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Efficacy of Glass Fiber Reinforced Concrete by using Supplementary Cementitious Materials

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Abstract: ***Concrete is a building material which is being utilized excessively in the world adjacent to water. The nature is influenced due to the extraction of raw matter and also because of the evolution of gases like CO_2. In the ongoing years, there is a speedy growth in the production of waste materials like glass wastes, plastic, Ground Granulated Blast furnace Slag, silica fume, coal ash, wood ash, rice husk ash, etc. Controlling and discarding issues emerge due to these wastes and inflict havoc on the nature. So as to curtail these issues, the waste materials are used as additives or partial substitutions for cement and aggregates in construction field. This paper focuses on strength properties and durability of concrete containing glass fibers by partial substitution of cement and fine aggregate with GGBS and Coal ash respectively. For this work, mix design using IS method is prepared for M30 grade and the tests are conducted for various dosages of glass fibers as 0.5, 1%, 1.5% and 2% by weight of cement. The substitution degree of GGBS is 30% and that of coal ash is 20%. The obtained outcomes are contrasted with conventional concrete.***

Keywords**:** ***Coal ash, Durability, Glass fibers, Ground Granulated Blast Furnace Slag.***

I. INTRODUCTION

The concrete industry creates 5-8% of the worldwide man-made outflows of carbon dioxide of which noteworthy measure of half is from the synthetic mechanism of calcination to produce cement and 40% from consuming fuel. Major push for the infrastructure spending and development, the cement and concrete production can be expected to have a major impact on the energy exigency. Besides, there is a plenty of compulsion on the existing deficient unprocessed materials and fuels. Environmental jeopardy is playing a crucial function in the sustainable origination of the construction industry. Also, monetary effect due to excessive value of Portland cement production plants command that supplementary cementitious matter be employed in abundant volume to substitute cement in concrete.

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Durability is also an important factor to produce sustainable concrete. In a way to process sustainable concrete, coal ignited substances like coal ash [1-9], fly ash and other pozzolans such as GGBS [10-12], silica fume, rice-husk ash are used.

Coal is the biggest wellspring of power on the planet. India is the second largest producer of coal with 716 million tonnes in 2018-19. Burning coal produces coal ash which is blameworthy for 40% of carbon dioxide outcome. A gleaming gritty by-product derived during iron and steel manufacturing mechanism which is dried and crushed as fine powdery grains is termed as GGBS. Steel-iron production is also accountable for CO_2 outcomes of 19-20% in India. Besides CO_2 emission, handling-disposal problems and low recycling rate arises due to scarcity of dumping and recycling sources. These complications levy havoc on the habitat. So, usage of these materials is considered to be the advantageous for sustainable concrete. Additionally, the potential concern of concrete or any blended concrete is the phenomenon of cracks, when administered on concrete systems at the large-scale, may be overly brittle with deficient ductility of materials for works as concrete is feeble in tension. This tensile weakness overcomes by inducing steel reinforcement. It has been uncovered that concrete fortified with an acceptable proportion of fibers procure superior achievement and minimizes the formation of fissures as fibers provide some amount of reinforcement everywhere, gives strength even after cracking, reduces permeability and reduce damage in fire. Concrete associated with fiber is effective in strength, energy absorption and toughness, in which the intensity of betterment counts on the class of fibers used [13-17]. The selection of material of fiber, its size, shape and characteristics must be relevant for the intended practices and chemical compatibility should be assured with the binder. Glass fiber reinforced concrete (GFRC) is anticipated to rise by a compound yearly growth rate of ~10.3% in 2018-19 years. Expanding construction projects in the developed or developing countries act as a driving factor for GFRC market. Due to traits like climate, fire resistance, design adaptability, dimensional stability, ease of managing and quick installation, GFRC is favored in the construction industry. Many researches were carried out by directly replacing cement with GGBS and coal ash with fine aggregate either fully or partially and by incorporating glass fibers. Incorporating coal ash in concrete has resulted in high durability [1], low workability [2], light-weight structure [4], environmental friendly [3-5], increase in porosity [6], reduced unit weight and freeze-thaw resistance [7], greater resistance to chemical agents [8], high abrasion resistance and water absorption [9]. It is treated as a better replacement for sand. Partial replacement of GGBS with cement increases efficiency [10], strength [11], workability, chloride binding capacity and accelerates hydration process of ordinary Portland cement [12]. Studies on GFRC resulted in increase in strength [13-15], load carrying capacity [15], toughness [16-17] and, decrease in workability [17]. The current paper centers on the enhancement of strength properties and durability of concrete by slightly switching GGBS for cement and coal ash for sand by joining with glass fibers. The intention of the work was to interpret the impact of glass strand measure on workability, compression strength, modulus of rupture, split tensile strength, sorptivity and acid resistance maintaining the levels of GGBS and coal ash constant.

II. METHODOLOGY

The experimental program is planned as follows:

1. Literature review is to be studied regarding the work and sources of materials are to be identified and collected.
2. Tests are to be conducted for finding attributes of materials viz., binder, GGBS, aggregates and coal ash.
3. Mix configuration is to be organized for concrete of M30 grade utilizing IS technique (10262-2009) [18].
4. Concrete specimens are to be prepared such as cubes for compression, beams for flexural, cylinders for tension and also cubes for durability tests like sorptivity and acid resistance by taking dosages of glass fibres as 0%, 0.5%, 1%, 1.5% and 2% by weight of cement using 30% GGBS substitution for cement and 20% coal ash for sand.
5. Hardened cubes, cylinders and prisms are to be drowned in water for 7 and 28 days.
6. Tests are to be conducted for strength and durability with 3% and 5% concentrations of sulphuric acid till 90days.
7. Results are to be evaluated and contrasted with normal concrete.

III. MATERIALS

A. Cement

53 grade Ordinary Portland cement (Ultra Tech) was employed from nearby market confirming to various specifications as per IS: 12269-1987 [19]. Cement properties are conferred in tables I and II.

Table- I: Physical features of Cement

Properties	Output
Fineness	2.4%
Specific gravity	3.24
Normal consistency	32%
Initial setting time	60 min
Final setting time	320 min
Soundness	3 mm

Table- II: Chemical attributes of Cement

Parameters	% by mass
SiO_2	20.14
Al_2O_3	5.67
Fe_2O_3	3.81
CaO	62.35
MgO	1.68
Na_2O	0.24
K_2O	0.75
SO_3	2.92

B. Fine Aggregate

Natural sand from nearby market is employed as fine aggregate for this study. The specific gravity is found to be 2.343 and the fineness modulus is 3.09. Gradation analysis of sand is completed affirming to Zone III of IS: 383 [20].

C. Coarse Aggregate

20mm extreme sized squashed coarse which is round shaped employed from neighborhood market is utilized. The specific gravity is observed to be 2.74. Gradation analysis of coarse aggregate is done affirming to Table II of IS: 383 [20]. The flakiness and elongation indices are found to be 26% and 19% respectively.

D. Ground Granulated Blast Furnace Slag (GGBS)

The off-white GGBS for the present investigation is purchased from Rank RMC plant, IDA Bollaram, Hyderabad, Telangana. The specific gravity is found to be 2.87. The chemical analysis is conferred in table III.

Table- III: Chemical attributes of GGBS

Parameters	% by mass
Calcium as CaO	37.04
Silica as SiO_2	32.16
Aluminium as Al_2O_3	15.91
Magnesium as MgO	9.63
Iron as Fe_2O_3	0.58
Sulphur as SO_3	0.2

E. Glass Fibers

Fiber glass type used in this work is E-Glass and the surface is coated with silane is shown in “Fig. 1”. Fiber length of 3mm and 13microns in diameter is adopted.

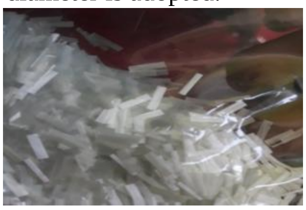

Fig. 1. Glass Fibers

F. Coal Ash

For the present work, coal ash is brought from the Aurobindo Pharma Limited, Hyderabad, Telangana. The specific gravity is acquired as 2.26. Table IV indicates the chemical attributes of coal ash.

Table- IV: Chemical attributes of Coal ash

Parameters	% by mass
Silica as SiO_2	35.91
Aluminium as Al_2O_3	15.24
Iron as Fe_2O_3	26.81
Manganese as MnO	0.29
Sodium as Na_2O	1.64
Potassium as K_2O	0.57
Calcium as CaO	8.13
Magnesium as MgO	5.45
Titanium as TiO_2	0.71
Sulphur as SO_3	2.39
Loss on ignition	2.51

G. Water

Normal water from valves is used for blending and curing.

IV. MIX PROPORTIONING

Using the laws of IS: 10262-1982 [18] and IS: 456-2000 [21], the mix configuration of concrete for M30 grade is computed. The water-binder ratio is 0.45 and the mix proportion is achieved as 1: 1.3: 2.7. CC denotes conventional concrete. Then a constant proportion of 30% of cement by weight is partially replaced by GGBS and 20% of fine aggregate by weight is partially replaced by coal ash. For this, glass fibers are added with dosages from 0-2%. Table V represents mix proportions.

Table- V: Mix proportions

Mix	Filament dosage
CC	0
GCGF 0.5	0.5
GCGF 1	1
GCGF 1.5	1.5
GCGF 2	2

V. EXPERIMENTAL PROCEDURE

A. Slump Test

The speedy and standard means of analyzing workability is slump cone test. The test is organized following IS 1199-1959 [22].

B. Compressive Strength Test

The trails for this test are organized on moulds of size 150mm*150mm*150mm. This test was performed confirming to IS: 516-1959 [23]. A total of 36 cubes are prepared, 6 for each mix. "Fig. 2" represents testing cube for compressive strength.

Fig. 2. Compressive Strength Test

C. Split Tensile Strength Test

An indirect means to ascertain concrete tensile strength is Split tensile test. This test is executed on 36 specimens in compression testing machine as shown in "Fig. 3" affirming to IS: 5816-1999 [24].

Fig. 3. Split Tensile Strength

D. Flexural Strength Test

Modulus of rupture is an oblique means of concrete flexural strength. This test is implemented on 36 prisms confirming to IS: 516-1959 [23]. "Fig. 4" represents testing beam for flexural strength.

Fig. 4. Flexural Strength

E. Sorptivity

The suction rate of water by concrete specimen through capillary rise is computed to assess sorptivity. The casted cubes are drenched in water for 28 days. These blocks are weighed after oven heating at 100°C temperature and then soaked with water level not surpassing 0.5 cm up on the base of block and the ingestion of water through edges is arrested by shutting it with a non-absorbent. The absorption of water in 30 minutes span is measured by weighting the specimen. This trail was directed confirming to ASTM C642 – 06 [25]. "Fig. 5" shows sorptivity test arrangement.

Fig. 5. Sorptivity test

F. Acid Attack Test

The cubes of size 150mm are casted and water stored for 28 days. Initially, weight of these blocks is noted after drying. The acid solution is prepared by using water and concentrated sulphuric acid of 3% and 5% concentrations separately.

Then those cubes are immersed in acid water till 90 days as shown in "Fig. 6". The acid water should be replaced periodically so as to maintain the pH level. The mass of the cubes should be counted for indicated time periods such as 15, 30, 60 and 90 days. After specified periods, compression quality test is performed on these cubes. Mass loss and strength loss of acid submerged blocks are assessed. Also, the Acid Durability Factor (ADF) is calculated using the relation,

$$ADF = (100-C_s) \times A/B$$

Where, C_s = Compressive strength loss at A days (%)
A = Age where durability factor is required
B = Age at which the exposure is ceased.

Fig. 6. Acid immersion of cubes

VI. RESULTS AND DISCUSSIONS

A. Slump Test

From the outcomes of "Fig. 7", it is spotted that the feasibility of conventional concrete is declined by the inclusion of GGBS, coal ash and fibers. The fineness of GGBS with high specific surface [12] and increase in cohesivity due to coal ash [2] leads to increased water demand which may be the reason for decrease in workability. Also, workability is decreased with the addition of glass fibers. This may be due to increase in fiber dosage which absorbs high cement paste to cover those fibers leading to increase in viscosity thereby reducing slump [17].

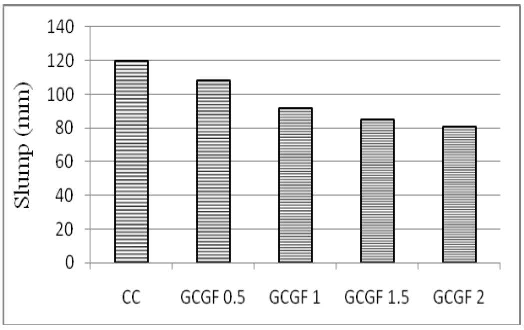

Fig. 7. Slump Test

B. Compressive Strength

From the outcomes of "Fig. 8", it is noticed that strength is advanced up to 1% in compression and then decreased. Hence optimum mix is obtained at 1% fiber dosage. The strength of amended concrete is elevated by 10.10% and 14.11% with the addition of 0.5% and 1% fibers in concrete at 28days. At 1.5% fiber dosage, strength is increased by 2.96% with respect to normal concrete and decreased by 10.83% with respect to optimum fiber content. The enhancement of strength could be due to filling up of voids by the hydrates of calcium and aluminate formed from the pozzolanic reactions of active silica and lime [3] in the presence of glass fibers. 2% fiber addition resulted in decrease in strength beyond normal concrete by 6.75%. Lack of proper interface of glass fibers with the cement paste [16] and also increase in porosity [4] due to further insertion of glass filaments could be the reasons for strength reduction.

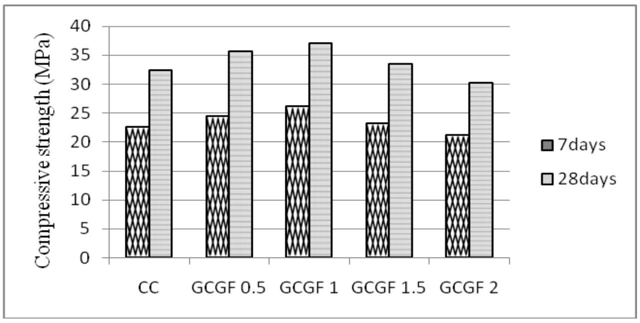

Fig. 8. Compressive Strength

C. Split Tensile Strength

Based on the outcomes indicated in "Fig. 9", strength of all amended mixes are better than ordinary concrete. The strength of amended concrete is raised by 36.68% and 48.37% at 28days with 0.5% and 1% increment of fiber. Similarly strength is increased by 39.67% and 31.52% at 1.5% and 2% fiber content. Strength is better in tension at 1% fiber mix which is inferred as ideal and further fiber addition declines strength.

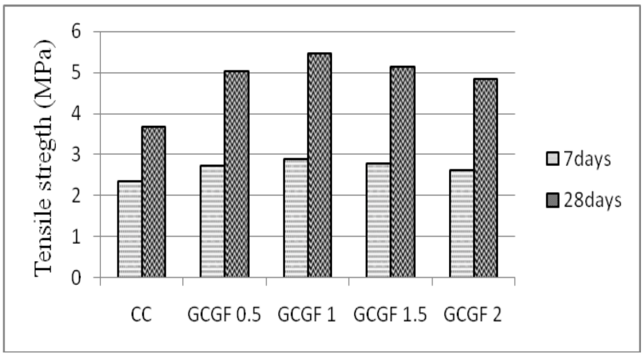

Fig. 9. Split Tensile Strength

D. Flexural Strength Test

From "Fig. 10", it is interpreted that strength of all mixes is better in contrast to normal concrete. The rise in strength may be because of shifting of tensile stresses to glass filaments from concrete [16]. The flexural strength of modified mixes at 28days is raised by 31.68% and 50% with 0.5% and 1% dosage of fiber. Similarly strength is increased by 41.61% and 43.17% at 1.5% and 2% fiber content. At 1%, flexural strength is high which is concluded as optimum mix.

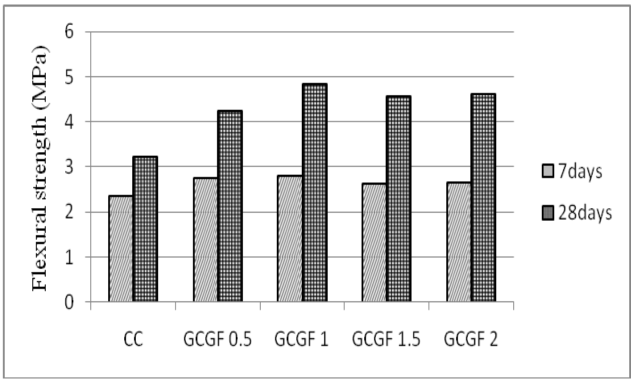

Fig. 10. Flexural Strength

E. Sorptivity

From "Fig. 11", it is observed that at 0.5%, its value is beyond control concrete. The emergence of the auxiliary C-S-H gel from the pozzolanic response of slag and coal ash helps in filling up of voids in concrete forming into a dense structure thereby reducing water absorption could be the reason for sorptivity reduction [26]. Sorptivity of modified mixes follows an ascending pattern with highest at 2% fiber dosage. The growth of pores with elevation in fiber content leading to improper interface with cement paste results in high water absorption [16].

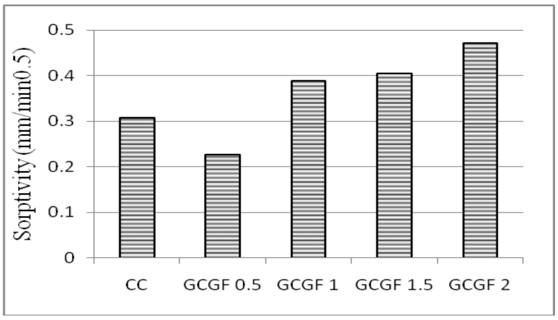

Fig. 11. Sorptivity

F. Acid Attack Test

- *Loss in Weight:* The "Fig. 12" and "Fig. 13" noted that weight loss of conventional concrete at any age is high and 5% acid concentration shows greater impact on weight loss than that of 3%. Weight loss of modified mixes is dropped by multiplying the dosage of fibers after 15days. At 30days, same pattern was observed as that of 15days. At 1% fiber dosage, weight loss is more for modified mixes at 60 and 90days and further inclusion of fibers deplete mass loss.

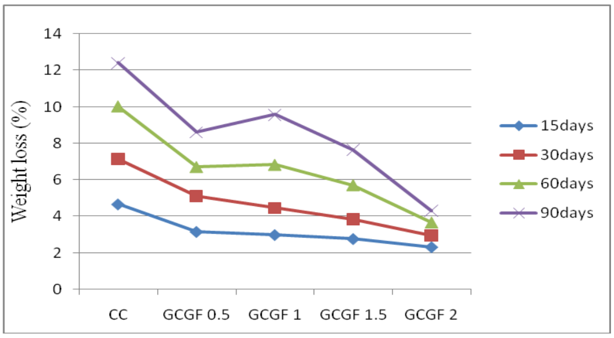

Fig. 12. Mass loss due to 3% H_2SO_4 attack

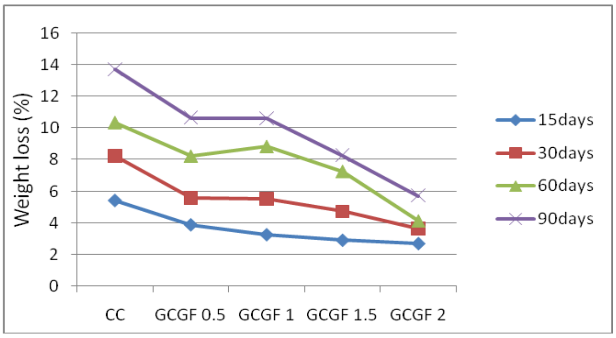

Fig. 13. Mass loss due to 3% H_2SO_4 attack

- *Loss in Compressive Strength:* From "Fig. 14" and "Fig. 15", it is spotted that strength depletion is intensified with age and is high for 5% H_2SO_4 attack in contrast to 3%. Strength loss is higher with 21.6% for 3% H_2SO_4 and 23.86% for 5% H_2SO_4 for control concrete. Also the strength loss of modified mixes is low at 1% fiber dosage which is optimum dosage and further addition of fibers resulted in increase in strength loss.

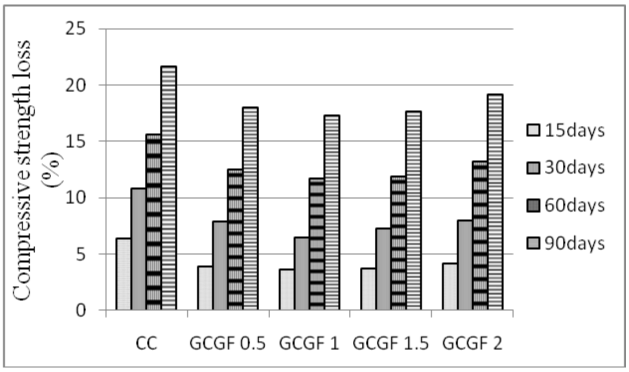

Fig. 14. Compressive strength loss due to 3% H_2SO_4

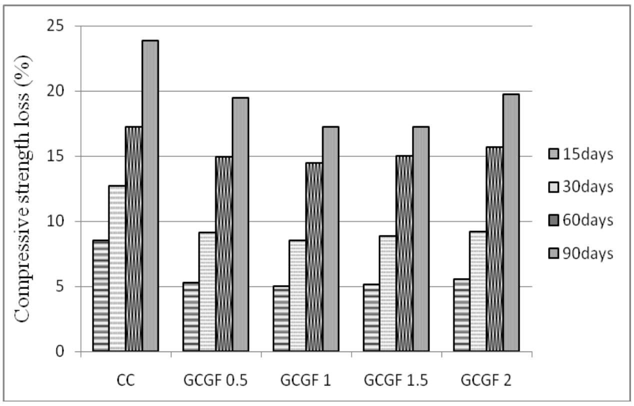

Fig. 15. Compressive strength loss due to 5% H_2SO_4

- *Acid Durability Factor:* "Fig. 16" and "Fig. 17" shows ADF values of 3% and 5% sulphuric acid attack. Results indicated that at optimum fiber dosage, ADF value is high at all ages. ADF of concrete under both acid concentrations at optimum dosage have approximately near values of 82.67% and 82.79%. ADF of blended mixes is high compared to conventional concrete.

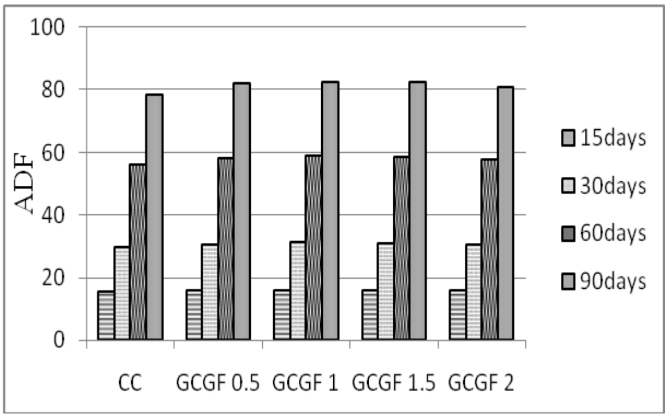

Fig. 16. ADF for 3% H_2SO_4

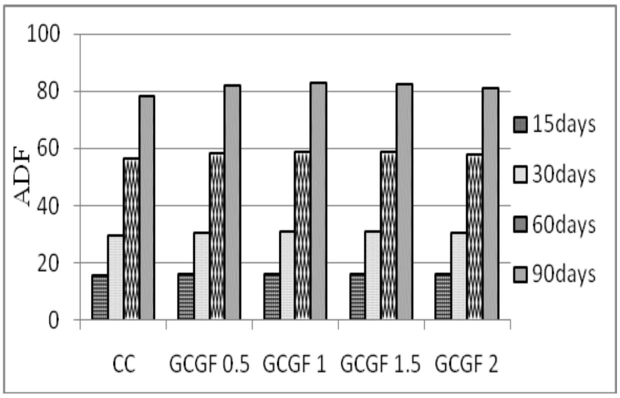

Fig. 17. ADF for 5% H_2SO_4

VII. CONCLUSIONS

The ensuing inferences are drawn from the prevailing study:

1. Workability declines by intensifying the dosage of fibers with or without using GGBS and coal ash.
2. Strength is enhanced up to 14.11% in compression, 48.37% in tension and 50% in flexure for 1% fiber dosage and beyond this, the strength decreases.
3. Sorptivity increases with elevation in the quantity of fibers in GGBS and coal ash blended GFRC.
4. Mass loss and strength depletion of GGBS and coal ash blended GFRC declines with rise in fiber dosage whereas acid durability factor improves.
5. Strength loss is low and Acid durability factor is high at optimum fiber dosage i.e., at 1%.

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