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Research Paper

Durability properties of ternary blended geopolymer concrete under ambient curing

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Abstract

The present paper is an attempt to explore the durability properties of ternary blended geopolymer concrete incorporating fly ash, GGBS, wollastonite as appendage of strength parameters. The Large scale production of cement is triggering environmental problems. This has made the researchers to prefer supplementary cementatious material in fabricating concrete. Fly ash [1], GGBS is a waste material produced by industries used as binder material to way towards the waste utilization. Wollastonite, a naturally occurring mineral can be exploited in geopolymer concrete as a partial replacement of fly ash. G40 grade of geopolymer concrete is used in this study and mix design was built accordingly by replacing fly ash by the combinations of wollastonite and GGBS with suitable alkaline solution and Superplasticizer. A constant 50% of fly ash was used for all the mixes and rest 50% with the combinations of 15%, 35%; 25%, 25%; 35%, 15% of wollastonite and GGBS respectively .In this present experimental work durability tests (mass loss tests) like resistance to sulphate attack, chloride attack; sorptivity, abrasion resistance were explored for plain mix and optimal mix, which was extracted from previous experimental work of compressive strength properties of ternary blended geopolymer concrete.

Keywords: *Geopolymer Concrete; Fly Ash; GGBS; Wollastonite; Ambient Curing; Compressive Strength; Durability; Efflorescence.*

1. Introduction

Geopolymer concrete stands highly durable in nature and even in any aggressive environments existing at present. Addition of wollostonite, GGBS in low calcium based fly-ash based geopolymer concrete [4] demonstates standard raise in the compressive strength and durability section. low calcium Fly ash based geopolymer concrete renders slightly economic benefits over Portland cement concrete it yields in reduction of damage to enivironment. The filler materials like fly-ash [1], GGBS helps in depletion of excessive heat produced while constructing geopolymer concrete is also well known as cool & green concrete as it is free from major pollutant CO_2 which deterirates the enivironment. Alkaline solutions in geopolymer concrete play a major role in assisting the durability properties of ternary blended geopolymer concrete.

Regarding geopolymer: Davidovits (1988, 1994) proffered an alkaline liquid could be suitable to react with the silicon (Si) and the aluminum (Al) components in source compounds the materials such as Fly-ash & also GGBS to initiate binders as the chemical reaction process which takes place is a Polymerization process, he conceived the word ‘Geopolymer’ to represent these binders. This Geopolymerisation [2] represents the chemical reaction of aluminosilicate oxides with alkali polysilicates yielding polymeric Si – O – Al bonds. Water swelled out from the mixture throughout the curing process. A critical feature is that water is present only to promote workability and does not become a part of the resulting geopolymer structure.

Generally sodium hydroxide with sodium silicate at liquid ratio of 2.0 is utilised as a alkaline liquid ratio. Sodium is preferred over potassium predomionantly because it is economical. . This review briefs about the durability studies on GPC for exposure to elevated temperature, resiliences to sulphates, chlorides and acid.

2. Materials

Various ingredients which are used for making geopolymer concrete for the present experimental work are presented in this section.

Fly-ash (class F) [1] was obtained from Navayuga RMC plant, Hyderabad, commercially available ground blast furnace slag (GGBS) and wollastonite mineral (powder form) from Rajasthan was used along with fly ash as a binder. Locally available River sand was used as fine aggregate passing through IS sieve 4.57mm was taken. Uncrushed, crushed or partially crushed gravel or stone were used as coarse aggregate which should be hard, strong, dense, durable, clear and free from veins and adherent coatings which were retained on IS sieve 20mm. Water used for mixing and curing was fresh potable water. Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In this investigation sodium silicate 2.0 (ratio between Na_2O to SiO_2) was used. As per the manufacture, silicates were supplied to the detergent company and textile industry as bonding agent, Sodium Silicate liquid used in this study was provided in gel form by Famous Chemicals industries, Hyderabad. Generally the sodium hydroxides are available in solid state by means of pellets and flakes. In this present investigation the sodium hydroxide pellets of purity 97 % were utilized.

3. Geopolymer concrete mix procedure

The sodium hydroxide flakes or pellets were dissolved in distilled water to make a solution with desired concentration atleast 1 day prior to use. Considering 10 molarity concentration, should be noted that 10M sodium hydroxide solution should have 10 × 40 = 400g of NaOH solids per 1Ltr of sodium hydroxide solution. To prepare this, 400g of NaOH pellets were taken in a glass beaker containing 750ml of water and then subjected to stirring until dissolved. The left over portion was poured with water upto 1ltr and mixed thorouly to make NaOH solution.

Fly-ash and aggregates were mixed in a concrete pan mixer for 3 minutes, then sodium hydroxide solution and sodium silicate gel was allowed to mix with it for 4 more minutes and finally desired quantity of superplasticizer was dropped and mixed to achieve desired geopolymer concrete.

After mixing, the slump of the freshly mixed geopolymer concrete was noted in accordance with the IS: 1199-1959 slump cone test.

Then the geopolymer concrete was cast into the greased moulds of Cubes of size 150mm×150mm×150mm are casted for plain Gpc and Wollastonite, GGBS replaced GPC The concrete is to be poured in three layers and compacted with manual strokes by applying 25 blows to each layer with the help of a tamping rod. The moulds can then be placed on a vibrating table for further compaction. Immediately after making the cubes they should be marked clearly.

Fig. 1: Pan Mixer.

Fig. 2: Fresh Geopolymer Concrete.

Fig. 3: Moulds.

Fig. 4: Vibrator.

After casting, the specimens should be kept in a mould for 1 day. For GPC the specimens were demoulded after 1 day. The moulds were cured under ambient curing [9] method by placing the moulds in an open air and are allowed to cool down slowly at room temperature to prevent formation of cracks. The term rest period indicates the time taken from the completion of casting of test specimens to the start of curing at an elevated temperature. After one day the specimens demoulded and left it to in an open air condition until the testing period.

4. Mix design and data

Unit weight of Geopolymer concrete is 2400 kg/m^3 [7]

The Mass of Combined aggregate as 0.75% of the mass of

Concrete i. e, 0.75 x 2400 = 1800 kg/m^3

Taking mass of Coarse aggregate as 65% to the mass of combined

Aggregate= (65x 1800)/100 =1170 kg/m^3

Then taking mass of Fine aggregate as 35% to the mass of

Combined aggregate= (35x 1800)/100 =630 kg/m^3

Mass of Fly ash and alkaline Liquid = 2400-1800 = 600 kg/m^3

Considering alkaline liquid to fly ash ratio as 0.35

Mass of fly ash= (600)/ (1+0.35) = 444.44 kg/m^3

Mass of alkaline liquid= 600-444.44= 155.56 kg/m^3

Considering the ratio of NaOH to Na_2SiO_3 as 2

Mass of Na_2SiO_3 solution=155.56-51.85= 103.71 kg/m^3

Now calculating the total amount of mass of water and mass of solids in the sodium hydroxide and sodium silicate solution:
Sodium Hydroxide solution (NaOH):

10 X 40(molecular weight) = 400 grams of sodium hydroxide solids per one liter of sodium hydroxide solution.

The water content in the NaOH solution in observed as 63.5%.

The mass of NaOH solution = (155.56)/ (1+2) =51.85 kg/m^3

The Mass of Water= (63.5/100) x (51.85) = 32.92 Kg

Mass of solids = 51.85 – 32.92= 18.93 Kg

Sodium Silicate Solution (Na_2SiO_3):
The water content in the silicate solution in observed as 63.5%.

The Mass of Water= (63.5/100) x (103.71) = 65.85 Kg

Mass of solid =103.71 – 65.85= 37.86Kg

Total mass of water:

Mass of water in NaoH solution + mass of water in Na_2SiO_3.Solution= 65.85+32.92= 98.77 Kg

Total mass of solids:

Mass of solids in NaOH solution + mass of solids in Na_2SiO_3 solution + mass of Fly ash = 37.86+444.44+18.93= 501.2 Kg

Ratio of water to Geopolymer Solids = 98.77/501.2= 0.19

(Not aimed for target mean strength, aimed for 40Mpa).

Table 1: Mix Design of Control and Optimal Mix

S.NO.	1	2
Mix Id	M0	M2
C.A (kg/m^3)	1170	1170
F.A (kg/m^3)	630	630
Flyash (kg/m^3)	444.44	222.22
Wollastonite (kg/m^3)	--	111.11
GGBS (kg/m^3)	--	111.11
NaOH (kg/m^3)	51.85	51.85
Na_2SiO_3 (kg/m^3)	103.71	103.71
SP(430) (kg/m^3)	13.33	13.33

5. Experimental procedure and testing

5.1. Compression test

The cube specimens of size 150mmx150mmx150mm were tested in accordance with IS: 516 - 1999.
The testing was done on a compression testing machine of 2000KN capacity. Specimens were placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom. The maximum load applied to the specimen was recorded. The compressive strength [7] of the specimen was calculated using the equation,

$$fc = P/A$$

Where, fc is the compressive strength,
P is the maximum load applied to the specimen,
A is the cross-sectional area of the specimen.

Fig. 5: Compression Test Machine.

5.2. Acid resistance

The test was performed to study the effect of sulphate on concrete. Sulphate may be present in soil or ground water which comes in to the contact of concrete and affect it. Three specimens of plain GPC mix and three specimens of wollastonite, GGBS replaced GPC mix were prepared to measure change in mass to take average result of the specimen. Cubes were immersed in 5% concentrated H_2So_4 solution after 28 days of curing period for a specific exposure period.
Solution with 5% concentration was used as the standard exposure solution. The specimens were immersed in the H_2So_4 solution in a tank. To prepare the solution of 5% concentration, for each 100gm solution 95gm of water and 5gm (by weight) of Sulfuric acid is added. After preparation of the solution pH value of the solution is measured by using digital pH meter. In order to maintain the concentration of H_2So_4 throughout the test, the pH value of the solution was measured at every 15 days interval and by considering the initial pH as reference Sulfuric acid or water was added and by trial and error initial pH value is achieved.

5.3. Chloride attack

The test was performed to study the effect of chloride on concrete. Chloride may be present in soil or ground water which comes in to the contact of concrete and affect it.Three specimens of plain GPC mix and three specimens of wollastonite, GGBS replaced GPC mix were prepared to measure change in mass to take average result of the specimen. Cubes were immersed in 5% concentrated HCL solution after 28 days of curing period for a specific exposure period.
Solution with 5% concentration was used as the standard exposure solution. The specimens were immersed in the HCL solution in a tank. To prepare the solution of 5% concentration, for each 100gm solution 95gm of water and 5gm (by weight) of Hydrochloric acid is added. After preparation of the solution pH value of the solution is measured by using digital pH meter. In order to maintain the concentration of HCL throughout the test, the pH value of the solution was measured at every 15 days interval and by considering the initial pH as reference Hydrochloric acid or water was added and by trial and error initial pH value is achieved.

5.4. Sulphate resistance

The test was performed to study the effect of sulphate on concrete. Sulphate may be present in soil or ground water which comes in to the contact of concrete and affect it. Three specimens of plain GPC mix and three specimens of wollastonite, GGBS replaced GPC mix were prepared to measure change in mass to take average result of the specimen. Cubes were immersed in 5% concentrated $MgSo_4$ solution after 28 days of curing period for a specific exposure period. [10]
Solution with 5% concentration was used as the standard exposure solution. The specimens were immersed in the $MgSo_4$ solution in

a tank. To prepare the solution of 5% concentration, for each 100gm solution 95gm of water and 5gm (by weight) of Magnesium sulphate is added. After preparation of the solution pH value of the solution is measured by using digital pH meter. In order to maintain the concentration of $MgSo_4$ throughout the test, the pH value of the solution was measured at every 15 days interval and by considering the initial pH as reference Magnesium sulphate or water was added and by trial and error initial pH value is achieved.

Fig. 4: Solutions Tubs.

5.5. Sorptivity

Sorptivity [5] test for geopolymer concrete & wollastonite, GGBS based geopolymer concrete was performed on the standard cube specimens based on Hall's method. The water sorptivity test shall be conducted at room temperature. After 28 days of Ambient curing, the specimens are coated with a waterproofing agent of all four sides such that only unidirectional uptake from the bottom is possible. The initial weights of the cubes are noted after the agent has sufficiently dried. The specimens were placed in container filled with distilled water. The water level should be 10mm from the bottom. The cubes are placed on small glass rods, such that to facilitate water contact on the bottom surface of the cube. The cubes absorb water from the bottom and transmit up by capillary action. The specimens are weighed at 15min, 30min, 1hr, 2hr, 4hr, 6hr, 24hr, 48hr, after patting it once on a damp piece of absorbent paper. The specimen should appear saturated surface dry (SSD) on the exposed face at the time the mass is determined. The mass determination method must not consume longer than 15 seconds per specimen on each instance that the mass is determined. The stopwatch shall not be paused during the weighing procedure. Two cubes for control & optimal mix which were taken for the Sorptivity test based on the previous experimental work, optimal mix was taken from compressive strength results.

$S = i/\sqrt{t}$

The sorptivity coefficient(s) are obtained by using the above expression

Where, $i = \Delta W/ (A \times d)$

ΔW = the amount of water absorbed in (kg);
A = the cross-section of specimen that was in contact with water (m^2);
d = density of the medium in which the specimen was dipped. (d = 1, as the medium used is water);
t = time (min);
S = the sorptivity coefficient of the specimen ($kg/m^2/\sqrt{min}$).

5.6. Abrasion resistance (under water method)

This test method is used for determining the relative resistance of concrete (including concrete overlays and impregnated concrete) to abrasion [6] under water. This procedure simulates the abrasive action of waterborne particles (silt, sand, gravel, and other solids). This test method is delibrated to qualitatively simulate the performance of swirling water containing suspended and transported solid objects that offer abrasion of concrete and generate potholes and related effects. This test method should provide a relative evaluation of the resistance of concrete to such action. The results are expected to be useful in selection of materials, mixtures, and construction practices for use where such action is to be expected. The test method is not deliberated to provide a quantitative measurement of the length of service that may be expected from a specific concrete.
Position the specimen in the test container with the surface to be tested siding up and the seating blocks in place. Placing the specimen so that its surface is normal to the drill shaft and the center of the specimen concurs with the drill shaft. Mount the agitation paddle in the drill press. The bottom of the agitation paddle shall be 38mm above the surface of the specimen. Determine and record the mass of the abrasive [6] charge to the nearest 10 g (0.02 lb). Place it on the surface of the specimen and add water of the same type as used in the saturation period to 165mm above the surface of the specimen. Start the paddle rotating and check that the paddle is rotating at the required speed with the paddle immersed. Remove the specimen from the test container at periodical operation of 12hr. Flush off the abraded material and surface dry. Determine and record the mass of the specimen in air and in water. The standard test shall consist of six 12hr periods for a total of 72hr. The Abrasion Resistance test conducted on the two cylindrical discs of dimensions 100mm×200mm depth and diameter on plain mix disc and optimal mix disc.

$V_t = (V_{air}-V_{water})/G_w$

Where: Vt =volume of the specimen at the desired time, m3,
Wair = mass of the specimen in air at the desired time, kg,
Wwater = apparent mass of the specimen in water at the desired time, kg,
Gw =unit weight of water kg/m3.

Fig. 7: Abrasion Resistance.

Fig. 8: Abrasion Resistance.

Apparatus Specimen

6. Results

i) Compressive strength(N/mm^2)

Compressive strengths for control mix and ternary blended geo-polymer concrete mixes are shown in table 2.

Table 2: Compressive Strength Variation

Mix Id	7 days	28 days
M0	17.48	41.18
M1	18.33	43.25
M2	22.66	47.85
M3	16.88	39.11

ii) Acid resistance

Control mix and optimal mix cube specimens undergone acid resistance in H_2SO_4 solution, mass loss is shown in table 3.

Table 3: % Loss when Immersed in H_2SO_4

Mix Id	Initial Weight	Final Weight	% loss (90 days)
M0	7.58	6.85	9.63
M2	7.64	6.94	6.73

iii) Chloride resistance

Control mix and optimal mix cube specimens undergone Chloride resistance in HCL solution, mass loss is shown in table 4.

Table 4: % Loss when Immersed in HCL

Mix Id	Initial Weight	Final Weight	% loss (90 days)
M0	7.73	7.58	1.97
M2	7.69	7.56	1.69

iv) Sulphate resistance

Control mix and optimal mix cube specimens undergone sulphate resistance in $MgSO_4$ solution, mass loss is shown in table 5.

Table 5: % Loss when Immersed in $Mgso_4$

Mix Id	Initial Weight	Final Weight	% loss (90 days)
M0	7.62	7.48	1.83
M2	7.85	7.76	1.16

v) Sorptivity

Control mix and optimal mix cube specimens undergone sorptivity test, sorptivity coefficients of it are tabulated in table 6.

Table 6: Sorptivity Coefficient

Concrete Grade	M0	M2
15 min	0.071	0.045
30 min	0.059	0.042
1 hr	0.057	0.034
2 hr	0.051	0.024
4 hr	0.041	0.026
6 hr	0.039	0.02
24 hr	0.037	0.045
48 hr	0.031	0.024

vi) Abrasion resistance

Control mix and optimal mix cylindrical specimens which undergone abrasion resistance test, results of it are tabulated in table 7 & 8.

Table 7: Abrasion Resistance Results for GPC Specimen

Hrs	Wair	Wwater	Vt	VLt	Avg. depth of abrasion(mm)
0	16.203	11.076	5.127	-	-
12	15.671	10.807	4.864	0.263	3.72
24	15.239	10.589	4.65	0.214	3.02
36	14.888	10.412	4.476	0.174	2.46
48	14.551	10.242	4.309	0.167	2.36
60	14.248	10.089	4.159	0.15	2.12
72	13.94	9.934	4.006	0.153	2.16

Table 8: Abrasion Resistance Results for Optimised GPC Specimen

Hrs	W air	W water	Vt	VLt	Avg. depth of abrasion(mm)
0	14.94	9.896	5.044	-	-
12	14.55	9.699	4.851	0.193	2.73
24	14.197	9.521	4.676	0.175	2.47
36	13.976	9.3	4.566	0.11	1.55
48	13.804	9.29	4.514	0.052	0.74
60	13.623	9.232	4.391	0.09	1.27
72	13.495	9.167	4.328	0.063	0.89

7. Conclusions

In present experimental analysis various tests on ternary blended geopolymer concrete the compressive strength resulted optimal strength at M2 (25% Wollostonite & 25 % GGBS & 50% Fly-Ash) inclusions so, the durability tests are carried out for control & optimal strength obtained mix. Average Abrasion depth for plain GPC specimen is recorded as 15.84mm and for ternary blended GPC specimens as 9.65 mm which is much less than control mix. Optimal ternary blended GPC has performed better than plain geopolymer concrete mix in case of Sorptivity.

The incorporation of wollostonite in geopolymer composites has performed better results in Abrasion, resistance against sulpahate ($MgSO_4$), chloride (HCL) and acid (H_2SO_4) and also Sorptivity as compared to control mix. Replacement of fly-ash by wollastonite & GGBS has improved the overall performance in Mechanical & Durability [10] characteristics of ternary blended geopolymer concrete.

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