increases load bearing capacity while reducing deflection. The partial replacement of cement by GGBS helps in better utilization of wastage from iron industry without compromising on concrete strength. In addition, fibres make the strength in concrete more uniform.

Keywords: High performance concrete (HPC), ground granulated blast furnace slag (GGBS), steel fibres, glass fibres.

1. INTRODUCTION

Concrete as a building material has become inseparable part of modern construction industry right from its inception into it. The usage of concrete gained tremendous popularity due to easy availability of natural raw materials present in abundant quantity and the strength it possesses. The concrete also possesses high durability compared to other materials used for construction [1]. As with the case of most production industries, the production of cement which is the main component in concrete results in release of enormous amounts of toxic fumes into the atmosphere. This has been a major concern in recent years as it affects the air quality subsequently leading to global warming. Also, due to vast production, resources are fast depleting at an alarming pace. Hence it is vital to efficiently utilize naturally available resources as well as to use by-products from other industry in concrete production to minimize material wastage [2].

One such material which could be used as a partial replacement to cement is Ground Granulated Blast Furnace Slag (GGBS) which is a by-product from iron and steel industry. Among the several replacement materials which are currently used, GGBS which is fine powdery material containing calcium and magnesium oxides as its major components is the most widely used one [3]. GGBS used in the current work is manufactured by rapid quenching of pig iron slag which results in formation of glassy substance which is then powdered to obtain its original powder like form. The chemical composition of GGBS is similar to those of the glass due to presence of silicates and aluminates [4] and hence they impart higher strength compared to other admixtures. The elastic modulus of GGBS concrete varies slightly to that of Portland cement concrete. This coupled with several other characteristics such as prolonged solidifying time, slump retention, and high toughness index makes them an ideal constituent to cement concrete. GGBS is added only as a partial replacement to cement and not as an alternative. Concrete with GGBS generally has a lighter complexion and hence the heat of hydration will be lower [5]. This reduces the water requirement during curing stages. It also prevents plastic shrinkage.

The mechanical strength of concrete depends upon the constituents added to it. While the strength various in proportion to the grade of concrete, the addition of fibres greatly enhances them. Several hundred types of fibres are available naturally which could be used in concrete but the most commonly preferred are artificially produced fibres such as glass fibres, steel fibres, carbon fibres, etc. Fibres are threaded like linear discrete materials which are broken down into smaller individual components. As a result, they have larger surface area to weight ratio compared to conventional reinforcements [6]. These fibres provide additional tensile and flexural strength to the concrete [7]. Fibres which are heavily deformed afford better post-crack strength [8]. The usage of fibres in concrete keeps on increasing to satisfy the requirements of advanced modern-day construction. Sudden failure of concrete is eliminated substantially because the fibres continue to support load even after occurrence of crack [9]. The fibre reinforced concrete provides greater abrasion resistance as well as high impact load capacity due to their high aspect ratio and uniform cross section [10]. The fibres are usually added in the range of 0.1% to 1.5% by volume of concrete. Excess fibre addition results in the formation of balling effect wherein fibres segregate [11].

The fibre reinforced concrete usually has reduced workability due to their physical properties and hence it is necessary to add super plasticizer as per the mix requirement. Super plasticizers are synthetic chemicals

which help in reducing water cement ratio and provide indirect strength to concrete depending upon the type being used [12]. Plasticizers are generally added in the range of 0.5-3% by weight of cement. GGBS concrete with fibres are used nowadays in advanced engineering constructions such as airports, warehouses, dams, etc. The combined usage of GGBS and fibres in concrete helps in strong structural bonding initially and greater durability over a longer period of time.

The objective of this study is to find the optimal percentage of GGBS replacement to cement from partial GGBS replacement levels of 40%, 50%, and 60% to cement and use that optimal mix for fibre addition. The mix is then tested for various mechanical properties (compressive strength, tensile strength, flexural strength) and durability property (acid attack) at curing age of 14,28 and 56 days. Further, reinforced concrete beams of each mixer tested for flexure.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials used

The Cement used is of OPC 53 Grade which is commonly available in the market confirms to IS 12269-1987.The specific gravity of cement was found to be 3.14 while the initial setting and final setting time were found to be 45 minutes and 300 minutes respectively.GGBS is primarily used in concrete structures in combination with cement and/or other pozzolanic materials to make it highly durable. GGBS is a by-product from steel industry which is much finer than cement and as a result provides a better binding medium in concrete. GGBS used satisfies the specifications mentioned in IS 12089:1987. The particle size of GGBS used in the current work is 45 microns. The surface area as specified by manufacturer is 350 m^2/kg and the glass content is 92%. Silica fumeis an amorphous form of silicon dioxide. It is a by-product from steel industry and consists of particles with an average diameter of 150 named having particle size less than 1 µm. Particles is spherical in shape. The individual particle size of silica fume is extremely small which is roughly about 1/100th of individual cement particle. The surface area is 20000 m^2/kg and the bulk density is300 kg/m^3.

Locally available river sand of zone II category as per IS 383-1970 has been used. The fine aggregate used had grainy texture to it. Only those aggregates which passed through 12mm sieve and retained on 10mm sieve were used as coarse aggregates for the work and it confirms to IS 383:1970 standards. Potable water used for drinking which is available in the experimental laboratory has been used for the entire work. Commercially available naphthalene-based super plasticizer having solid content 40% is used. The main objective of adding super plasticizer is to reduce water content while increasing workability.

Hooked end steel fibres of 30mm length and aspect ratio 50 have been used. The tensile strength of the fibres as specified by manufacturer is greater than 1450 MPa. The strain at failure is less than 4%.The glass fibres used in this project are of S-type. The density is about 1140 kg/m^3 and flexural strength 69 MPa. The Charpy notched impact strength of the fibres being used is 29.52 KJ/m^2.

For the purpose of RC beams, rebars of size 8mm is used as compression reinforcement and 10mmis used as compression reinforcement. The sizes of reinforcement bars are obtained after proper design of beams. The RC beams used for testing were of the size 200mm X 200mm X 1500mm. The rebars used are tied together with cover of 20mm.

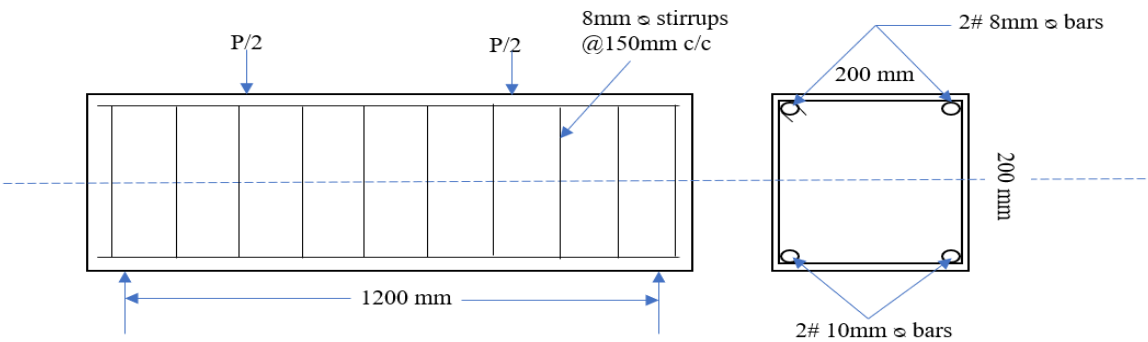

Figure-1. RC beam for Reinforcement Details

The various concrete mixes used in the current work are represented below:

Table-1. The various Concrete Mix proportions.

Mix	Cement (kg/m^3)	GGBS (kg/m^3)	Silica fume (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Superplasticizer(kg/m^3)	Water (kg/m^3)	Steel fibre (kg/m^3)	Glass fibre (kg/m^3)
M1	287.34	191.56	23.8	683.24	1108	7.52	141.61	-	-
M2	287.34	191.56	23.8	683.24	1108	7.52	141.61	19.25	5.85
M3	287.34	191.56	23.8	683.24	1108	7.52	141.61	38.50	2.93
M4	287.34	191.56	23.8	683.24	1108	7.52	141.61	38.50	5.85

3. RESULTS AND DISCUSSIONS

3.1 Initial testing result:

In order to find optimal GGBS replacement levels, three mixes of different GGBS replacement levels of 40%,50% and 60% were taken and tested for compressive strength at 28 days. The strength increased with increase in GGBS replacement unto 40% and reduced on further replacement. The mix containing 40% GGBS was found to have the highest compressive strength of 63 N/mm^2 while mix containing 60% GGBS replacement had least strength of about 58 N/mm^2. Hence, the optimal mix of 40% GGBS is further taken for the addition of fibres.

3.2 Compressive strength results:

The specimens were cast and tested at age of 14, 28, 56 days. Testing was done in compression testing machine as per IS 516:1959 with load applied at the rate of 3kN/s. It can be seen from the graph that compressive strength of mix containing 0.5% glass fibre at 56 days is 4.26% less than conventional mix and 5.3% less than M4 which had the maximum strength at 77.23 N/mm^2. From the test results it can be seen that strength increases with increase in steel fibre up to 0.5% while in case of glass fibres, the strength started reducing after 0.25%. The increase in strength between 14 days and 56 days is highest for M3.

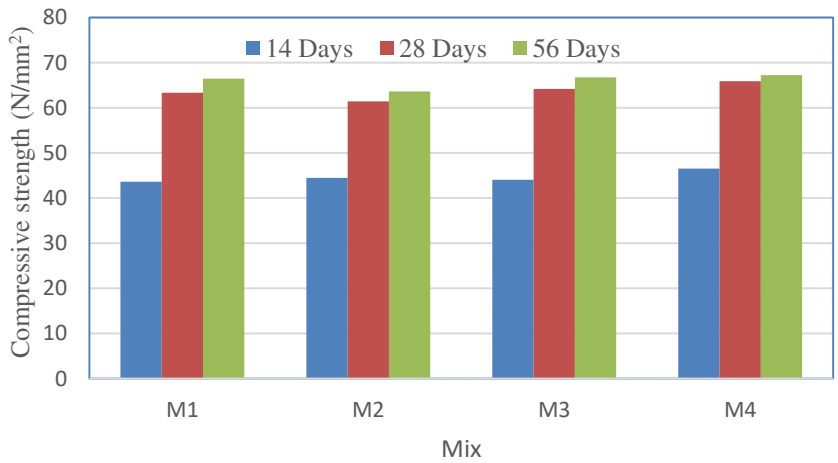

Figure-2. Compressive strength of concrete mix

3.3 Splitting tensile strength results:

The splitting tensile strength test was carried out on a cylinder of 100mm diameter and 200mm length. The test was conducted with load applied at the rate of 2 kN/s in compression testing machine until crack occurs along vertical diameter of the cylinder. The average splitting tensile strength was taken for all mixes and graph is plotted. The test was in accordance with IS 519:1959. The splitting tensile strength of mix containing 0.5% steel fibre M3 and M4 had strength of about 8.11 N/mm^2. This is 17.6% more than conventional mix strength of 6.68 N/mm^2 and 14% more than the mix containing 0.5% glass fibre.

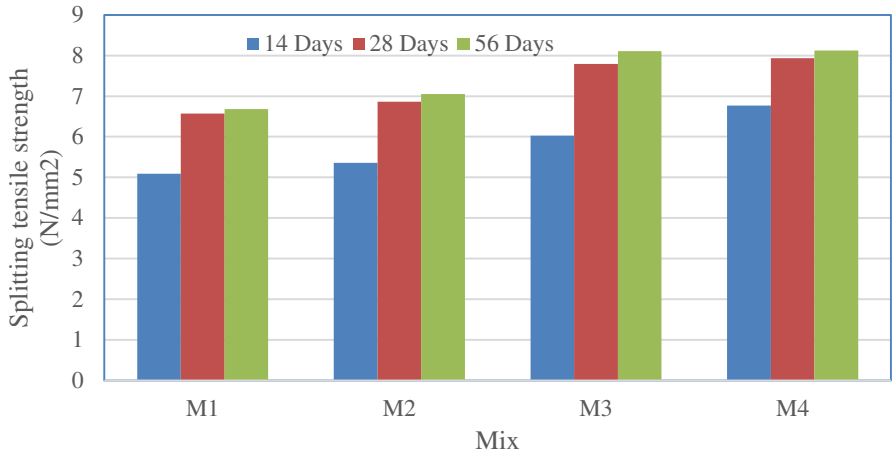

Figure-3. The various concrete mixes for split tensile strength

3.4 Flexural strength result:

Flexural strength of all four mixes was tested from flexural beams in same machine as previous two tests with load applied at the rate of 2kN/s. The testing was done on 14, 28, 56 days. The load applied was two-point loading with supports at a distance of L/3 from each end.

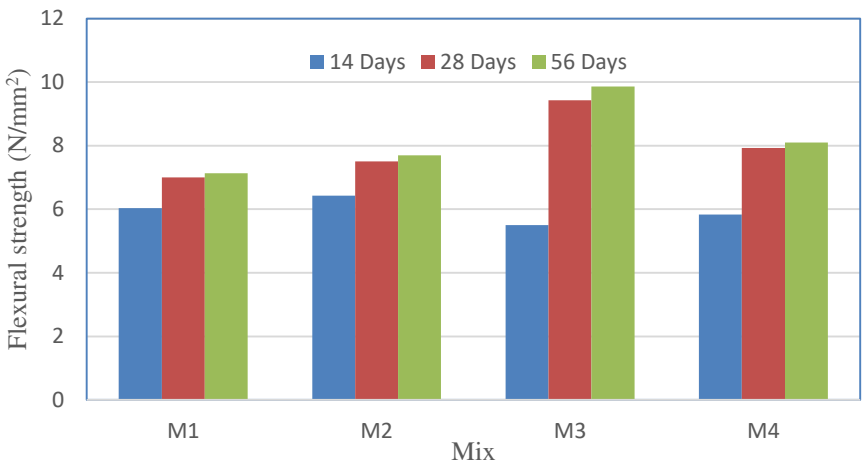

Figure-4. Flexural strength of concrete mix

The strength at 14 days strength was maximum for mix M2 while strength at 56 days was maximum for the mix containing 0.5% steel fibres and 0.25% glass fibres. The 28 days flexural strength of 0.5% steel fibre concrete is 5.4 N/mm^2 which is nearer to the result obtained by Wasim Abbas *et al.* [12]. The mix M3 has strength which is 27% more than the conventional mix at 56 days of testing. The difference in strength of 0.5% steel fibre mix and 0.5% glass fibre mix is about 22%.

3.5 RC beam testing:

The beams are designed in accordance with IS 456:2000. Three beams of each mix are cast and tested. The supports were placed at a distance of L/3 from the end supports. Deflection was taken at three different points on the beams at regular intervals. Readings were taken with each applied load until the failure of beams occur above which loads cannot be applied further. The mean value of three deflection readings are taken for plotting graph. Load vs deflection graph is plotted for all the twelve beams. Finally, all the results were combined to a single graph to show the difference in deflection of the beams with respect to load applied.

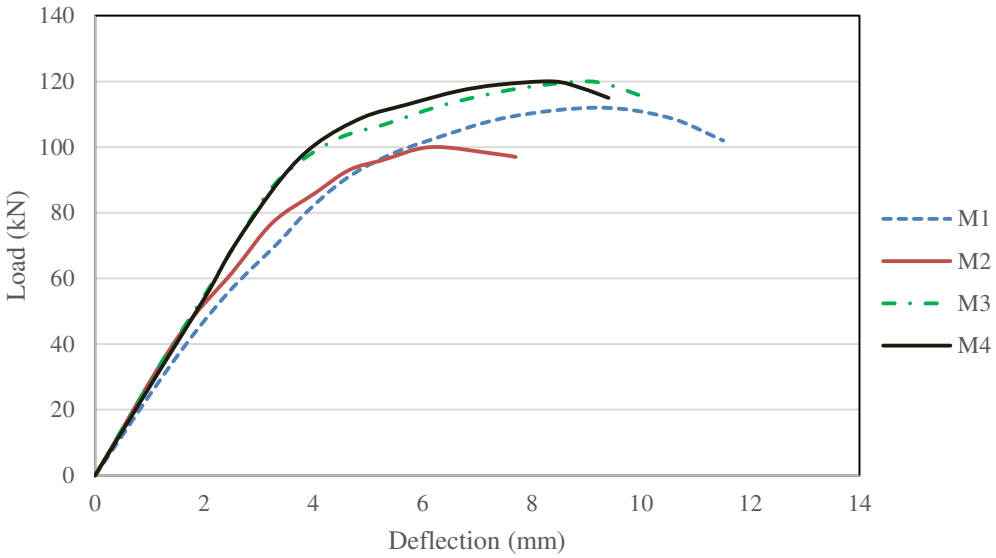

Figure-5. Consolidated RCbeam result.

The maximum load carrying capacity of conventional concrete is 112 kN and deflection at failure load is 9.21 mm. It must be noted that deflection is maximum for conventional concrete mix compared to fibre added concrete mixes. The load carrying capacity is highest for M3 and M4 each containing 0.5% steel fibres at 120kN which is almost similar to results obtained by Wasim Abbas *et al.*, [12] and their deflection at ultimate load is 8.90 and 8.38 respectively. This shows that addition of steel fibres increases load carrying capacity of the beam. The least load carrying capacity is for the mix containing 0.5% glass fibres and 0.25% steel fibres at 100kN.

3.6 Acid attack result:

For the purpose of durability, hydrochloric acid attack test was done and the cubes were tested for compressive strength at 56 days of curing.

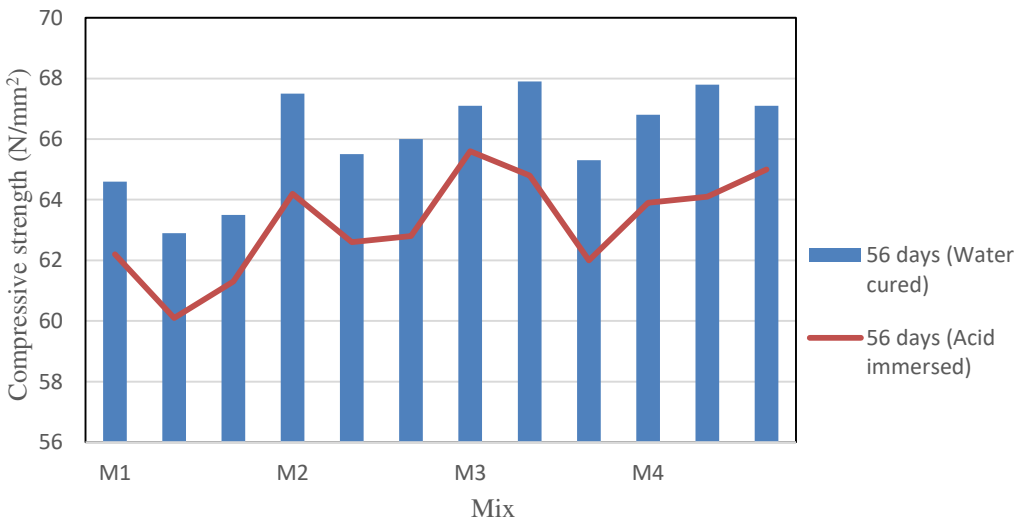

Figure-6. Acid attack result.

It can be seen from the above graph that the exposure to acid reduces the strength of the concrete by 3-6% across all the mix. Mix M2 had less reduction in strength which indicates glass fibres are more resistant to acid attacks than steel fibres.

4. CONCLUSIONS

a) The addition of fibres to concrete improves the overall strength distribution. The test results showed an increase in strength across all parameters of testing.
b) The compressive strength of 0.5%steel fibre concrete mix showed an increase of 3-4.5% in strength over the

conventional mix while mix containing 0.5% glass and 0.25% steel showed 4.2% reduction in strength

c) The splitting tensile strength results showed an increase in strength of all the mixes with mix M4 having maximum strength of 8.2 N/mm^2. The results show that mix containing maximum steel fibres has higher splitting tensile strength compared to glass fibres.
d) The flexural testing of small beams showed that the addition of fibres increases strength up to 22% compared to conventional mix over 56 days of curing
e) The maximum deflection occurred on RC beam M1 compared to other beams. This shows that addition of fibres reduces deflection. The ultimate load carrying capacity for mixes containing 0.5% steel fibres was 120kN but beam M3 deflected 5% more than beam M4 at failure load point. The beam M2 has least load carrying capacity at 100kN.
f) The acid attack results showed a decrease in strength for all the mixes with strength decreasing between 3-6%.
g) The mix M3 and M4 proved to be better than other mixes in terms of overall strength which shows that steel fibres inhibit more strength compared to glass fibres in a combined mix.

ACKNOWLEDGEMENT

The authors are thankful to SRM institute of science and technology for providing materials and Fosroc Chemicals for providing super plasticizer needed to complete this work.

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