Study on Mechanical Properties of Geopolymer Concrete

R. Saravanan, M. Pavan Kumar, S. Elavenil

Abstract*: *Geopolymer Concrete (GPC) is the most promising and novel concreting technology which primarily focuses on the eco-friendly aspects. In this work, the mechanical properties of fly-ash based GPC which includes compressive strength, split tensile strength and non-destructive testing methods like UPV and rebound hammer tests results will be examined and analyzed based on the different mix parameters for 8 mixes. The main varying parameters of the mix are alkaline solution ratio and concentration and binder proportions. Based on the optimum mix from 8 normal GPC mixes, one mix will be studied under the granite powder replacement. The granite powder is utilized for the partial replacement of binder for the 5%, 10%, 15%, and 20% of the binder volume. The concrete cube specimens are casted according to Indian standards and the 7th and 28th days strength are used for the analysis.

***Index Terms*: Compressive strength, Geopolymer concrete, Granite powder.**

I. INTRODUCTION

In construction industries, the Ordinary Portland Cement (OPC) Concrete has been utilized vividly due to its virtuous mechanical and durability properties. Due to the industrial development of the last few decades, the utilization of OPC is enormous and that results in a rise in the level of CO_2 in the atmosphere. In order to maintain the environment eco-friendly, there is a need for a sustainable alternative for OPC. For such a sustainable eco-friendly environment, geopolymer concrete was developed. Geopolymer Concrete redefines the concreting technology by its lesser carbon dioxide emission and utilization of industrial waste such as fly-ash, GGBS and granite waste powder. Geopolymer Concrete is formed by activating the alumina and silica-rich materials by the alkali activators. The Alumina and Silica from the binder materials react with the activator solution to initiate the polymerization process. The activator solutions are made up of alkali bases such as sodium or potassium. In this work Sodium Hydroxide (SH) and Sodium Silicate (SS) are used as alkali activators. These activators have a huge impact on the strength like compressive and tensile strength and workability parameters.

Nagaraj and Venkatesh Babu have studied the effect of molarity of NaOH (2,4,6,8,10and 12M) and the alkaline ratio (2.0, 2.5, 3.0, 3.5, 4.0 and 4.5) on workability, compressive strength and durability properties. Based on the work the workability of GPC gets decreased with increase in concentration and workability gets increased with increases in alkaline ratio. But the compressive strength was increased with the increase of molarity and gets reduced with increase alkaline ratio, the optimum mix was observed at a molarity of 12M and alkaline ratio 2.0. The higher molarity and lower alkaline ratio showed better durability properties [1].

Ehsan Mohseni showed there is a 10% hike in compressive strength when the ratio of sodium silicate to sodium hydroxide increased from 2 to 3. Also, the water absorption gets decreases with increasing the ratio of sodium silicate to sodium hydroxide from 2 to 2.5. Greater the Silica to Alumina ratio, the higher will be the compressive and flexural strength [2].

Ghasan Fahim Huseien et al. investigated the influence of the type of activator (combination of SS with SH, SS with water and SS alone) and calcium content on compressive strength, flexural strength, tensile strength and microstructure of GPC mixes. The workability and initial setting time were reduced with calcium content. The activator sodium silicate alone gave good strength results at 60°C temperature [3].

Ubolluk Rattanasak and Prinya Chadraprasirt have studied the effect of newly introduced long time mixing process for preparation geopolymer and compared with the normal mixing process. The parameters considered are alkaline ratio (0.5, 1,1.5and 2) and molarity variation (5, 10and 15M). The leaching test results showed good results for 10M NaOH. The newly proposed long-time mixing process gave some better results in compressive strength and infrared spectroscopy [4].

Kiatsuda Somna et al. have investigated the compressive strength and microstructure properties (using SEM, EDS and infrared spectroscopy) on geopolymer pastes. Here, two types of fly ash used one was ordinary fly ash and another one ground fly ash and activated with different concentrations of NaOH (4.5,7, 9.5, 12, 14 and 16.5M). From the obtained results ground fly ash mix having an alkaline ratio in the range 9.5M to 14M gave good compressive strength increments. From the Microstructure study, it was cleared the ground fly ash have higher polymerization compared to the ordinary one [5].

Pradip Natha and Prabir Kumar Sarker have investigated the fresh and mechanical properties of GPC and geopolymer mortar. The variables were GGBS content (10, 20 and30%), alkaline ratio (1.5,2 and 2.5) and activator content (35, 40 and 45). From the obtained results slump and initial setting time was reduced with the GGBS content and alkaline ratio, but due to the increase in activator content the slump and initial setting time were increased. Compressive

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strength was increased with the increase of GGBS content and reduced with the increase in alkaline ratio and activator content. The microstructure was well compacted with the increment in GGBS content [6].

Sanjaykumar et al. investigated the influence of GGBS on polymerization at different temperatures. GGBS has shown greater reaction at 27°C temperature due to the formation of C-S-H gel through higher calcium presence. For the combination of fly ash and GGBS has a greater reaction at 60° C temperature. The compressive strength increased with the increase of GGBS content [7].

Partha Sarathi Deb et al. investigated the effect of activator liquid content (40and 35), alkaline ratio (1.5 and 2.50) and GGBFS content (0,10 and 20%) on workability and mechanical properties like compressive strength and split tensile strength up to 180 days ambient curing. Both compressive and split tensile strength results were greater for the GGBS of 20%, activator liquid content 40 and alkaline ratio 1.5. The strength predictions were conservative for heat cured GPC and not for ambient cured GPC [8].

Rajarajeswari and Dhinkaran studied the influence of alkaline ratio and Liquid to binder ratio on GPC at elevated temperatures. At an early age, the rate of reaction was more when compared at a higher age. From the cost analysis, the optimum mix was obtained with the liquid to binder ratio of 0.30, the alkaline ratio of 1.5 and a temperature of 80°C. The water absorption results are higher at alkaline ratio of 2.5 [9].

Jayant Sharma et al. showed the 10% replacement of granite waste showed higher compressive strength of concrete at all ages of concrete. Flexural strength of concrete containing granite slurry waste increased with increase in the replacement level up to 10% of granite slurry waste [10].

Allam M. E et al., conducted split tensile strength with granite waste replacement up to 25% of binder volume and showed 5% replacement will give 20% more higher tensile strength and bond strength than the control mix. Also, higher replacement ratios gave lower values [11].

Nabeel A. Farhan et al. have tested engineering properties like workability, dry density, Ultrasonic pulse velocity (UPV), indirect tensile strength, direct tensile strength, compressive strength, modulus of elasticity, flexural strength and Microscopic analysis through SEM on fly ash geopolymer concrete (FAGPC), alkali-activated slag concrete (AASC) and OPC concrete. The results of UPV, Dry density of FAGP were lower when compared with OPC of similar strength. Microstructures of FAGPC and AASC were denser compared with the OPC concrete of normal strength. It was different for high strength concrete microstructure was more compact for OPC compared with FAGPC and AASC [12].

Temuunjin et al. have investigated on compressive strength and microscopic characteristic of all three geopolymer paste mixes. In their work fly ash has undergone some mechanical treatment, obtained fly ash named as milled fly ash. The compressive strength obtained for milled fly ash was more compared with other mixes and the microstructure was transferred to be dense and compact. Due to the mechanical operations, raw fly ash particle size was reduced and dissolved alumina-silica contents present in fly ash were increased [13].

Rachit Gosh et al. have correlated compressive strength results with results of UPV. Three different fly ash types and molarity variation (6, 8 and 10M) were considered as parameters. The higher compressive strength results were obtained for type 3 fly ash with 6M concentration of NaOH at 90 days. There was a linear relationship observed between compressive strength and UPV, the R2 values were 0.914, 0.882 and 0.956 for type 1, 2 and 3 fly ash respectively [14].

Pitta Archana et.al studied the influence of molarity (1M,2M,3M,4M&5M) on mechanical and non-destructive properties of geopolymer concrete made of GGBS. The 3M mix has given good compressive strength, split tensile strength and flexural strength. the UPV values of GPC are more when the molarity of NaOH increases. the rebound hammer strength results are more for 3M mix [15].

Saravanan et al., have studied the various parameters of the mix design proportions and effect of each material parameters in attaining the compressive strength. They showed compressive strength is directly proportional to alkali activators concentration and proportion, also shows lower molarity of sodium hydroxide solution giver higher compressive strength [16].

Prakash R. Vora et al., have studied on compressive strength of geopolymer concrete varying the parameters such as liquid to binder ratio(0.35 and 0.4), Alkaline ratio(2 and 2.5), molarity of NaOH(8, 10, 12 and 14M), curing time(24 and 48 hours), curing temperature(60, 75 and 90°C), superplasticizer content(2, 3 and 4%), rest period(0 and 1 day) and extra water(43, 64,and 86).from the obtained results there was no significant effect on compressive strength with the increase of liquid to binder ratio and strength increase with increase of concentration of NaOH. Strength was increased with an increase of curing temperature and age respectively [17].

Marios Soutsos et al. investigated the effect of alkaline modulus, fly ash sample, GGBS content on compressive strengths of GPC pastes activated by the combination of NaOH and Na_2SiO_3 under various temperature curing, the particle size of fly ash effects the reaction. From the obtained results of microstructural characterization, 50% fly ash and 50%GGBS has better bonding and compact structure. At the temperature 70°C the reaction rate was higher compared with 50°C. Due to the inclusion of GGBS, the calcium alumina hydrate silica was formed [18].

II. MATERIALS AND METHODOLOGY

A. Materials

The chief ingredients for the developing the sustainable geopolymer concrete are fly ash, granite powder, ground granulated blast furnace slag (GGBS), sodium silicate solution (Na_2SiO_3) and sodium hydroxide (NaOH). Fly ash, GGBS and Granite powder were the supplementary cementitious materials (SCM) to develop the binding and bonding forces in the concrete mixture. The fly ash used for this work is of class F type and the properties are confirming to the Indian standards. GGBS is the slag material obtained from the steel manufacturing industry, which is the main source to develop the

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accelerated setting time of concrete. The granite waste is the finely powdered dust material obtained from the quarry site in Tamilnadu, India. It is obtained as a waste product during the sawing of the granite pieces. Primarily the work focuses on the study on granite waste. The physical properties of the supplementary cementitious materials are discussed in Table 1.

Table 1. Properties of SCM

Property	Fly ash	GGBS	Granite powder
Colour	Grey	Clear white	Grey
Form	Fine powder	Fine powder	Fine Powder
Specific gravity	2.21	2.75	2.64
Particle size	< 90 microns	<75 microns	<90 microns
Bulk Density (kg/m^3)	1510	1290	1110

Sodium silicate and sodium hydroxide are the alkali activators used in the process to activate the binding properties of SCM. The sodium hydroxide is purchased in the form of pellets and then liquefied with distilled water for the recommended concentrations. Sodium silicate is in the liquid form. The physical properties of the alkali activators are discussed in Table 2.

Table 2. Properties of Alkali Activators

Property	NaOH	Na_2SiO_3
Colour	White	Yellowish
Form	Flaky solid	Viscous Liquid
Specific gravity	1.41	1.52
Bulk Density (kg/m3)	3544	5760

M-sand is graded as zone-II and the aggregates used were tested and the properties are within the permissible limits confirming to IS 2386 and IS 383. The physical properties of the aggregates are discussed in Table 2.

Table 3. Properties of Aggregates

Property	M Sand	12 mm aggregate	20 mm aggregate
Specific Gravity	2.72	2.71	2.72
Water Absorption (%)	3.14	0.50	0.33
Crushing Value (%)	-	20.23	14.88
Bulk Density (kg/m^3)	1699	1461	1463

B. Methodology

The contemporary trends in the development of GPC are studied based on recent issues and journals. Based on the study the objectives are framed along with the proper methodology. The works start with the finalizing the material utilization for the project and preliminary tests on the materials. This is followed by the preparation of mix design and trail mix. Based on the required strength criteria, the final developed mix is studied.

There are 9 mixes developed by varying the sodium silicate to sodium hydroxide ratio and sodium hydroxide concentrations. The sodium silicate to sodium hydroxide ratio was varied at a ratio of 1.5, 2.0 and 2.5. Similarly, the concentration of sodium hydroxide is varied by 6, 8 and 10 molar concentrations. The developed 9 mixes variation is shown in table 4.

Table 4. Mix Variational Parameters

Mix ID	Ratio of Na_2SiO_3 to NaOH	NaOH Concentration	Granite Powder Replacement
M1	1.5	6 M	-
M2	1.5	8 M	-
M3	1.5	10 M	-
M4	2.0	6 M	-
M5	2.0	8 M	-
M6	2.0	10 M	-
M7	2.5	6 M	-
M8	2.5	8 M	-
M9	2.5	10 M	0
M9G1	2.5	10 M	5
M9G2	2.5	10 M	10
M9G3	2.5	10 M	15
M9G4	2.5	10 M	20

With this normally developed 9 GPC mixes the mix M9 is considered for the granite powder replacement. In the total binder volume of the granite powder is replaced at 5, 10, 15 and 20%. The final mix proportion is shown in table 5a, 5b and 5c.

Table 5a. Final Mix proportion

Material	Mix Proportion (kg/m^3)			
	M1	M2	M3	M4
Fly ash	331.03	331.03	331.03	331.03
GGBS	82.76	82.76	82.76	82.76
M-Sand	720.00	720.00	720.00	720.00
20mm aggregates	594.00	594.00	594.00	594.00
12mm aggregates	486.00	486.00	486.00	486.00
NaOH	74.48	74.48	74.48	62.07
NaOH Molarity	6 M	6 M	6 M	8M
Na_2SiO_3	111.72	111.72	111.72	124.14

Table 5b. Final Mix proportion

Material	Mix Proportion (kg/m^3)				
	M5	M6	M7	M8	M9
Fly ash	331.03	331.03	331.03	331.03	331.03
GGBS	82.76	82.76	82.76	82.76	82.76

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M-Sand	720.00	720.00	720.00	720.00	720.00
20mm aggregates	594.00	594.00	594.00	594.00	594.00
12mm aggregates	486.00	486.00	486.00	486.00	486.00
NaOH	62.07	62.07	53.20	53.20	53.20
NaOH Molarity	8 M	8 M	10 M	10 M	10 M
Na_2SiO_3	124.14	124.14	133.00	133.00	133.00

Table 5c. Final Mix proportion

Material	Mix Proportion (kg/m^3)			
	M9G1	**M9G2**	**M9G3**	**M9G4**
Fly ash	314.48	297.93	281.38	264.83
Granite Powder	16.55	33.10	49.66	66.21
GGBS	82.76	82.76	82.76	82.76
M-Sand	720.00	720.00	720.00	720.00
20mm aggregates	594.00	594.00	594.00	594.00
12mm aggregates	486.00	486.00	486.00	486.00
NaOH	53.20	53.20	53.20	53.20
NaOH Molarity	10 M	10 M	10 M	10 M
Na_2SiO_3	133.00	133.00	133.00	133.00

C. Experimental Execution

For the strength assessment the compressive strength test, split tensile strength test, ultrasonic pulse velocity (UPV) test and rebound hammer (RH) test were conducted. The compressive and split tensile strength were conducted for all 13 mixes. The UPV and RH test was conducted only for normal GPC mix M9 and granite powder replacement mixes M9G1, M9G2, M9G3 and M9G4. The UPV and RH test was conducted for comparing the strength properties. For compression strength, UPV and RH test cubes specimens and for split tensile strength cylinder specimen were casted. The cube specimen is 150mm (L) x 150mm (B) x 150mm (H) in size and the cylinder specimen were 100mm in diameter and 200mm in height. All the cubes and cylinders were given a rest period of 1 day after that kept for ambient curing. For compression strength test and split tensile strength, the casted cubes were tested by Compression Testing Machine of capacity 2000 KN as per IS:516-1959. For compressive stress test the load at failure of each cube was noted and for split tensile strength test, a compressive load is applying across the diameter of cylinder till it splits. For UPV and RH test the cube specimen is used and the tests were done in accordance with IS:13311-1992 part 1 and 2 respectively.

III. RESULTS AND DISCUSSIONS

A. Compressive Strength Test

The compressive strength test is conducted at 7th and 28th days. The results are shown in table 6.

Table 6. Compressive stress test results

Mix ID	7 days	28 days
M1	15.07	39.29
M2	22.78	46.68
M3	25.69	50.38
M4	17.45	35.22
M5	18.73	44.18
M6	24.97	49.37
M7	16.8	31.22
M8	15.69	31.89
M9	17.21	34.54
M9G1	19.52	35.62
M9G2	21.95	38.54
M9G3	22.62	35.48
M9G4	20.82	33.25

From the compressive strength test results, it is evident that the increase in sodium hydroxide concentration results in higher compressive strength. Also, the lower the ratio of sodium silicate to hydroxide higher will be the strength. The alkaline ratio of 1.5 and 2.0 yields almost similar and maximum strength. The compressive strength for the mix M3 exhibits a greater maximum strength of 50 MPa. Almost 50% of the compressive strength is achieved at the age of 7 days for all mixes. The strength development at 7 days for the granite powder mixes are less than 45%. This shows the granite powder gives less early strength when compared with normal GPC mixes. The 10% replacement of granite powder gives a maximum of 38.54 MPa compressive stress, which is 11.5% higher than the normal mix M9. Figure 1 shows the graphical variation of compressive stress for all mixes.

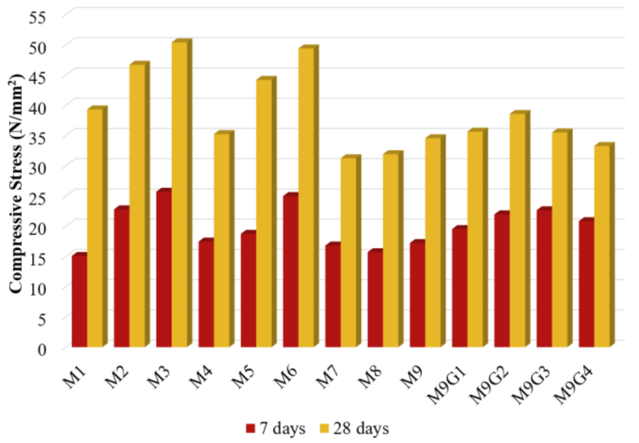

Fig 1. Compressive Stress Results

B. Tensile Strength Test

The tensile strength test is conducted at 7th and 28th days. The results are shown in table 7.

Table 7. Tensile stress test results

Mix ID	7 days	28 days
M1	2.66	3.85
M2	3.24	4.63
M3	3.34	4.79
M4	2.89	4.04
M5	2.88	4.45
M6	3.44	4.74

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M7	2.78	3.93
M8	2.69	4.07
M9	2.84	4.12
M9G1	3.01	4.15
M9G2	3.22	4.53
M9G3	3.12	3.96
M9G4	3.01	3.88

The tensile stress values obtained for all mixes are in accordance with the compressive strength results as per Indian standards. Also, a similar variation of strength is obtained. The maximum tensile stress is obtained as 4.79 MPa in mix M3. The increase in concentration and decrease in alkaline solution ratio, results in higher tensile stress. The replacement of granite powder up to 10% yields higher tensile stress, which almost 10% higher than the normal mix M9. The 10% replacement of granite powder gives a maximum of 4.53 MPa tensile stress. Figure 2 shows the graphical variation of tensile stress for all mixes.

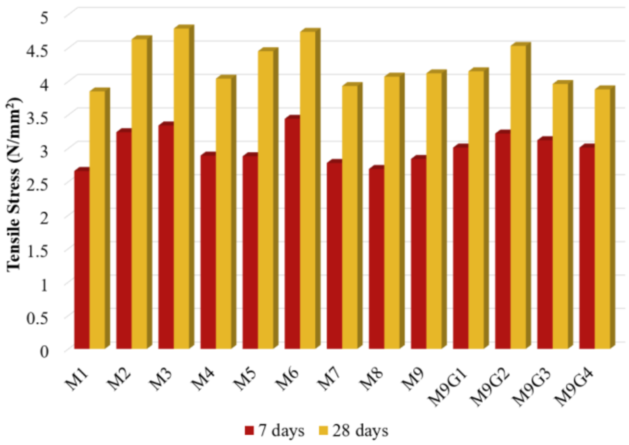

Fig 2. Tensile Stress Results

C. Ultrasonic Pulse Velocity Test

The UPV test is done at 28 days for comparing the granite powder properties. The UPV results are shown in table 8.

Table 8. UPV test results

Mix ID	Pulse Velocity (m/s)	Quality of Concrete
M9	3835	Good (3500-4500)
M9G1	4021	Good (3500-4500)
M9G2	4373	Good (3500-4500)
M9G3	4310	Good (3500-4500)
M9G4	4202	Good (3500-4500)

From the results, the quality of the normal mix and granite powder mixes have shown good quality concrete, when compared with the UPV values from IS 13311-part 1 consideration. All the concrete mixes have good internal structures with lesser voids. Also, the granite powder helps in the reduction of internal voids. The figure 3 shows the graphical variation for the UPV for granite powder replaced mixes.

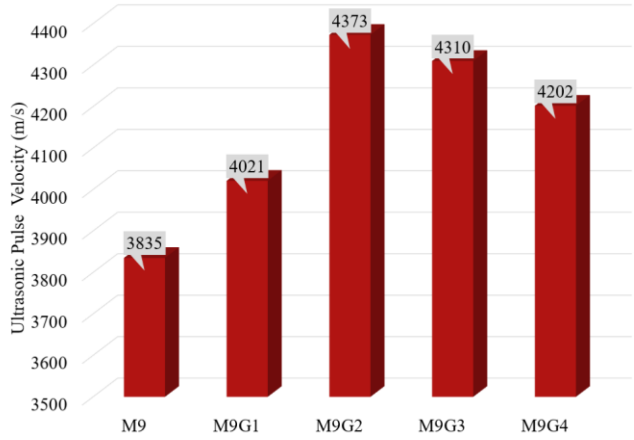

Fig 3. UPV test Results

D. Rebound Hammer Test

The RH test is done at 28 days for comparing the granite powder properties. The RH results are shown in table 9.

Table 9. RH test results

Mix ID	Rebound Number	Compressive Strength from Rebound Index (N/mm²)
M9	29	28.5±6.0
M9G1	31	32.0±6.5
M9G2	34	37.0±6.5
M9G3	32	34.0±6.5
M9G4	28.5	27.0±6.0

From the results, the predicted compressive stress from the RH index was similar for the mix M9. The remaining mixes with granite powder have shown more strength values than predicted results when compared with the values compression testing results.

IV. CONCLUSION

1. Lower alkaline ratio and higher molarity have good mechanical properties for all mixes.
2. For all mixes, 40% of the mechanical strength is achieved at the age of 7 days.
3. The 10% granite powder replacement is obtained as optimum replacement percentage.
4. The 10 % replacement of granite powder showed 11.5% increase in compressive strength at the age of 28 days when compared with the M9 mix. Similarly, the M9G2 mix with 10% replaced granite powder showed a 10% increase in split tensile strength at the age of 28 days when compared with the M9 mix.
5. Based on the UPV results, we can infer that the sustainable developed concrete has lesser voids and with good internal structure, which helps in higher strength properties.
6. The rebound hammer test results for the granite waste replacement mixes show inconsistencies with the actual compressive stress results. A similar strength variation is observed, which is proportional to the normal compressive stress with a slight reduction in strength.

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