EXPERIMENTAL EVALUATION OF THE SPLIT TENSILE STRENGTH OF COMBINED HOOKED END AND SOFT FIBER REINFORCED GEOPOLYMER CONCRETE.

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Abstract: The experimental program aimed to determine the Split Tensile Strength (fct) of Combined Fiber Reinforced Geopolymer Concrete (CFRGPC) by casting and testing cylinders with dimensions of 100 mm in diameter and 200 mm in height. The study employed two different Ground Granulated Blast Furnace Slag (GGBS) to Fly Ash (FA) ratios: 60:40 and 40:60. Additionally, three molarities (8, 10, and 12) were tested. To create CFRGPC, various fiber combinations were used, including R0S10, R2S8, R4S6, R6S4, R8S2, and R10S0. For each variation, three identical specimens were cast and tested at both 7 and 28 days under ambient curing conditions. Two parameters, the 'Binder Index' and 'Modified Binder Index,' were introduced to quantify the influence of molarity, GGBS, fly ash, and fiber content on the Split Tensile Strength of CFRGPC.

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:

Global warming is primarily driven by the emission of greenhouse gases, such as carbon dioxide (CO2), into the atmosphere. The cement industry is responsible for approximately 65% of global warming due to its CO2 emissions [1]. In response, extensive research is underway to identify alternative materials for cement production. These alternatives include the use of supplementary cementing materials like fly ash, silica fume, granulated blast furnace slag, rice husk ash, and metakaolin, as well as the development of binders that can replace Portland cement. Geopolymer technology, in particular, has the potential to significantly reduce CO2 emissions from the cement industry. In India, coal is a major source of power generation, and its byproduct, fly ash, poses an environmental threat. In 2016-2017, India produced 169.6 million tons of fly ash. Geopolymer production requires two key materials: one that contains alumina and silica, and an alkali to activate the polymerization reaction. Davidovits proposed that an alkaline solution could react with the silicon (Si) and aluminum (Al) in source materials, including geological or byproduct materials like fly ash and blast furnace slag, to create binders. Because the chemical process involved is polymerization, he coined the term "Geopolymer" for these binders [2]. For preparing the alkali solution, a single alkali or a mixture of alkalis can be used. The most common alkali solution for Geopolymer production is a blend of NaOH and Na2SiO3. Prudon, cited by Torgal, conducted early investigations on alkali-activated cement (binder) in 1940, using blast furnace slag as an alumina-silicate material and sodium hydroxide as the alkali [3]. Since then, studies on alkali activation have been conducted worldwide, gaining significant momentum in the 1990s. Building on previous research on Geopolymer concrete, the present study investigates the effect of combined fibers on the split tensile strength of Geopolymer concrete. The split tensile strength of Combined Fiber Reinforced Geopolymer Concrete (CFRGPC) is studied by incorporating steel and polypropylene fibers in different volume proportions. Two parameters, the Binder Index and Modified Binder Index, are introduced to quantify the effects of molarity, fly ash, GGBS, and fiber content on the split tensile strength of CFRGPC.

2.0 EXPERIMENTAL PROGRAM:

The experimental program aimed to determine the split tensile strength of Combined Fiber Reinforced Geopolymer Concrete (CFRGPC) by casting and testing cylinders with dimensions of 100 mm in diameter and 200 mm in height. Two different Fly Ash to GGBS proportions, 60:40 and 40:60, were used. Additionally, three different alkaline molar activators, with molarities of 8, 10, and 12, were employed. To prepare CFRGPC, combined fiber combinations R0S10, R2S8, R4S6, R6S4, R8S2, and R10S0 were utilized. For each variation, three identical specimens were cast and tested after 7 and 28 days of ambient curing.

2.1 Materials:

Fly ash was sourced from the Kothagudem Thermal Power Station in Bhadradri Kothagudem District, Telangana, India, while Ground Granulated Blast Furnace Slag (GGBS) was obtained from Blue Way Exports, Vijayawada, Andhra Pradesh, India. The specific gravity of fly ash and GGBS were found to be 2.17 and 2.90, respectively. The chemical composition of both materials is detailed in Table 1. Natural river sand, conforming to grading zone II of IS 383:1970, was used in the mix. The specific gravity and fineness modulus of the sand were 2.32 and 2.81, respectively. Coarse aggregate with a maximum size of 12 mm, sourced locally, was also used. Hooked-end steel fibers, with an aspect ratio of 60 and a tensile strength of 1100 MPa, were incorporated. Polypropylene fibers (Recron 3S), with a length of 12 mm, diameter of 20 microns, and tensile strength of 490.3 MPa, were used as well. The densities of rigid and soft fibers were 7850 kg/m^3 and 946 kg/m^3, respectively. The alkaline activators used were sodium hydroxide solutions with molarities of 8, 10, and 12. Sodium hydroxide pellets used for preparing the NaOH solution are provided in Table 2. The NaOH solution was then mixed with sodium silicate (Na_2SiO_3) solution, maintaining a ratio of 2.5:1 between the sodium silicate and sodium hydroxide solutions [4, 5, 6]. The mixture was allowed to cure at room temperature for 24 hours before casting. To achieve the desired workability, the superplasticizer Conplast SP-430 was added to the mix.

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.

Fly ash: GGBS	Molarity	Combined fiber reinforced Geopolymer concrete Composition (Kg/m^3)					
		Coarse aggregate	Fine Aggregate	Fly Ash	GGBS	NaoH Solution	Sodium Silicate
60:40	8	1100	517.45	345.10	230.10	59.10	148.25

60:40	10	1100	517.45	345.10	230.10	59.10	148.25
60:40	12	1100	517.45	345.10	230.10	59.10	148.25
40:60	8	1100	517.45	230.10	345.10	59.10	148.25
40:60	10	1100	517.45	230.10	345.10	59.10	148.25
40:60	12	1100	517.45	230.10	345.10	59.10	148.25

TABLE 4. FIBER MIX PROPORTION.

Combined fiber mix proportions				
@fiber designat ion.	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 solid constituents of the CFRGPC, including aggregates, fly ash, GGBS, and fibers (both rigid and soft), were dry mixed for approximately three minutes. The liquid components, comprising the alkaline solution, added water, and superplasticizer, were premixed separately before being added to the dry mix. The wet mixing continued for an additional four minutes. The freshly mixed CFRGPC concrete had a dark color and a shiny appearance, and the mixture was highly cohesive. Workability was assessed using the conventional slump test. To compact the fresh concrete in cylindrical molds, the mixture was placed in three equal layers, each compacted on a vibration table for ten seconds. The specimens were demolded after 24 hours and then left to cure under ambient conditions.

2.3 Split Tensile Strength: The split tensile strength tests on hardened CFRGPC were conducted using a 1000 kN capacity universal testing machine, following the guidelines of the relevant Indian Standard IS 516[7]. Three identical CFRGPC cylinders, each 100 mm in diameter and 200 mm in length, were tested for their average split tensile strength for each variation. The results presented in the various figures and tables represent the mean values of these tests. To assess the combined effect of fly ash, GGBS, and the molarity of the alkaline activator on CFRGPC, a parameter called the binder index was introduced. The binder index is defined as the product of the molarity of the alkaline activator and the binder ratio, as shown 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)	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	3.34	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	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	4.14	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	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	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	4.78	5.38	5.19	6.05	5.41	6.85	5.70	7.2	6.40	7.64	7.0	8.5

To evaluate the effect of combined fibers on the split tensile strength of Combined Fiber Reinforced Geopolymer Concrete (CFRGPC), a modified binder index is introduced. This index combines the effects of the binder index, tensile strength, and the volume fraction of fibers for each fiber combination. To account for the reduced impact of soft fibers in combination, a factor of 0.85 is applied when calculating the modified binder index [9, 10].

The modified binder index (P) is calculated as:

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	√RFef	√SFef	0.85 √SFef	√RFef +0.85 √SFef
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

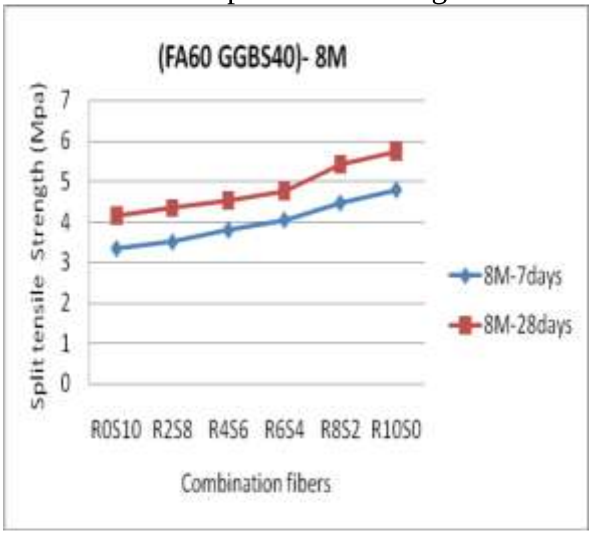
10	6	11.28	20.28	23.16	24.9	25.38	22.8
12	7.2	13.54	24.336	27.792	29.88	30.456	27.36

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.



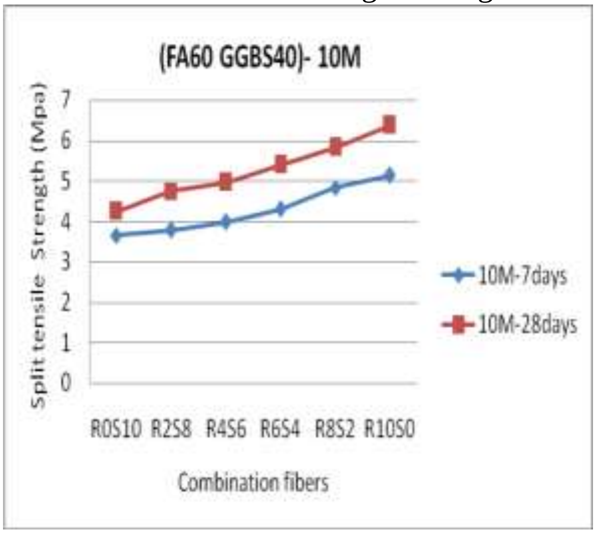
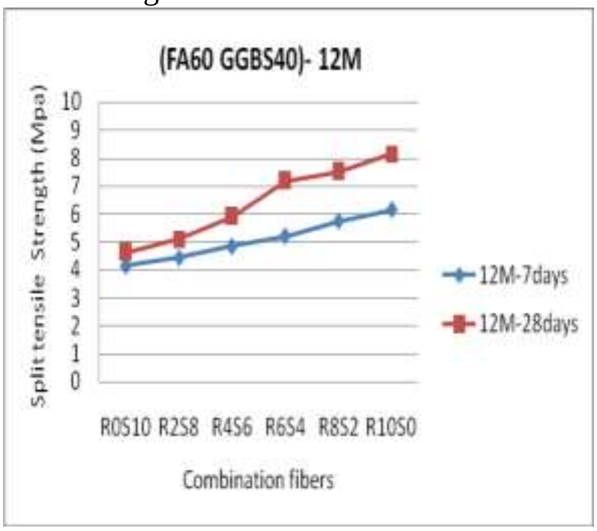


Fig.1 Combination fiber effect on split tensile Fig.2 Combination fiber effect on split tensile
Strength of CFRGPC strength of CFRGPC



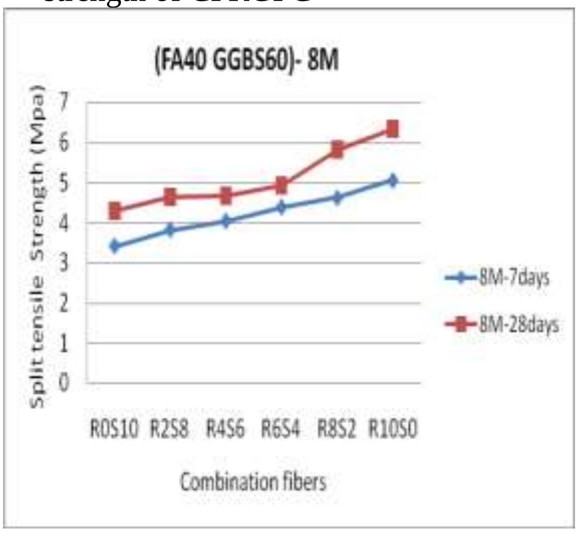


Fig.3 Combination fiber effect on split tensile Fig.4 Combination fiber effect on split tensile
Strength of CFRGPC strength of CFRGPC

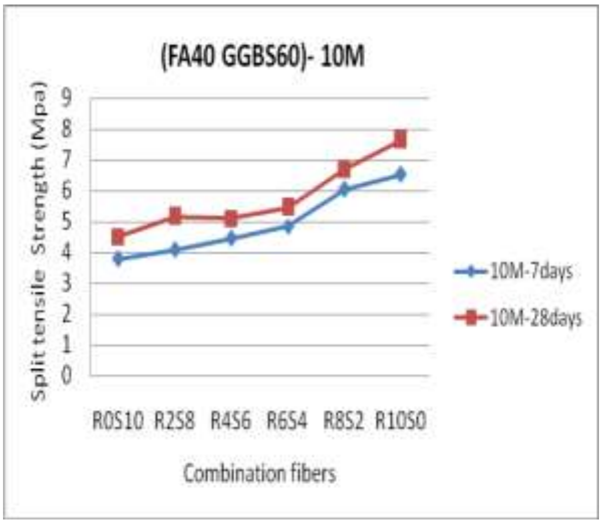


Fig.5 Combination fiber effect on split tensile split tensile
Strength of CFRGPC

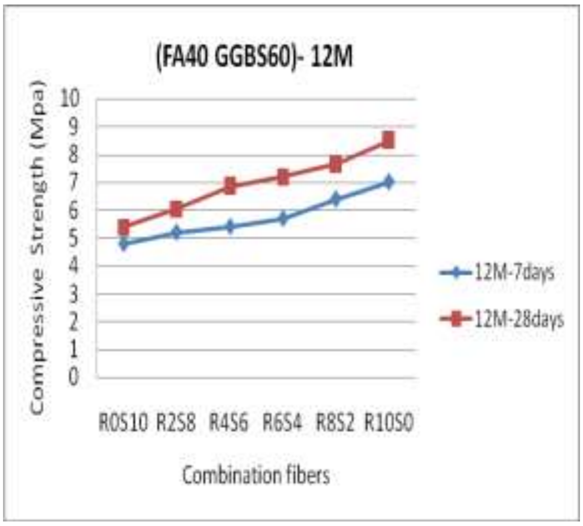


Fig.6 Combination fiber effect on
Strength of CFRGPC

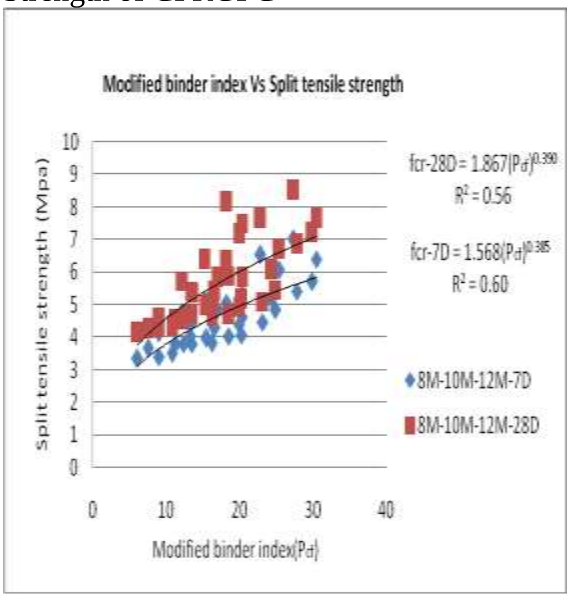


Fig.7 Modified binder index effect on split tensile strength of Combined fiber reinforced Gopolymer concrete .

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

The effect of the molarity of the alkaline activator on different fiber combinations is illustrated in Figures 1 to 6. Generally, as the molarity increased, the split tensile strength of the Combined Fiber Reinforced Geopolymer Concrete (CFRGPC) improved at both 7 days and 28 days.

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

From Figures 1 to 6, it is observed that for any chosen molarity of the alkaline activator and GGBS to FA ratio, the split tensile strength of Combined Fiber Reinforced Geopolymer Concrete (CFRGPC) at both 7 days and 28 days increased as the proportion of rigid fibers was raised.

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 split tensile strength of Combined Fiber Reinforced Geopolymer Concrete (CFRGPC) at both 7 days and 28 days increased with higher 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).

fcr-7D=1.568(Pcf)0.385 $R^2 = 0.600$

fcr-28D=1.867(Pcf)0.390 $R^2 = 0.560$ Where ' P_{cf} ' is modified binder index for combination fibers.

4.0 Conclusions

The following conclusions can be drawn from the experimental analysis:

1. The split tensile strength of Combined Fiber Reinforced Geopolymer Concrete (CFRGPC) at both 7 days and 28 days increased with the molarity of the alkaline activator, regardless of the chosen fiber combination.
2. The split tensile strength at 7 days and 28 days increased with the proportion of rigid fibers, for any selected molarity of the alkaline activator.
3. The split tensile strength at 7 days and 28 days of CFRGPC increased with higher binder index values.
4. The modified binder index, which combines the effects of molarity, GGBS, fly ash, and fiber content, can be considered a unique parameter for characterizing the split tensile strength of CFRGPC.
5. A non-linear relationship exists between the modified binder index and the split tensile strength of CFRGPC.
6. The split tensile strength of CFRGPC at both 7 days and 28 days was higher for a fly ash to GGBS ratio of 40:60 compared to a 60:40 ratio.

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