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# AN EXPERIMENTAL INVESTIGATION ON THE PROPERTIES OF TERNARY BLENDED FIBRE REINFORCED CONCRETE

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**Abstract:** *Extensive research work is in progress throughout the world in concrete technology to find alternative materials which can be partially or fully replace of Ordinary Portland Cement and which can also meet the required strength and durability, mainly aims at reducing cost and environmental effects due to cement manufacturing processes.. In the present study, Ordinary Portland Cement (OPC) of 43 grade is partially replaced by up to 30% of mineral admixtures such as, Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume (SF) and Red mud (RM) by weight of cement used in making Galvanized Iron (GI) Fibre Reinforced Concrete. GI Fibre Reinforced Concrete with 0.5% and 1.0% GI-Fibre content by volume fraction are considered for study $M_{30}$ grade of concrete with a constant Water-Cement ratio of 0.4 has been used in the work. The workability characteristics are studied through slump test. The strength characteristics of Ternary Blended GI Fibre Reinforced Concrete such as, compressive strength, split tensile strength and shear strength test are compared with Reference Mixes of 0.5% GI-FRC and 1.0% GI-FRC.*

*In this work, a total of 135 specimen have been cast and tested at 28 days for Compressive Strength, Split Tensile Strength and Shear Strength.*

*The Ternary Blended FRC with 20% Fly Ash and 10% Silica Fume replacement of cement has yielded maximum increase in Compressive Strength, Split Tensile Strength and Shear Strength compared with Reference Mixes of 0.5% GI-FRC and 1.0% GI-FRC.*

***Key Words:*** *Ternary Blended Concrete, Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume (SF), Red mud (RM), Galvanized Iron Fibres (GI Fibres).*

## 1. Introduction

Concrete is the most abundantly consumed material which is commonly utilized for the construction purposes all over the world. Many researches are going-on in the area of Concrete Technology to find alternative materials which can be partially or fully replace of Ordinary Portland Cement. Amongst some alternative materials tried for partial replacement of cement are mineral admixtures like Fly Ash, Ground Granulated Blast Furnace Slag, Silica Fume, Metakaolin, Red mud, Rice Husk Ash etc. Moreover, most of the mineral admixtures are the by-product materials and the use of these materials leads to reduction in waste and savings in energy consumption required to produce cement and blended mix concretes. Most recently the production of multi-blended concretes by incorporating industrial by-products/pozzolanic materials is becoming an active area of research due to their improved properties such as workability, long-term strength and durability. This leads to the development of Ternary Blended Concrete.

## 2. Objective of Experimental Work

The main objective of this experimental investigation is to study the Properties of Ternary Blended Fibre Reinforced Concrete (FRC) by partially replacing OPC with up to 30% of Fly Ash, GGBFS, Silica Fume and Red mud in different combinations of three. A design concrete mix of $M_{30}$ grade are proposed with a constant Water-Cement ratio of 0.4. The proposed FRC is to have Galvanized Iron Fibres (GI Fibres) at 0.5% and 1.0% by volume fraction.

Following combinations of cement replacement are proposed in this work to study their influence of the strength of Ternary Blended GI-FRC.

Ternary Blended Mixes 1 (TBM 1)

1. Cement + Fly Ash + GGBFS
2. Cement + Fly Ash + Silica Fume } in 70:15:15 proportion
3. Cement + Fly Ash + Red Mud

Ternary Blended Mixes 2 (TBM 2)

1. Cement + Fly Ash + GGBFS
2. Cement + Fly Ash + Silica Fume } in 70:20:10 proportion
3. Cement + Fly Ash + Red Mud

FRC: 0.5% GI-FRC is having 0.5% of GI Fibre content
1.0% GI-FRC is having 1.0% of GI Fibre content
i.e. 0.5% GI-FRC with TBM 1 has ternary blended mixes in 70:15:15 proportion.

0.5% GI-FRC with TBM 2 has ternary blended mixes in 70:20:10 proportion.

1.0% GI-FRC with TBM 1 has ternary blended mixes in 70:15:15 proportion.

1.0% GI-FRC with TBM 2 has ternary blended mixes in 70:20:10 proportion.

The two Reference Mixes are proposed to compare with 0.5% and 1.0% GI-FRC with TBM 1 and TBM 2 are as follows,

1. GI-FRC Mix of 0.5%
2. GI-FRC Mix of 1.0%

Slump test is proposed to be employed for studying workability characteristics. The Strength characteristics of Ternary Blended GI-FRC are proposed to be determined using Compressive Strength, Split Tensile Strength and Shear Strength test.

## 3. Materials and Methodology

The concrete mix of $M_{30}$ grade has been designed as per of IS 10262:2009 and it was prepared by using the following ingredients.

**3.1 Cement:** In this work Ordinary Portland Cement (OPC) of 43 grade produced by Ultra Tech has been used. The OPC is of uniform grey colour and free from lumps. The properties of cement obtained from testing as per IS 8112:1989 are shown in table 01.

Table 01. Test Results of Ultra Tech brand OPC of 43 grade

| Properties | Experimental Value | Limitations as per IS 8112:1989 |
|---|---|---|
| Fineness of Cement | 5.67% | Should not be greater than 10% |
| Normal Consistency | 29% | ---- |
| Initial Setting Time | 58 minutes | Should not be less than 30 minutes |
| Final Setting Time | 270 minutes | Should not be greater than 600 minutes |
| Specific Gravity | 3.15 | 2.5-3.15 |
| Compressive Strength<br>3 days<br>7 days<br>28 days | <br><br>28.23 MPa<br>37.23 MPa<br>46.93 MPa | <br><br>Minimum 23 MPa<br>Minimum 33 MPa<br>Minimum 43 MPa |

**3.2 Fine Aggregate:** Locally available Manufactured Sand (M-Sand) passing through 4.75mm IS sieve conforming to Zone I of IS 383:1970 has been used. The physical properties of fine aggregate i.e specific gravity, fineness modulus and water absorption were 2.3, 2.94 and 1% respectively.

**3.3 Coarse Aggregate:** Locally available crushed aggregate passing through 20mm IS sieve conforming to IS 383:1970 was used. The physical properties of coarse aggregate i.e specific gravity, fineness modulus and water absorption were 2.82, 6.88 and 0.55% respectively.

**3.4 Water:** Clean fresh water has been used for mixing and curing the specimens.

**3.5 Superplastizers:** To obtain better workability Conplast SP-430, superplasticizer admixtures are used in this work. The specific gravity of Conplast SP-430 is 1.18. For the present experimental work, according to mix design the dosage of 0.9% Conplast SP-430 by weight of cement are taken to achieve the slump of 50mm.

**3.6 Fly Ash (FA):** Low calcium, class F dry Fly Ash collected from Raichur Thermal Power Plant, Karnataka, conforming to IS 3812 (Part 1):2013. The specific gravity of Fly Ash is 2.3.

**3.7 Ground Granulated Blast Furnace Slag (GGBFS):** GGBFS collected from JSW Steel, Bellary, Karnataka, conforming to IS 12089:1987. The specific gravity of GGBFS is 2.88.

**3.8 Silica Fume (SF):** Silica Fume collected from Sai Durga Enterprises, Bengaluru, Karnataka, conforming to IS 15388:2003. The specific gravity of Silica Fume is 2.2.

**3.9 Red Mud (RM):** Red Mud has been collected from Hindalco Industried Limited, Belagavi, Karnataka. The specific gravity of Red Mud is 2.74.

**3.10 Galvanized Iron Fibres (GI Fibres):** In the present work GI Fibre of 1mm diameter and 50mm length is used with an aspect ratio of 50. GI Fibres are collected locally in the form of coils. The density of GI Fibres is 7850 kg/m$^3$.

## 4. Casting of Specimens

Following specimen are cast and cured in an immersion pond for 28 days,

1. Standard Cubes of (150x150x150)mm size as per IS 516:1959 for determining the Compressive Strength.[21]
2. Standard Cylinders of 150mm diameter and 300mm long as per IS 5816:1999 for determining the Split Tensile Strength.[22]
3. L-Shaped specimen are referred in ASCE Journals for determining the Shear Strength.[10]

4.1 Mix Design: Mix design for $M_{30}$ grade Concrete as per IS 10262:2009 has been carried out as shown in table 02.

Table 02. Concrete Mix Design Proportion (W/C = 0.4)

| Mix Type | Cement | Cement Replaced by Mineral Admixtures | Fine Aggregate | Coarse Aggregate |
|---|---|---|---|---|
| **1.** Reference 0.5% GI-FRC of $M_{30}$ grade | 1 | - | 1.604 | 3.209 |
| **2.** Reference 1.0% GI-FRC of $M_{30}$ grade | 1 | - | 1.604 | 3.209 |
| **3.** 0.5% GI-FRC with TBM 1 and TBM 2. | | | | |
| a) OPC + 15% FA + 15% GGBFS | 0.7 | 0.15 + 0.15 | 1.604 | 3.209 |
| b) OPC + 15% FA + 15% SF | 0.7 | 0.15 + 0.15 | 1.604 | 3.209 |
| c) OPC + 15% FA + 15% RM | 0.7 | 0.15 + 0.15 | 1.604 | 3.209 |
| d) OPC + 20% FA + 10% GGBFS | 0.7 | 0.20 + 0.10 | 1.604 | 3.209 |
| e) OPC + 20% FA + 10% SF | 0.7 | 0.20 + 0.10 | 1.604 | 3.209 |
| f) OPC + 20% FA + 10% RM | 0.7 | 0.20 + 0.10 | 1.604 | 3.209 |
| **4.** 1.0% GI-FRC with TBM 1 and TBM 2. | | | | |
| a) OPC + 15% FA + 15% GGBFS | 0.7 | 0.15 + 0.15 | 1.604 | 3.209 |
| b) OPC + 15% FA + 15% SF | 0.7 | 0.15 + 0.15 | 1.604 | 3.209 |
| c) OPC + 15% FA + 15% RM | 0.7 | 0.15 + 0.15 | 1.604 | 3.209 |
| d) OPC + 20% FA + 10% GGBFS | 0.7 | 0.20 + 0.10 | 1.604 | 3.209 |
| e) OPC + 20% FA + 10% SF | 0.7 | 0.20 + 0.10 | 1.604 | 3.209 |
| f) OPC + 20% FA + 10% RM | 0.7 | 0.20 + 0.10 | 1.604 | 3.209 |

Where, GI-FRC - Galvanized Iron Fibre Reinforced Concrete ; GI Fibres - Galvanized Iron
TBM - Ternary Blended Mixes ; OPC - Ordinary Portland Cement
FA - Fly Ash ; GGBFS - Ground Granulated Blast Furnace Slag
SF - Silica Fume ; RM - Red Mud

## 5. Results and Discussions

The results of Compressive Strength, Split Tensile Strength and Shear Strength tests are discussed below,

### 5.1Results of Compressive Strength

Table 03 shows, Comparative Results of Compressive Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade. The variations of strength is plotted in Fig. 01.

Table 03. Comparative Results of Compressive Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.

| Mix Type | Compressive Strength (MPa) | % increase or decrease of Compressive Strength |
|---|---|---|
| 1) Reference 0.5% GI-FRC of $M_{30}$ grade | 40.74 | - |
| 2) 0.5% GI-FRC + 15% FA + 15% GGBFS | 40.15 | -1.45 |
| 3) 0.5% GI-FRC + 15% FA + 15% SF | 41.04 | 0.74 |
| 4) 0.5% GI-FRC + 15% FA + 15% RM | 34.37 | -15.64 |
| 5) 0.5% GI-FRC + 20% | 39.26 | -3.63 |

| | | |
|---|---|---|
| FA + 10% GGBFS | | |
| 6) 0.5% GI-FRC + 20% FA + 10% SF | 42.37 | 4 |
| 7) 0.5% GI-FRC + 20% FA + 10% RM | 38.07 | -6.55 |
| 8) Reference 1.0% GI-FRC of $M_{30}$ grade | 42.81 | - |
| 9) 1.0% GI-FRC + 15% FA + 15% GGBFS | 42.07 | -1.73 |
| 10) 1.0% GI-FRC + 15% FA + 15% SF | 43.26 | 1.05 |
| 11) 1.0% GI-FRC + 15% FA + 15% RM | 37.48 | -12.45 |
| 12) 1.0% GI-FRC + 20% FA + 10% GGBFS | 40.74 | -4.84 |
| 13) 1.0% GI-FRC + 20% FA + 10% SF | 44.15 | 3.13 |
| 14) 1.0% GI-FRC + 20% FA + 10% RM | 39.85 | -6.91 |

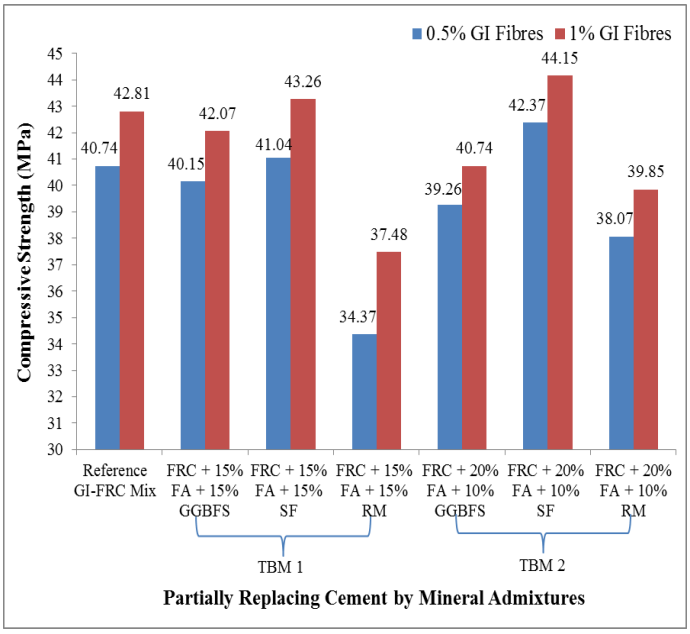


Fig. 01: Variation of Compressive Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.

It can be observed that the Compressive strength of Ternary blended FRC has shown maximum increase in strength for TBM 2 i.e., when Cement is partially replaced by 20% Fly Ash and 10% Silica Fume with 0.5% and 1.0% GI Fibre content. At this replacement combination, the increase is 4% for 0.5% GI-FRC of TBM 2 and 3.13% for 1.0% GI-FRC of TBM 2.

The Compressive strength of Ternary blended FRC has shown maximum decrease in strength for TBM 1 i.e., when Cement partially replaced by 15% Fly Ash and 15% Red Mud with 0.5% and 1.0% GI Fibre content. At this replacement combination, the reduction is 15.64% for 0.5% GI-FRC of TBM 1 and 12.45% for 1.0% GI-FRC of TBM 1.

### 5.2Results of Split Tensile Strength

Table 04 shows, Comparative Results of Split Tensile Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade. The variations of strength is plotted in Fig. 02.

Table 04. Comparative Results of Split Tensile Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.

| Mix Type | Split Tensile Strength (MPa) | % of increase or decrease of Split Tensile Strength |
|---|---|---|
| 1) Reference 0.5% GI-FRC of $M_{30}$ grade | 2.92 | - |
| 2) 0.5% GI-FRC + 15% FA + 15% GGBFS | 3.49 | 19.52 |
| 3) 0.5% GI-FRC + 15% FA + 15% SF | 3.35 | 14.73 |
| 4) 0.5% GI-FRC + 15% FA + 15% RM | 2.45 | -16.1 |
| 5) 0.5% GI-FRC + 20% FA + 10% GGBFS | 3.16 | 8.23 |
| 6) 0.5% GI-FRC + 20% FA + 10% SF | 3.72 | 27.40 |
| 7) 0.5% GI-FRC + 20% FA + 10% RM | 2.73 | -6.51 |
| 8) Reference 1.0% GI-FRC of $M_{30}$ grade | 3.06 | - |
| 9) 1.0% GI-FRC + 15% FA + 15% GGBFS | 3.63 | 18.63 |
| 10) 1.0% GI-FRC + 15% FA + 15% SF | 3.58 | 16.99 |
| 11) 1.0% GI-FRC + 15% FA + 15% RM | 2.5 | -18.3 |
| 12) 1.0% GI-FRC + 20% FA + 10% GGBFS | 3.3 | 7.84 |
| 13) 1.0% GI-FRC + 20% FA + 10% SF | 3.87 | 26.47 |
| 14) 1.0% GI-FRC + 20% FA + 10% RM | 2.88 | -5.88 |

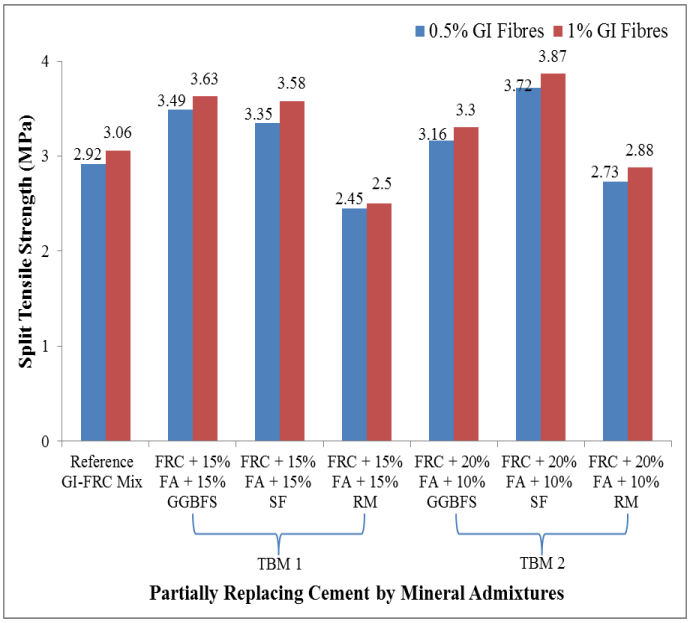


Fig. 02: Variation of Split Tensile Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.

It can be observed that the Split Tensile strength of Ternary blended FRC has shown maximum increase in strength for TBM 2 i.e., when Cement is partially replaced by 20% Fly Ash and 10% Silica Fume with 0.5% and 1.0% GI Fibre content. At this replacement combination, the increase is 27.40% for 0.5% GI-FRC of TBM 2 and 26.47% for 1.0% GI-FRC of TBM 2.

The Split Tensile strength of Ternary blended FRC has shown maximum decrease in strength for TBM 1 i.e., when Cement is partially replaced by 15% Fly Ash and 15% Red Mud with 0.5% and 1.0% GI Fibre content. At this replacement combination, the reduction is 16.10% for 0.5% GI-FRC of TBM 1 and 18.30% for 1.0% GI-FRC of TBM 1.

### 5.3 Results of Shear Strength

Table 05 shows, Comparative results of Shear Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade. The variations of strength is plotted in Fig. 03.

Table 05. Comparative Results of Shear Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.

| Mix Type | Shear Strength (MPa) | % increase or decrease of Shear Strength |
|---|---|---|
| 1) Reference 0.5% GI-FRC of $M_{30}$ grade | 8.7 | - |
| 2) 0.5% GI-FRC + 15% FA + 15% GGBFS | 8.52 | -2.07 |
| 3) 0.5% GI-FRC + 15% FA + 15% SF | 9.07 | 4.25 |
| 4) 0.5% GI-FRC + 15% FA + 15% RM | 5.74 | -34.02 |
| 5) 0.5% GI-FRC + 20% FA + 10% GGBFS | 9.63 | 10.69 |
| 6) 0.5% GI-FRC + 20% FA + 10% SF | 10.19 | 17.13 |
| 7) 0.5% GI-FRC + 20% FA + 10% RM | 7.59 | -12.76 |
| 8) Reference 1.0% GI-FRC of $M_{30}$ grade | 9.81 | - |
| 9) 1.0% GI-FRC + 15% FA + 15% GGBFS | 9.26 | -5.61 |
| 10) 1.0% GI-FRC + 15% FA + 15% SF | 9.63 | -1.83 |
| 11) 1.0% GI-FRC + 15% FA + 15% RM | 6.85 | -30.17 |
| 12) 1.0% GI-FRC + 20% FA + 10% GGBFS | 10.37 | 5.71 |
| 13) 1.0% GI-FRC + 20% FA + 10% SF | 11.3 | 15.19 |
| 14) 1.0% GI-FRC + 20% FA + 10% RM | 8.52 | -13.15 |

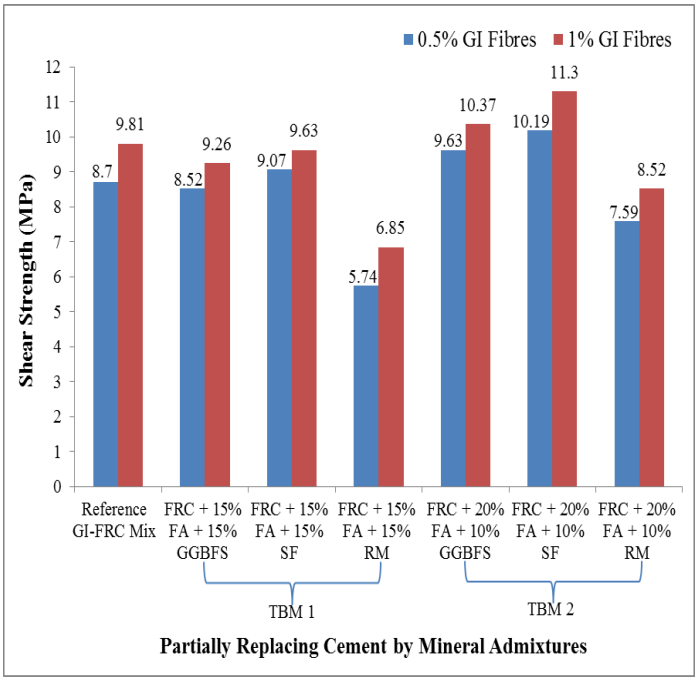


Fig. 03: Variation of Shear Strength of GI-FRC with TBM 1 and TBM 2 with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.

It can be observed that the Shear strength of Ternary blended FRC has shown maximum increase in strength for TBM 2 i.e., when Cement is partially replaced by 20% Fly Ash and 10% Silica Fume with 0.5% and 1.0% GI Fibre content.

At this replacement combination, the increase is 17.13% for 0.5% GI-FRC of TBM 2 and 15.19% for 1.0% GI-FRC of TBM 2.

The Shear strength of Ternary blended FRC has shown maximum decrease in strength for TBM 1 i.e., when Cement is partially replaced by 15% Fly Ash and 15% Red Mud with 0.5% and 1.0% GI Fibre content. At this replacement combination, the reduction is 34.02% for 0.5% GI-FRC of TBM 1 and 30.17% for 1.0% GI-FRC of TBM 1.

**Conclusions**

The following conclusions are drawn from the analysis of results for various strength tests,

1. The Compressive Strength of Ternary Blended FRC has shown maximum increase in Strength for TBM 2 i.e., when Cement is partially replaced by 20% Fly Ash and 10% Silica Fume for 0.5% and 1.0% GI Fibre content. For this replacement combination, the increase is 4% for 0.5% GI-FRC of TBM 2 and 3.13% for 1.0% GI-FRC of TBM 2 are compared with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.
2. The Split Tensile Strength of Ternary Blended FRC has shown maximum increase in Strength for TBM 2 i.e., when Cement is partially replaced by 20% Fly Ash and 10% Silica Fume with 0.5% and 1.0% GI Fibre content. For this replacement combination, the increase is 27.40% for 0.5% GI-FRC of TBM 2 and 26.47% for 1.0% GI-FRC of TBM 2 are compared with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.
3. The Shear Strength of Ternary Blended FRC has shown maximum increase in Strength for TBM 2 i.e., when Cement is partially replaced by 20% Fly Ash and 10% Silica Fume with 0.5% and 1.0% GI Fibre content. For this replacement combination, the increase is 17.13% for 0.5% GI-FRC of TBM 2 and 15.19% for 1.0% GI-FRC of TBM 2 are compared with Reference 0.5% and 1.0% GI-FRC of $M_{30}$ grade.
4. The Strength of Ternary Blended Cement Fibre Reinforced Concrete has increased in case of TBM 2 (20% Fly Ash and 10% Silica Fume). Therefore, it is recommended that partial replacement of Cement by Fly Ash and Silica Fume be used in FRC for better Strength. The durability is also expected to be high due to reduced voids and micro voids.
5. The Strength of FRCs with TBM 1 (15% Fly Ash and 15% Red Mud) has shown reduction. This is probably due to reduced workability at higher Red Mud content.

**Scope for Future Study**

The Following work can be taken up for better understanding of the performance of Ternary Blended Fibre Reinforced Concrete,

1. Ordinary Portland Cement can be further replace by mineral admixtures such as, Metakaolin, Quartz Powder, Rice Husk Ash, Bagasse Ash, Wood Ash.
2. Manufactured Sand be partially or fully replaced with Steel Slag or River Sand.
3. Ternary Blended FRC be partially replaced with Recycled Aggregates.
4. Ternary Blended FRC with different types of Fibres like, Steel Fibres, Glass Fibres, Polypropylene Fibres, Carbon Fibres can be added instead of GI Fibres.
5. The Effects of Ternary Blended FRC on Flexure Strength and Impact Strength.
6. Durability studies on Ternary Blended FRC.

**References**

1. G. Dhinakaran, K. Revanth Kumar, S. Vijayarakhavan, M. Avinash, Strength characteristics of ternary blend and lightweight HPC, Elsevier, 6th January 2017, Vol. 134, pp. 727–736.
2. G.V. Ramana, Malsani Potharaju, N. V. Mahure and Murari Ratnam, Strength studies of multi blended concretes containing fly ash and silica fume, The Indian Concrete Journal, March 2016, Vol. 41, pp. 221-234.
3. R Rathan Raj, E B Perumal Pillai, A R Santhakumar, Evaluation and mix design for ternary blended high strength concrete, Elsevier, January 2013, Vol. 51, pp. 65-74.
4. P Sarika, D.Audinarayana, Dr. Seshadri Sekhar T, Dr. Srinivasa Rao, Dr P Sravana G.Apparao, Studies on Compressive Strength Of Ternary Blended Concretes At Different Water Binder Ratios, American Journal of Engineering Research (AJER), September 2013, Vol. 02, pp. 37-45.
5. Bun Kim Ngun, Hasmaliza Mohamad, Etsuo Sakai and Zainal Arifin Ahmad, Effect of rice husk ash and silica fume in ternary system on the properties of blended cement paste and concrete, Journal of Ceramic Processing Research, June 2010, Vol. 11, pp. 311-315.
6. Mehmet Gesoglu, Erhan Guneyisi, Erdogan Ozbay, Properties of self-compacting concretes made with binary and ternary cementitious blends of fly ash, blast furnace slag and silica fume, Elsevier, 6th November 2009, Vol. 23, pp. 1847–1854
7. Ravi.K, K.B.Prakash, Strength characteristics of hybrid fibre reinforced self compacting concrete subjected to sustained elevated temperature, 33rd Conference on Our World in Concrete and Structures, 25th August 2008, Singapore.
8. A.K. Mullick, Performance of concrete with binary and ternary cement blends, The Indian Concrete Journal, January 2007, Vol. 79, pp. 13-22.
9. M.D.A. Thomas, M.H. Shehata, S.G. Shashiprakash, D.S. Hopkins, K. Cail, Use of ternary cementitious systems containing silica fume and fly ash in concrete, Cement and Concrete Research, 19th April 1999, Vol. 29, pp. 1207-1214.

10. Arjun Ramakrishna Kurup, K. Senthil Kumar, Effect of Recycled PVC Fibres from Electronic Waste and Silica Powder on Shear Strength of Concrete, American Society of Civil Engineering (ASCE), 2nd November 2016, Vol. 03, pp. 48-51.

**Text Books**

11. M S Shetty, Concrete Technology, S Chand Publishing, December 2006.
12. Dr. B C Punmia, Ashok Kumar Jain, Arun Kumar Jain, Building Construction, Laxmi Publications Pvt. Ltd. March 2008.

**IS Codes**

13. IS 10262:2009, Indian Standard Concrete Mix Proportioning, Bureau of Indian Standards, New Delhi.
14. IS 2386(Part 3):1963, Indian Standard Method of Test for Aggregates for Concrete, Bureau of Indian Standards, New Delhi.
15. IS 383:1970, Indian Standard Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standards, New Delhi.
16. IS 8112:1989, Indian Standard Specification for 43 grade Ordinary Portland Cement, Bureau of Indian Standards, New Delhi.
17. IS 3812 (Part 1):2013, Indian Standard Specification for Pulverized Fuel Ash, Bureau of Indian Standards, New Delhi.
18. IS 12089:1987, Indian Standard Specification for Granulated Slag for the Manufacture of Portland Slag Cement, Bureau of Indian Standards, New Delhi.
19. IS 15388:2003, Indian Standard Specification for Silica Fume, Bureau of Indian Standards, New Delhi.
20. IS 456:2000, Indian Standard code of Practice for Plain and Reinforced Cement Concrete, Bureau of Indian Standards, New Delhi.
21. IS 516:1959, Indian Standard Methods of Tests for Strength of concrete, Bureau of Indian Standards, New Delhi.
22. IS 5816:1999, Indian Standard Methods of Test for Splitting Tensile Strength of Concrete, Bureau of Indian Standards, New Delhi.