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Geopolymer Concrete Mix Design Efficiencies BY Taguchi Method

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Abstract: Geopolymer concrete has had an extra edge over normal concrete for the past 2-3 decades. According to research, geopolymer concrete offers improved strength, modulus of elasticity, and durability. In this work, Ordinary Portland cement is fully replaced by a mixture of Sugar Cane Bagasse Ash(SCBA) and Ground Granulated Blast Furnace Slag(GGBS), with alkaline liquids added for reactivity. Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) are used for the polymerization to achieve good workability in the geopolymer concrete. The combined quantities of geopolymer concrete were optimized using the Taguchi method to meet the specified strength parameters for the concrete grade of M30 with nine mixes. Binder content, which included three proportions of SCBA and GGBS, NaOH/Na_2SiO_3 ratios (1:2, 1:2.5, and 1:3), molarity(4M,8M,12M), and alkaline activator to binder content ratio(AAC/BC) of 0.4,0.5,0.6 were among the various parameters of study. Compressive strength and split-tensile strength was investigated using these components and variables during the work.
Keywords: Molarity, Sugar Cane Bagasse Ash, Ground Granulated Blast Furnace Slag, AAC/BC ratio

I. INTRODUCTION

In the world's fastest-growing sector, construction, concrete is the second most often used material after water. The most common substance used in a concrete building is cement. Annually, around 298 million tonnes of cement are produced, with this figure likely to rise in the next 5-10 years to suit modern-day demands.

The most fundamental ingredient in cement manufacture is limestone. However, an alternative must be found due to a severe lack of material. Furthermore, because the production of cement needs a great deal of heat, it is an extremely energy and emissions-intensive process. A tone of cement, which is comparable to 400 pounds of coal, requires around 4.7 million BTUs of energy and creates about a tone of CO2. CO2 is a greenhouse gas that can contribute to global warming. When it comes to the environment, it's extremely critical to seek an alternate binding substance.

To lower carbon emissions, efforts are being made to find cement replacements that will lessen the cement industry's environmental effects. Alternatives to traditional materials for producing concrete can be found in industries that produce waste, such as thermal industries that create fly ash, steel industries that create GGBS, and agriculture-based industries that have been producing waste in the form of fodder for decades. Owing to land restrictions and environmental concerns, the handling of these waste materials is a crucial problem for industries. Instead of just wasting all of these things, we could use them to produce environmentally friendly products like Geopolymer Concrete (GPC) which are made of GGBS, Sugarcane Bagasse Ash (SCBA), Alkaline Activators, and water. Davidovits (1982) proved that an alkaline liquid may be utilised to create binders by reacting with Silicon (Si) and Aluminium (Al) in the geological source material or by-product materials such as fly ash, GGBS, rice husk ash, and bagasse ash. He invented the word "Geopolymer" to characterize these binders since the chemical reaction that occurs in this setting is a polymerization event. The Geopolymer materials' microstructure is amorphous, yet its chemical composition is comparable to that of naturall0y occurring zeolitic materials. Currently, it is unclear exactly how the Geopolymer material is set and hardened, as well as the final statement that claimed water is released during the chemical reaction that results in Geopolymer production. Discontinuous nano-pores are left behind in the matrix when water is evacuated from the Geopolymer matrix during curing and subsequent drying, increasing the Geopolymer's effectiveness. On the other hand, water in a geopolymer mixture just provides workability during handling and has no impact on the chemical reaction that occurs. In contrast, during the hydration phase, the water in a Portland cement concrete mixture experiences a chemical reaction. Alkaline liquids and raw materials are the two basic components of geopolymers. For alumina-silicate geopolymers, the raw materials should have significant amounts of silicon (Si) and aluminum (Al). There may be natural minerals present, including clays and kaolinite. It is also possible to employ by-product goods as source materials, including fly ash, silica fume, slag, rice-husk ash, red dust, and other by-product materials. Geopolymer raw materials are chosen based on variables including supply, quality, kind of usage, and end-user demand.

II. EXPERIMENTAL DETAILS

A. Materials

GGBS is supplied by JSW Cement Ltd, India. Sugarcane Bagasse Ash is obtained from Mandya Sugarcane Factory, Karnataka, India. After being sieved via a 4.75 mm sieve, Manufactured sand (Zone-II, per IS: 383-1970) is utilized as fine aggregate. The coarse aggregate used was typical, measuring 20 mm and 10 mm. According to reports, coarse aggregate and fine aggregate have specific gravities of 2.8 and 2.46, respectively. N M Enterprises provides sodium-based silicate solution (Na_2SiO_3). The sodium hydroxide (NaOH) flakes are obtained from N M Enterprises.

B. Design of Experiments

The trials are designed using the Taguchi method, which takes into account four parameters and three-level variables. The parameters are Molar Concentration (4M,8M,12M), Alkaline Activator content / Binder content (AAC/BC) (0.4,0.5,0.6), different percentage of binder content (GGBS + SCBA) of different ratio of Sodium Hydroxide + Sodium Silicate (NaOH + Na2SiO_3) and 3 different levels are proportions of GGBS + SCBA (60 + 40, 70 + 30, 80 + 20).

Table 1: Taguchi L9 Orthogonal Table

Experiment No.	A GGBS+SCBA	B AAC/BC	C Molarity	D $NaOH/Na_2SiO_3$
1	60+40	0.4	4M	1:2
2	60+40	0.5	8M	1:2.5
3	60+40	0.6	12M	1:3
4	70+30	0.4	8M	1:3
5	70+30	0.5	12M	1:2
6	70+30	0.6	4M	1:2.5
7	80+20	0.4	12M	1:2.5
8	80+20	0.5	4M	1:3
9	80+20	0.6	8M	1:2

C. Methodology

1) Preparation of NaOH Solution: The sodium hydroxide pellets are weighed in the tray as per the mix design, followed by distilled water in a bucket. After weighing the sodium hydroxide pellets, slowly pour them into the distilled water. About 5 to 10 minutes of constant stirring is required until the pellets have completely dissolved and the solution has a uniform colorless appearance. To complete the exothermic process, leave the solution undisturbed for 24 hours.
2) Preparation of Alkaline Solution: As stated previously, the sodium hydroxide solution is being prepared. Add the required amount of sodium silicate to the prepared sodium hydroxide solution and mix thoroughly before casting to get uniform, homogenous solutions.
3) Ambient Curing: By definition, ambient curing depends on elements present in an ambient setting, such as a reasonable temperature, daylight, moisture, and air. Geopolymer concrete samples are demolded after 24 hours of casting and left in direct sunshine for 28 days to complete the ambient curing process.

III. RESULTS AND DISCUSSIONS

A. Slump Value

According to IS 7320-1974, the slump value of Geopolymer concrete has been evaluated using a standard slump cone test. The slump cone has a top diameter of 10 cm, a height of 30 cm, and a bottom diameter of 20 cm. Three layers of concrete have been added to the cone and thoroughly tamped to eliminate air spaces. A steel scale is then used to record the measurements once the cone has been elevated vertically. In Figure 1 and Table 2, the slump values of nine blends are displayed. The mix with a 0.4 AAC/BC ratio achieves the required minimum slump of 75 mm. The mix with a 0.6 AAC/BC ratio achieves the maximum slump value of 100 mm. It is very evident that as the parameter levels rise, so does the workability. However, Taguchi analysis was used to examine each factor that affects the slump value.

Table 2: Slump Cone Test Values

Sl.No.	Mix designation	Slump, mm
1	MD1	75
2	MD2	80
3	MD3	95
4	MD4	75
5	MD5	80
6	MD6	100
7	MD7	75
8	MD8	80
9	MD9	95

B. Compressive Strength

Nine different mixes (M1 to M9) have all been cast and subjected to ambient curing. According to IS 516: 1959, the compressive strength test was performed. At 7 and 28 days after the concrete's placement, the compressive strength of the nine mixes was evaluated, and the results are shown in Tables 3 and 4. With a 0.4 AAC/BC ratio mix, the maximum compressive strength of 48.98MPa is attained. As seen in Figures 2 and 3, the mix with an AAC/BC ratio of 0.6 yields the lowest compressive strength of 35.29 MPa. However, Taguchi analysis is used to fully comprehend how factors affect compressive strength.

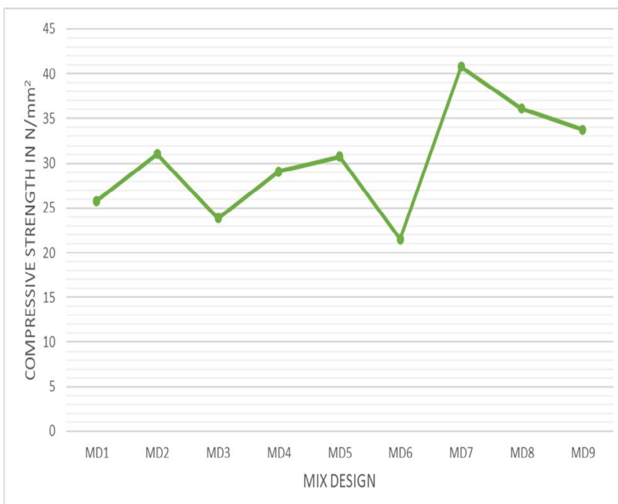

Figure 2. 7-days Compressive Strength

Table 3: Compressive Strength at 7 days

Mix Designation	7-day Compressive Strength, N/mm^2	28-day Compressive Strength, N/mm^2
MD1	25.80	35.85
MD2	31.05	39.70
MD3	23.85	36.20
MD4	29.10	38.85
MD5	30.70	41.75
MD6	21.50	35.30
MD7	40.80	49.00
MD8	36.10	42.00
MD9	33.75	41.00

Figure 3. 28-days Compressive Strength

C. Split Tensile Strength

Nine mixes in total (MD1 to MD9) has been cast and ambiently cured. According to IS 516: 1959, a split tensile strength test was performed. The average strength of the three specimens used to test the split tensile strength of the nine mixes at 28 days after the concrete's placement is shown in Table 5. With an AAC/BC ratio mix of 0.4, the greatest split tensile strength of 5.62MPa is reached. The mix with an AAC/BC ratio of 0.6 achieves the lowest compressive strength of 4.59 MPa, as illustrated in Figure 4. However, Taguchi analysis is used to fully comprehend how factors affect compressive strength.

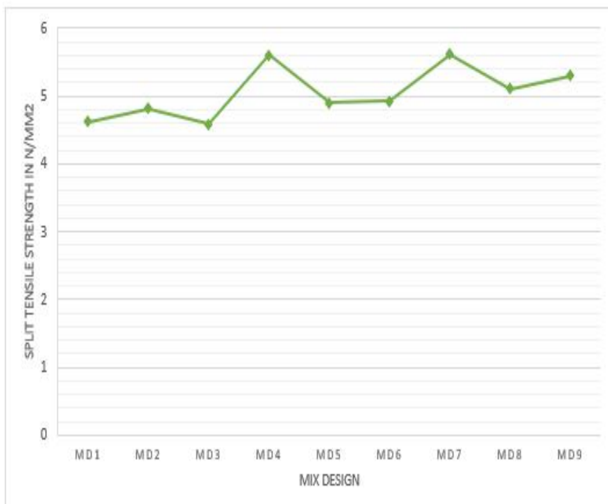

Figure 4. 28 days Split Tensile Strength

Table 5: Split Tensile Strength after 28 days

Mix Designation	28-day Split Tensile Strength, N/mm^2
MD1	4.60
MD2	4.80
MD3	4.60
MD4	5.60
MD5	4.90
MD6	4.90
MD7	5.60
MD8	5.10
MD9	5.30

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D. Flexural Strength

Nine mixes in total (M1 to M9) have been cast and ambient-cured. The flexural strength test was carried out in accordance with IS 516: 1959. The flexural strength of the nine mixes was evaluated at a 28-day age of concrete, and Table 6 reports the average strength of the three specimens. The AAC/BC ratio mix of 0.4 results in the maximum flexural strength of 3.2 MPa. As demonstrated in Figure 5, a combination with an AAC/BC ratio of 0.6 has the lowest compressive strength of 2.2 MPa. But Taguchi analysis is used to fully comprehend how factors affect compressive strength.

Figure 5: 28 days Flexural Strength

Table 6: Flexural Strength after 28 days

Mix Designation	28-day Flexural Strength, N/mm^2
MD1	5.00
MD2	5.50
MD3	5.05
MD4	5.45
MD5	5.85
MD6	4.95
MD7	6.85
MD8	5.00
MD9	4.65

IV. CONCLUSION

Higher sodium hydroxide solution concentration (measured in molar) increases the compressive, split tensile, and flexural strength of geopolymer concrete. Additionally, as the ratio of sodium silicate to sodium hydroxide by mass increases and the curing temperature in the range of 30°C to 90°C rises, so does the compressive, split, and flexural tensile strength of geopolymer concrete. The results of the current investigation indicate that geopolymer concrete may be used at room temperature with NaOH concentrations of 4M, 8M, and 12M. When compared to OPC concrete, GPC concrete sets up much more quickly and is more cohesive and rigid. Water usage is extremely limited, which promotes water sustainability or water conservation. Mix Design 7 exhibit highest compressive, split tensile, and flexural strengths possible.

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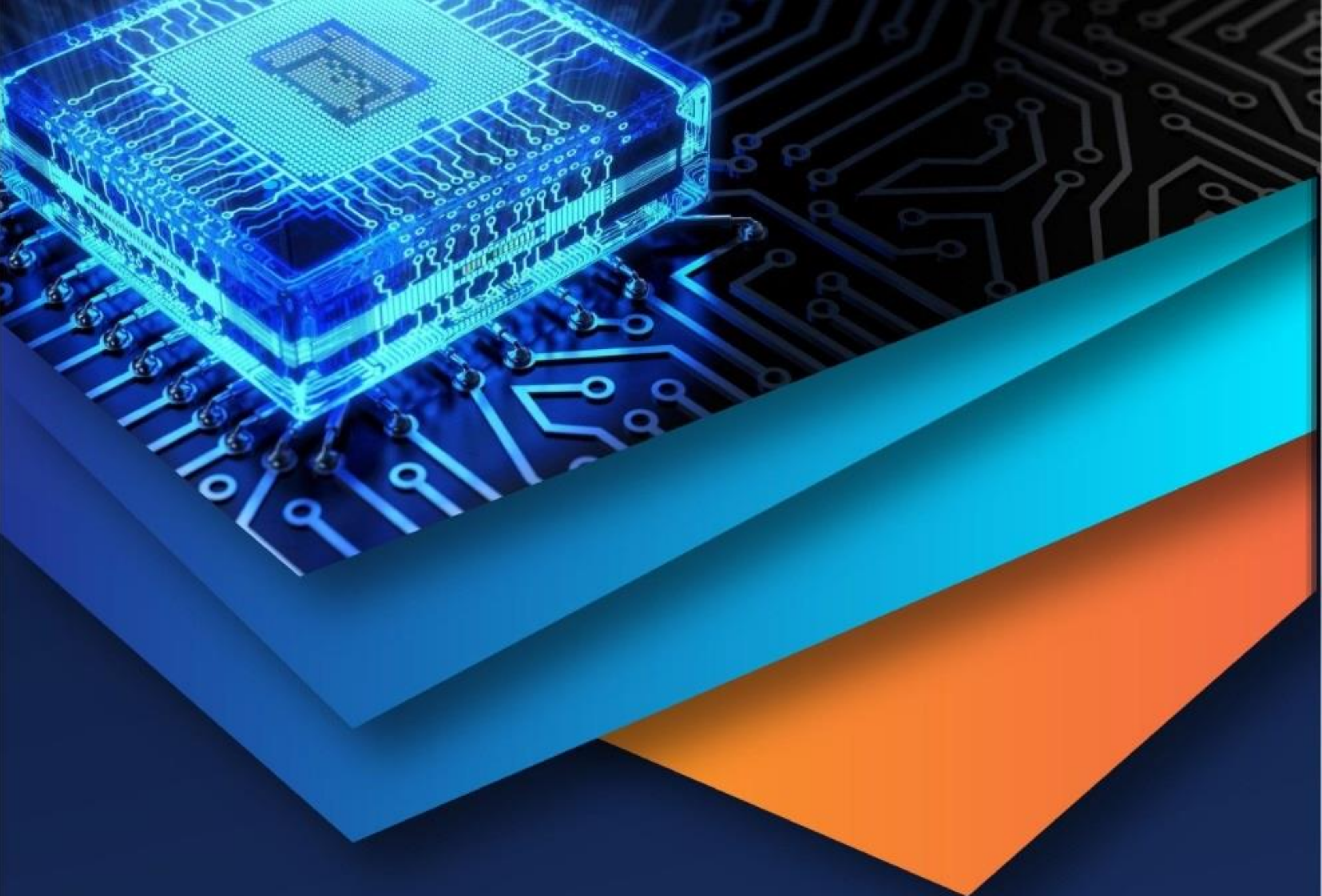

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