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# EXPERIMENTAL EVALUATION OF THE SPLIT TENSILE STRENGTH OF COMBINED FIBER REINFORCED GEOPOLYMER CONCRETE.

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***Abstract: The experimental program consisted of determination of the Split Tensile Strength ($f_{ct}$) of the Combined fiber Reinforced Geopolymer Concrete (CFRGPC) by casting and testing cylinders of size 100 mm wide 200 mm long. Two different Ground Granulated Blast Furnace Slag (GGBS) to Fly Ash (FA) ratios (60:40, 40:60) are used. Three different Molarities 8, 10 and 12 are used. For making CFRGPC, combined fiber combinations R0S10, R2S8, R4S6, R6S4, R8S2 and R10S0 are used. Three identical specimens for each variation were cast and tested for 7 days and 28 days ambient curing. Two Parameters called 'Binder Index and Modified Binder Index' are introduced to quantify the effects of molarity, GGBS, fly ash and fiber effect on split Tensile Strength of CFRGPC is presented.***

***Key words: Split tensile strength ($f_{ct}$), Combinded fiber reinforced Geopolymer Concrete (CFRGPC), Combination fibers (Rigid and Soft), Fly ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Aambient temperature, alkaline solutions (Molarity).***

## 1. INTRODUCTION:

The global warming is caused by the emission of greenhouse gases like carbon dioxide ($CO_2$) to the atmosphere. The cement industry contributes about 65% of global warming by emitting carbon dioxide to the atmosphere [1]. Several researches are in progress to invent the alternative material for cement. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement. In terms of global warming the Geopolymer technology could significantly reduce the $CO_2$ emissions to the atmosphere caused by the cement industries. In India, one of the major sources of material for power generation is coal and it's by product, fly ash is an environmental threat to the environment. Statistics shows that during the year 2016 -2017, production of fly ash in India was 169.6 Million tons .Two types of materials are required to make Geopolymer one is the source material containing alumina, silica and other is an alkali that activates the polymerization reaction. Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by product materials such as fly ash, blast furnace slag to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term Geopolymer to represent these binders [2]. For the preparation of the alkali solution a single alkali type or a mixture of different alkalis can be used. The most commonly used alkali for the manufacture of Geopolymer is a mixture of the solutions of NaOH and $Na_2SiO_3$. Prudon, cited by Torgal carried out investigation on the formation of alkali activated cement (binder) in 1940.The investigator used blast furnace slag as alumina silicate material and sodium hydroxide as alkali [3]. Since then alkali activation studies were carried out in different countries but it picked up momentum only in the 1990's. Keeping in view of the past research work done on Geopolymer concrete the present experimental investigation is aimed at studying the effect of combination fibers on Split tensile strength of Geopolymer concrete. The Split tensile strength of combined fiber reinforced Geopolymer concrete (CFRGPC) is studied by adding the fibers (Steel and Polypropylene) in different volume proportions. Two Parameters called **Binder Index and Modified Binder Index** are introduced to quantify the effects of molarity, fly ash, GGBS and fiber effect on Split tensile strength of combined fiber reinforced Geopolymer concrete is presented.

### 2.0 EXPERIMENTAL PROGRAM:

The experimental program consisted of determination of the Split tensile strength of CFRGPC by casting and testing cylinders of size 100 mm wide and 200 mm long. Two different Flyash to GGBS proportions 60:40 and 40:60 are used. Three different alkaline molar activators 8, 10 and 12 are used. For making CFRGPC, combined fiber combinations R0S10, R2S8, R4S6, R6S4, R8S2 and R10S0 are used. Three identical specimens for each variation were cast and tested after 7 days and 28 days of ambient curing.

**2.1 Materials:** Fly ash is obtained from Kothagudem Thermal Power Station, Bhadradri Kothagudem Dist, Telangana, India. GGBS is obtained from Blue way exports supplier, from Vijayawada, Andhra Pradesh, India. Specific gravity of Fly ash and GGBS are 2.17 and 2.90 respectively. Chemical composition details of fly ash and GGBS are shown in Table 1. Natural river sand confirming to grading zone II of IS 383:1970 was used. Specific gravity and fineness modulus of sand used were 2.32 and 2.81 respectively. Coarse aggregate of maximum size 12 mm from local source was used. Hooked end steel fibers of aspect ratio 60 with tensile Strength 1100 Mpa, is used. Polypropylene fiber (Recron 3S) of length 12mm and diameter 20 microns with tensile Strength 490.3 Mpa is used. The density of Rigid and Soft fibers is 7850 Kg/m$^3$ and 946 Kg/m$^3$ respectively. The alkaline molar activators of sodium hydroxide solution used are 8, 10 and 12. The sodium hydroxide pellets used for preparation of NaOH solution is given in table 2. The NaOH solution thus prepared is mixed with $Na_2SiO_3$ solution. The ratio of sodium silicate solution to sodium hydroxide solution is fixed as 2.5[4, 5, 6]. The mixture was stored for 24 hours at room temperature before casting. Super Plasticizer Conplast Sp-430 is used to obtain the desired workability.

TABLE 1. CHEMICAL COMPOSITION OF FLYASH AND GGBS PERCENTAGE BY MASS.

| Material | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $SO_3$ | CaO | MgO | $Na_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|
| Fly ash | 60.12 | 26.63 | 4.22 | 0.32 | 4.1 | 1.21 | 0.2 | 0.85 |
| GGBS | 34.16 | 20.1 | 0.81 | 0.88 | 32.8 | 7.69 | nd | . |

TABLE 2. MATERIALS USED FOR NAOH SOLUTION PREPARATION.

| | 8 moles/L | 10 moles/L | 12 moles/L |
|---|---|---|---|
| Sodium hydroxide pellets , (grams) | 262 | 314 | 361 |
| Potable Water (grams) | 738 | 686 | 639 |

**2.1 Mix proportions:** The unit weight of Geopolymer concrete is 2400 Kg/m$^3$.
The Geopolymer concrete and fiber mix proportions are shown in table 3 and 4.

TABLE 3. GPC MIX PROPORTION.

| FA:GGBS | Molarity(M) | Combined fiber reinforced Geopolymer concrete Composition (Kg/m$^3$ ) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Coarse Aggregate | Fine Aggregate | Fly Ash | GGBS | NaOH Solution | Sodium Silicate | Super Plasticizer(2% of the Binder) | Extra water (7.5% of the Binder) |
| 60:40 | 8 | 1100 | 517.45 | 345.10 | 230.10 | 59.10 | 148.25 | 11.50 | 43.15 |
| 60:40 | 10 | 1100 | 517.45 | 345.10 | 230.10 | 59.10 | 148.25 | 11.50 | 43.15 |
| 60:40 | 12 | 1100 | 517.45 | 345.10 | 230.10 | 59.10 | 148.25 | 11.50 | 43.15 |
| 40:60 | 8 | 1100 | 517.45 | 230.10 | 345.10 | 59.10 | 148.25 | 11.50 | 43.15 |
| 40:60 | 10 | 1100 | 517.45 | 230.10 | 345.10 | 59.10 | 148.25 | 11.50 | 43.15 |
| 40:60 | 12 | 1100 | 517.45 | 230.10 | 345.10 | 59.10 | 148.25 | 11.50 | 43.15 |

TABLE 4. FIBER MIX PROPORTION.

| Combined fiber mix proportions | | | | |
|---|---|---|---|---|
| @fiber designation. | Rigid fiber volume fraction (%) | Soft Fiber volume fraction (%) | Rigid fiber weight ($Kg/m^3$) | Soft fiber weight ($Kg/m^3$) |
| R0S10 | 0 | 1 | 0 | 9.5 |
| R2S8 | 0.20 | 0.80 | 15.7 | 7.6 |
| R4S6 | 0.40 | 0.60 | 31.4 | 5.7 |
| R6S4 | 0.60 | 0.40 | 47.1 | 3.8 |
| R8S2 | 0.80 | 0.20 | 62.8 | 1.9 |
| R10S0 | 1 | 0 | 78.5 | 0 |

**@** 1st letter indicates the Rigid fiber designation (R), 2nd letter indicates the volume fraction percentage for Rigid fiber (0,0.2,0.4,0.6,0.8 &1), 3rd letter indicates the Soft fiber designation (S) and 4th letter indicates the volume fraction percentage for Soft fiber (1,0.8,0.6,0.4,0.2 & 0).

**2.2 Casting of CFRGPC specimens:** The solids constituents of the CFRGPC i.e. the aggregates, fly ash, GGBS and fibers (Rigid and Soft) were dry mixed for about three minutes. The liquid part of the mixtures i.e. the alkaline solution, added water and the super plasticiser were premixed then added to the solids. The wet mixing usually continued for another four minutes. The fresh CFRGPC concrete was dark in colour and shiny in appearance. The mixtures were usually very cohesive. The workability of the fresh concrete was measured by means of the conventional slump test. Compaction of fresh concrete in the cylindrical moulds was done in three equal layers followed by compaction on a vibration table for ten seconds. The demoulding was done after 24 hours and kept for ambient curing.

**2.3 Split Tensile Strength:** The Split tensile strength tests on hardened CFRGPC were performed on a 1000 kN capacity universal testing machine in accordance to the relevant Indian Standard code IS 516[7]. Three identical 100 mm wide 200 mm long CFRGPC cylinders for each variation were tested for their average Split Tensile strength. The results given in the various Figures and Tables are the mean of these values. To know the combined effect of fly ash, GGBS and molarity of alkaline activator on CFRGPC parameter called binder index is introduced. Binder index is taken as the product of molarity of alkaline activator and binder's ratio, as given below [8, 9, 10].

**Binder Index = Molarity x [GGBS / (GGBS + Fly Ash)]**......eq (1)

TABLE 5. SPLIT TENSILE STRENGTH VALUES OF COMBINED FIBER REINFORCED GEOPOLYMER CONCRETE

| FA:GGBS | Molarity(M) | Binder Index | Split tensile strength values of Combined fiber reinforced Geopolymer concrete(CFRGPC) (Mpa) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | R0S10 | | R2S8 | | R4S6 | | R6S4 | | R8S2 | | R10S0 | |
| | | | 7D | 28D | 7D | 28D | 7D | 28D | 7D | 28D | 7D | 28D | 7D | 28D |
| 60:40 | 8 | 3.2 | 3.34 | 4.14 | 3.50 | 4.33 | 3.79 | 4.52 | 4.04 | 4.75 | 4.46 | 5.41 | 4.78 | 5.73 |
| 60:40 | 10 | 4 | 3.66 | 4.24 | 3.79 | 4.75 | 3.98 | 4.97 | 4.30 | 5.4 | 4.84 | 5.83 | 5.13 | 6.37 |
| 60:40 | 12 | 4.8 | 4.14 | 4.62 | 4.43 | 5.10 | 4.84 | 5.89 | 5.19 | 7.17 | 5.73 | 7.50 | 6.15 | 8.15 |
| 40:60 | 8 | 4.8 | 3.41 | 4.30 | 3.82 | 4.65 | 4.04 | 4.68 | 4.39 | 4.94 | 4.62 | 5.83 | 5.06 | 6.34 |
| 40:60 | 10 | 6 | 3.79 | 4.52 | 4.08 | 5.16 | 4.46 | 5.10 | 4.84 | 5.45 | 6.05 | 6.69 | 6.53 | 7.64 |
| 40:60 | 12 | 7.2 | 4.78 | 5.38 | 5.19 | 6.05 | 5.41 | 6.85 | 5.70 | 7.2 | 6.40 | 7.64 | 7.0 | 8.5 |

**Modified Binder Index (P):** To know the effect of combination fibers on Split Tensile Strength of Combined fiber Reinforced Geopolymer Concrete (CFRGPC), modified binder index combining the effect of Binder index, tensile strength and volume fraction of fibers shall be calculated for each fiber combination. To account for the reduced effect of soft fibers in combination fibers a factor 0.85 has been introduced, while evaluating modified binder index [9, 10].

Modified binder index (P) = $B_i$ x ($\sqrt{F_{ef}}$).....eq(2)

Where $F_{ef}$ is fiber effect. $F_{ef} = (F_{tr} \times V_{fr} + F_{ts} \times V_{fs})$ .....eq(3)

$F_{tr}$ = Tensile strength of Rigid fiber = 1450Mpa, $V_{fr}$=Volume fraction of rigid fiber,
$F_{ts}$ =Tensile strength of soft fiber =490.33Mpa, $V_{fs}$=Volume fraction of soft fiber.

Modified binder index for combination fibers is formulated as follows.

Modified binder index ($P_{cf}$) = $B_i$ X [$\sqrt{RF_{ef}}$ +0.85 $\sqrt{SF_{ef}}$] ...eq(4)

TABLE 6. FIBER EFFECT FOR COMBINATION OF FIBERS

| fiber designation | fiber designation | fiber designation | Binder index | $\sqrt{RF_{ef}}$ | $\sqrt{SF_{ef}}$ | 0.85 $\sqrt{SF_{ef}}$ | $\sqrt{RF_{ef}}$ +0.85 $\sqrt{SF_{ef}}$ |
|---|---|---|---|---|---|---|---|
| R0S10 | R0 | S10 | 3.2 | 0 | 2.21 | 1.88 | 1.88 |
| R2S8 | R2 | S8 | 4 | 1.70 | 1.98 | 1.68 | 3.38 |
| R4S6 | R4 | S6 | 4.8 | 2.40 | 1.72 | 1.46 | 3.86 |
| R6S4 | R6 | S4 | 4.8 | 2.95 | 1.96 | 1.2 | 4.15 |
| R8S2 | R8 | S2 | 6 | 3.40 | 0.98 | 0.83 | 4.23 |
| R10S0 | R10 | S0 | 7.2 | 3.80 | 0 | 0 | 3.80 |

TABLE 7. MODIFIED BINDER INDEX FOR COMBINATION OF FIBERS

| Molarity | Binder Index | Modified binder Index for combined fiber reinforced geopolymer concrete | | | | | |
|---|---|---|---|---|---|---|---|
| | | $P_{cf} = B_i$ X [ $\sqrt{RF_{ef}}$ + 0.85$\sqrt{SF_{ef}}$] | | | | | |
| | | R0S10 | R2S8 | R4S6 | R6S4 | R8S2 | R10S0 |
| 8 | 3.2 | 6.01 | 10.816 | 12.352 | 13.28 | 13.536 | 12.16 |
| 10 | 4 | 7.52 | 13.52 | 15.44 | 16.6 | 16.92 | 15.2 |
| 12 | 4.8 | 9.02 | 16.224 | 18.528 | 19.92 | 20.304 | 18.24 |
| 8 | 4.8 | 9.02 | 16.224 | 18.528 | 19.92 | 20.304 | 18.24 |
| 10 | 6 | 11.28 | 20.28 | 23.16 | 24.9 | 25.38 | 22.8 |
| 12 | 7.2 | 13.54 | 24.336 | 27.792 | 29.88 | 30.456 | 27.36 |

TABLE 8. BINDER INDEX Vs SPLIT TENSILE STRENGTH OF CFRGPC

| S.No | Binder Index | Modified binder index | Split tensile strength of CFRGPC | | Ratio of 7 day strength to 28 day strength of CFRGPC |
|---|---|---|---|---|---|
| | | | 7 days | 28 days | 7D/28D |
| 1 | 3.2 | 6.01 | 3.34 | 4.14 | 0.807 |
| 2 | 4 | 7.52 | 3.66 | 4.24 | 0.863 |
| 3 | 4.8 | 9.02 | 4.14 | 4.62 | 0.896 |
| 4 | 4.8 | 9.02 | 3.41 | 4.30 | 0.793 |
| 5 | 6 | 11.28 | 3.79 | 4.52 | 0.838 |
| 6 | 7.2 | 13.54 | 4.78 | 5.38 | 0.888 |
| 7 | 3.2 | 10.816 | 3.50 | 4.33 | 0.808 |
| 8 | 4 | 13.52 | 3.79 | 4.75 | 0.798 |
| 9 | 4.8 | 16.224 | 4.43 | 5.10 | 0.869 |
| 10 | 4.8 | 16.224 | 3.82 | 4.65 | 0.822 |

| | | | | | |
|---|---|---|---|---|---|
| 11 | 6 | 20.28 | 4.08 | 5.16 | 0.791 |
| 12 | 7.2 | 24.336 | 5.19 | 6.05 | 0.858 |
| 13 | 3.2 | 12.352 | 3.79 | 4.52 | 0.838 |
| 14 | 4 | 15.44 | 3.98 | 4.97 | 0.801 |
| 15 | 4.8 | 18.528 | 4.84 | 5.89 | 0.822 |
| 16 | 4.8 | 18.528 | 4.04 | 4.68 | 0.863 |
| 17 | 6 | 23.16 | 4.46 | 5.10 | 0.875 |
| 18 | 7.2 | 27.792 | 5.41 | 6.85 | 0.790 |
| 19 | 3.2 | 13.28 | 4.04 | 4.75 | 0.851 |
| 20 | 4 | 16.6 | 4.30 | 5.4 | 0.796 |
| 21 | 4.8 | 19.92 | 5.19 | 7.17 | 0.724 |
| 22 | 4.8 | 19.92 | 4.39 | 4.94 | 0.889 |
| 23 | 6 | 24.9 | 4.84 | 5.45 | 0.888 |
| 24 | 7.2 | 29.88 | 5.70 | 7.2 | 0.792 |
| 25 | 3.2 | 13.536 | 4.46 | 5.41 | 0.824 |
| 26 | 4 | 16.92 | 4.84 | 5.83 | 0.830 |
| 27 | 4.8 | 20.304 | 5.73 | 7.50 | 0.764 |
| 28 | 4.8 | 20.304 | 4.62 | 5.83 | 0.792 |
| 29 | 6 | 25.38 | 6.05 | 6.69 | 0.904 |
| 30 | 7.2 | 30.456 | 6.40 | 7.64 | 0.838 |
| 31 | 3.2 | 12.16 | 4.78 | 5.73 | 0.834 |
| 32 | 4 | 15.2 | 5.13 | 6.37 | 0.805 |
| 33 | 4.8 | 18.24 | 6.15 | 8.15 | 0.755 |
| 34 | 4.8 | 18.24 | 5.06 | 6.34 | 0.798 |
| 35 | 6 | 22.8 | 6.53 | 7.64 | 0.855 |
| 36 | 7.2 | 27.36 | 7.0 | 8.5 | 0.824 |

The variation of Split tensile strength with combination fibers is shown in fig 1. To fig 6.

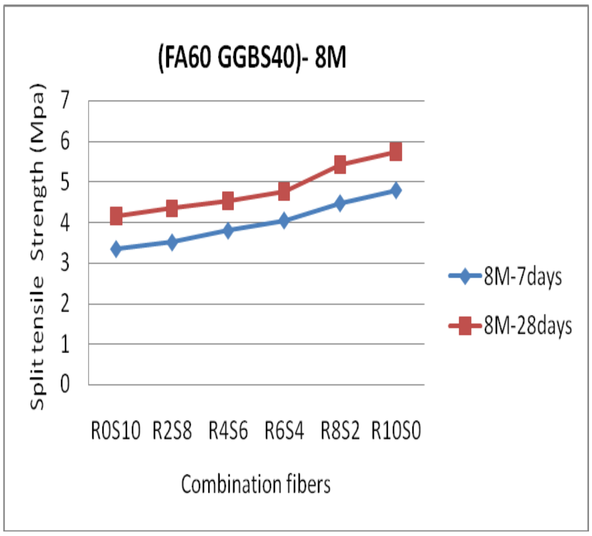


Fig.1 Combination fiber effect on split tensile Strength of CFRGPC

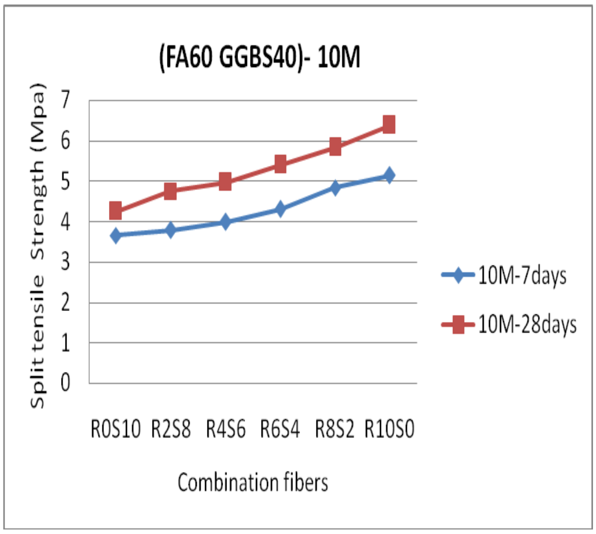


Fig.2 Combination fiber effect on split tensile strength of CFRGPC

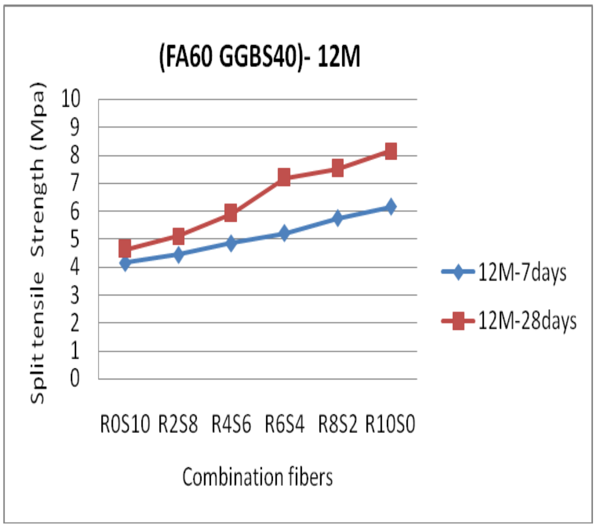


Fig.3 Combination fiber effect on split tensile Strength of CFRGPC

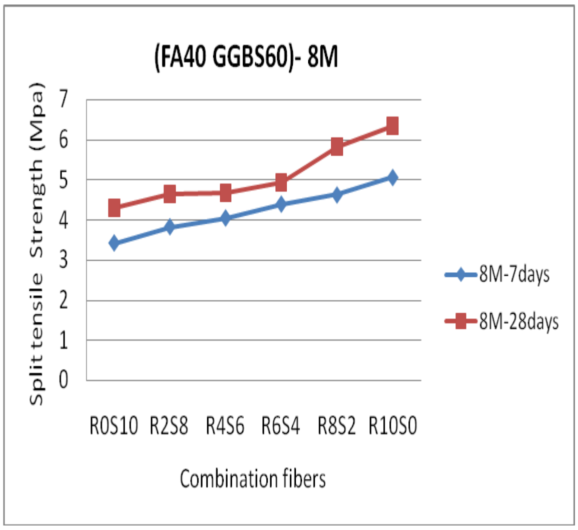


Fig.4 Combination fiber effect on split tensile strength of CFRGPC

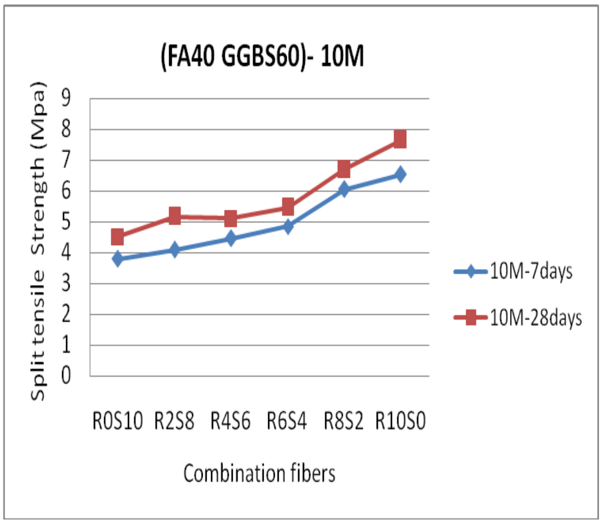


Fig.5 Combination fiber effect on split tensile Strength of CFRGPC

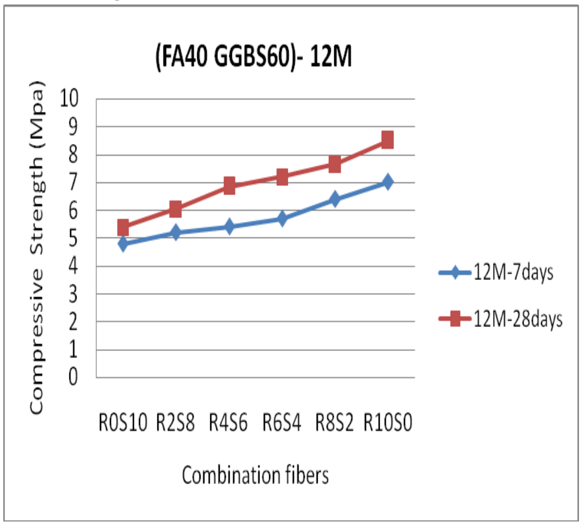


Fig.6 Combination fiber effect on split tensile Strength of CFRGPC

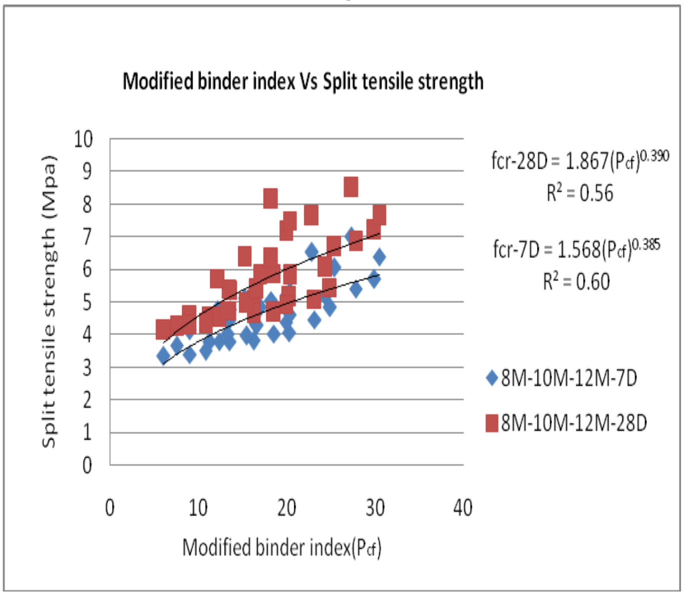


Fig.7 Modified binder index effect on split tensile strength of Combined fiber reinforced Gopolymer concrete .

### 3.1 Effect of molarity of alkaline activator on split tensile strength of Combined Fiber Reinforced Geopolymer concrete.

The effect of molarity of alkaline activator for different fiber combinations is shown in fig 1 to fig 6. In general as the molarity increased the 7 days and 28 days, split tensile strength of combined fiber reinforced Geopolymer concrete increased.

### 3.2 Effect of fiber combinations on split tensile strength of Combined Fiber reinforced Geopolymer concrete

From fig 1 to fig 6, it is observed that for any choosen molarity of alkaline activator and GGBS to FA ratio, the 7 days and 28 days, split tensile strength of combined fiber reinforced Geopolymer concrete increased with increase in rigid fiber proportions.

### 3.3 Effect of binder index on the split tensile strength of Combined Fiber Reinforced Geopolymer concrete.

From table 5, it is observed that the 7 days and 28 days, split tensile strength of combined fiber reinforced Geopolymer concrete increased with the increase in binder index values.

### 3.4 Effect of modified binder index on the split tensile strength of Combined Fiber Reinforced Geopolymer concrete

From fig 7, it is observed that the proposed modified binder index combining the effect of binder index, molarity and fiber effect reasonably well in predicting the split tensile strength. The following best fit equations give the relation between the spli tensile strength at 7 days and 28 days of ambient curing with modified binder index along with the correlation coefficient ($R^2$).

$f_{cr}$-7D=1.568$(P_{cf})^{0.385}$

$R^2 = 0.600$

$f_{cr}$-28D=1.867$(P_{cf})^{0.390}$

$R^2 = 0.560$

Where ' $P_{cf}$ ' is modified binder index for combination fibers.

## 4.0 Conclusions

The following conclusions can be made from the experimental analysis done.

1. The 7 days and 28 days split tensile strength of combined fiber reinforced Geopolymer concrete increased with increase in molarity of alakaline activator for any chosen fiber combination.
2. The 7 days and 28 days split tensile strength of combined fiber reinforced Geopolymer concrete increased with increae in rigid fiber proportions for any chosen molarity of alkaline activator.
3. The 7 days and 28 days split tensile strength of combined fiber reinforced Geopolymer concrete increased with the increase in binder index values.
4. The modified binder index which combines the effect of molarity, GGBS , Fly ash and fiber effect can be considered as a unique parameter in characterizing the split tensile strength of combinded fiber reinforced Geopolymer concrete.
5. There is a non linear relation between the modified binder index and spit tensile strength of combined fiber reinforced Geopolymer concrete.
6. The 7 days and 28 days split tensile strengths of combined fiber reinforced Geopolymer concrete increased for fly ash to GGBS proportion 40:60 compared to 60:40.

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