ABRASION RESISTANCE AND SORPTIVITY OF TERNARY BLENDED GEOPOLYMER CONCRETE

Karnatakam Sai Prasad[1], **Dr. Kolli Ramujee**[2]

[1] M.Tech. Structural Engineering, VNR Vignana Jyothi Institute of Engineering and Technology,
Hyderabad, Telangana-500090, India.

[2] Professor, Civil Engineering Department, VNR Vignana Jyothi Institute of Engineering and Technology,
Hyderabad, Telangana-500090, India.

Abstract: Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules. Fly Ash, a by- product of coal obtained from the thermal power plant is plenty available worldwide. Fly ash is rich in silica and alumina reacted with alkaline solution produced alumino silicate gel that acted as the binding material for the concrete. It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be produced without using any amount of ordinary Portland cement. Fly ash,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 utilized in geopolymer concrete as a partial replacement of fly ash. However, despite these advantages widespread commercial use of geopolymer concrete in the construction industry has encountered numerous technical and institutional barriers which need to be addressed. In the current study 50% of fly ash and rest 50% with the combination of 25% of wollastonite,25% of GGBS were used for one mix and the plain mix(100% fly-ash based) for another mix were prepared and the Abrasion Resistance(underwater method) and Sorptivity characteristics are studied. In addition to these, comparison studies are made between Flyash based GPC and wollastonite, GGBS, Flyash combination based GPC for Abrasion and Sorptivity.

Keywords: Fly ash; GGBS; Wollastonite; Abrasion Resistance; Sorptivity; Durability.

I. INTRODUCTION

The global use of concrete is second only to water. As the demand for concrete as a construction material increases, so also the demand for Portland cement. It is estimated that the production of cement will increase from about from 1.5 billion tons in 1995 to 2.2 billion tons in 2010. On the other hand, the climate change due to global warming and environmental protection has become major concerns.**[1][4][7]** The global warming is caused by the emission of greenhouse gases, such as carbon dioxide CO_2, to the atmosphere by human activities. Among the greenhouse gases, CO_2 contributes about 65% of global warming. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere. The environment must be protected by preventing dumping of waste/by-product materials in un-controlled manners. Several efforts are in progress to address these issues.**[1]** 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 this respect, the geopolymer concrete with a much lower environmental footprint shows considerable promise for application in the concrete industry. In terms of global warming, the geopolymer technology could significantly reduce the CO_2 emission to the atmosphere caused by the cement industries as shown by the detailed analyses by Gartner. The term ‘Geo polymer’ was coined by Davidovits in 1978 to describe a family of mineral binders with chemical composition similar to zeolites but with an amorphous microstructure **.[2]** Two main constituents of geopolymers are source materials and alkaline liquids. The source material should be rich in silicon (Si) and aluminium (Al). In this case, the source material used is fly ash. The chemical reaction which takes place in this case is a polymerization process. Unlike ordinary Portland pozzolanic cements, geopolymers do not form calcium-silicate-hydrates (CSHs) for matrix formation and strength, but utilize the polycondensation reaction of silica and alumina where adjacent hydroxyl ions from these near neighbors condense to form an oxygen bond linking the molecules, and a free molecule of water .The “monomers” so formed in solution can be represented in 2-dimensions by - Si – O – Al – O - (poly[silalate]), or, - Si – O – Al – O – Si – O - (poly[silalate-siloxi]), precursors to attain structural strength; hence the term ‘Geopolymer’ was initiated to represent the binders. Geopolymer is used as the binder, instead of cement paste, to produce concrete. The geopolymer paste binds the loose coarse aggregates, fine aggregates and other unreacted materials together to form the geopolymer concrete. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. As in the Portland cement concrete, the aggregates occupy the largest volume, that is, approximately 75 to 80% by mass, in geopolymer concrete. The silicon and the aluminum in the fly ash are activated by a combination of sodium hydroxide and sodium silicate solutions to form the geopolymer paste that binds the aggregates and other unreached materials.**[3]** Wollastonite is naturally occurring mineral formed due to interaction of limestone with silica in hot magmas(Paul 1977) .It is chemically calcium-meta silicate (Ramchandra et al 1981) wollastonite was found to possess reinforcing quality and resistance to chemical attack even in high temperature (USGS minerals book 2009) .It is white mineral highly modulus. India produced 120,000 tons of wollastonite in year 2010 which accounts 22% of total world production. It is abundantly available in Rajasthan Pali Sirohi Dist**[4].** Udaipur and also found in Tamil Nadu, Uttarakhand and Andhra Pradesh. it is being used for reduction of shrinkage cracks ceramic tiles and refractory improvement in tensile strength of plastics. Study available so far about wollastonite is a natural mineral with specific gravity ranging from 2.8 to 3.1 and indicates that it is potential mineral responsible for properties enhancement. The objective of the present work is to facilitate the utilization of wollastonite as a new material in geopolymer concrete with partial replacement of fly ash. And this is done by determining the optimum level of replacement based on compressive strength.

II. EXPERIMENTAL PROCEDURE

1. Materials

The properties of various ingredients such as wollastonite, GGBS, fly ash, Fine aggregate, Coarse aggregate, alkaline solutions used in the GPC and wollastonite, GGBS added GPC are presented in this section.

1.1 Wollastonite

The chemical formula of wollastonite is CaSiO3. It is composed of calcium (Ca) and silicon and oxygen (SiO^2, silica) Wollastonite has a high pH of 9.9 in a 10 percent water slurry That can stabilize acidity .Application of wollastonite in concrete mixes as partial replacement of cement, sand or both was reported by CRRI. From the results of study it was evident that incorporation of wollastonite in concrete increases flexural and compressive strength.

Table 1: Chemical Composition of Wollastonite

Sample	**SiO_2**	**CaO**	**FeO**	**MnO**	**MgO**	**Na_2O**	**K_2O**	**LOI**
Wollastonite (%)	50.84	48.16	0.18	0.05	0.24	0.12	0.09	0.54

Table 2: Properties of Wollastonite

Parameter	**Property**
Appearance	white
Form	Lump or powder
Specific Gravity	3.04
Molecular wt.	116
PH value	9.1

1.2 Coarse Aggregates-

This may be uncrushed, crushed or partially crushed gravel or stone. They should be hard, strong, dense, durable, clear and free from veins and adherent coatings and free from injurious amounts of disintegrated pieces, alkali organic matter. Tests are conducted to determine its physical properties. The aggregates passing through are 20mm sieved and retaining on 12.5mm sieve were taken for the experimental procedures.

Table: 3 Properties of Coarse Aggregates

Property	**Size**	**Shape**	**Specific gravity**	**Abrasion value**	**Water Absorption**	**Crushing value**
Value	20mm	non-uniform	2.72	27.52%	0.45%	12.22%

1.3 Fine Aggregate:

Sand generally greater than 70 micron and less than 4.75 mm is used as fine aggregate in concrete. It is a granular form of silica. In concrete, sand acts as a filling material, which fills the gap between coarse aggregate. This will provide carbon dioxide required for hydration. This gives additional strength to concrete and prevents it from shrinkage and cracking due to creep etc. Locally available River sand is used as fine aggregate and is tested for various properties required. The sand passing through IS sieve 2.36mm was taken.

Table 4: Properties of Fine Aggregates

Property	**size**	**Specific gravity**	**Water Absorption**	**Bulk Density**	**fineness modulus**
value	4.75 mm seive	2.6	0.90%	1850 kg/m^3	2.64

1.4 Fly-ash:

Fly ash is the waste obtained as a residue from burning of coal in furnaces and locomotives. It is obtained in the form of powder. It is a good pozzalona .The color of fly ash is light grey. In the present experimental work, low calcium Class F fly ash is used and it is obtained from Navyuga RMC, hyderabad. Telangana.

1.5 GGBS:

GGBS is a waste material produced by industries used as binder material to way towards the waste utilization commercially available ground blast furnace slag (GGBS).

Table 5: Chemical Composition of Fly Ash, GGBS

Sample	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**SO_3**	**P_2O_5**	**TiO_2**	**LOI**
Fly ash (%)	55.70	25.74	8.98	3.90	0.74	0.41	1.49	0.66	0.05	1.09	1.57
GBFS (%)	37.8	8.00	0.51	39.70	10.80	0.38	0.74	0.20	0.02	0.55	0.21

1.6 Alkaline liquids:

The alkaline solution was prepared by mixing both sodium silicate solution and sodium hydroxide solution together at least one day prior to use. The ratio of sodium silicate to sodium hydroxide solution was fixed as 2.

a) Sodium silicate:

Sodium silicate is also known as water glass or liquid glass, available in liquid (gel) form. In present investigation sodium silicate 2.0 (ratio between Na_2O to SiO_2) is used. As per the manufacture, silicates were supplied to the detergent company and textile industry as bonding agent.

The Sodium Silicate liquid used in this study was provided in liquid form by Famous chemical industries, Hyderabad.

b) Sodium hydroxide:

Generally the sodium hydroxides are available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. In this investigation the sodium hydroxide pellets of purity 97 % were used.

(a) (b)

Fig.1 (a) sodium hydroxide & (b) Sodium hydroxide

Table 6: Properties of Sodium silicate solution

Specific gravity	1.6
Molar mass	122.06 gm/mol
Na_2O (by mass)	14.70%
SiO_2 (by mass)	29.40%
Weight of solids (by mass)	44.1%
Water (by mass)	55.90%
Weight ratio (SiO_2 to Na_2O)	2.00
Molar ratio	2.06

Table 7: Properties of Sodium Hydroxide

Molar mass	40 gm/mol
Appearance	White solid
Density	2.1gm/cc
Melting point	318^0C
Boiling point	1390^0C

2. Mix Proportions:

2.1 Mixing:

After collecting all the materials in the required proportions i.e Fly Ash, wollastonite, fine aggregate, coarse aggregate, sodium hydroxide, sodium silicate, extra water for Geopolymer concrete specimens. They are mixed in the concrete mixer continuously for a time period of 3minutes.After mixing, the concrete is tested for workability using slump cone test.

2.2 Curing:

In this process the Conventional concrete cubes are placed in water in a curing tank for a total period of 28 days after demoulding. The Geopolymer concrete moulds are placed in the Hot air oven for heat curing and then they are demoulded and placed for ambient curing (kept in air) for the desired period OF 24 hours at 80degrees centigrade.

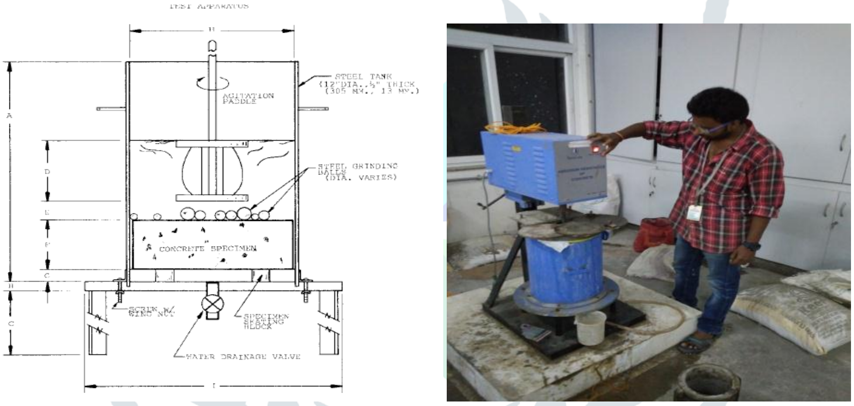
Table.8 Mix Design data: **(Kg/m^3);**

S.NO.	Mix ID	C.A	F.A	Fly ash	Wollastonite	GGBS	NaOH	Na2SiO3	SP(430)
1	M0	1170	630	444.44			51.85	103.71	13.33
2	M1	1170	630	222.22	111.11	111.11	51.85	103.71	13.33

3. METHODOLOGY:

3.1 Abrasion Resistance (Underwater Method):

This test method is used for determining the relative resistance of concrete (including concrete overlays and impregnated concrete) to abrasion under water. This procedure simulates the abrasive action of waterborne particles (silt, sand, gravel, and other solids). **[4][7][5].** This test method is intended to qualitatively simulate the behavior of swirling water containing suspended and transported solid objects that produce abrasion of concrete and cause 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 intended to provide a quantitative measurement of the length of service that may be expected from a specific concrete.



(b) **(d)**

Fig.2 (c) & (d) abrasion resistance apparatus

Procedure:

Place the specimen in the test container with the surface Vto be tested facing up and the seating blocks in place..Position the specimen so that its surface is normal to the drill shaft and the center of the specimen coincides 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 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 the end of every 12 h of operation. 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 12-h periods for a total of 72 h. The Abrasion Resistance test conducted based on the previous experimental work , optimal mix was taken from compressive strength results.

Calculations:

Calculate the abrasion loss as follows:

Calculate the volume of the specimen at any time as follows:

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

where:

*V*t =volume of the specimen at the desired time, m3,

*W*air = mass of the specimen in air at the desired time, kg,

*W*water = apparent mass of the specimen in water at the desired time, kg, and

*G*w =unit weight of water kg/m3.

Calculate the volume of concrete lost at the end of anytime increment of testing as follows:

$VL_t = V_i - V_t$

where:

*VL*t =volume of material lost by abrasion at the end of the test increment in question, m3,

*V*i = volume of specimen before testing, m3, and

*V*t = volume of the specimen at the end of the test increment in question m3.

Should it be desired to calculate the average depth of wear at the end of any time increment of testing based on volume of abraded material, it may be done as follows:

ADAt = VLt/A

Where: ADAt = average depth of abrasion at the end of the test increment in question, m.

3.2 Sorptivity Test:

Sorptivity 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.**[9]** 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.**[7]** The mass determination procedure must not take longer than fifteen seconds per specimen on each occasion that the mass is determined. The stopwatch shall not be stopped 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.

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

$$\boxed{S = i/\sqrt{t}}$$

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 ($kg/m^2/\sqrt{min}$).

4. Results & discussions:

4.1 Compressive Strength:

The cube specimens of size 150 mm x 150 mm x 150 mm were tested in accordance with IS: 516 - 1969.

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 load was applied without shock and increased continuously at a rate of approximately 14 N/mm^2/min until the resistance of the specimen to the increasing load breaks down and no greater load can be sustained. The maximum load applied to the specimen was recorded. The compressive strength of the specimen was calculated using the equation

Table.9 Compressive Strength results:

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

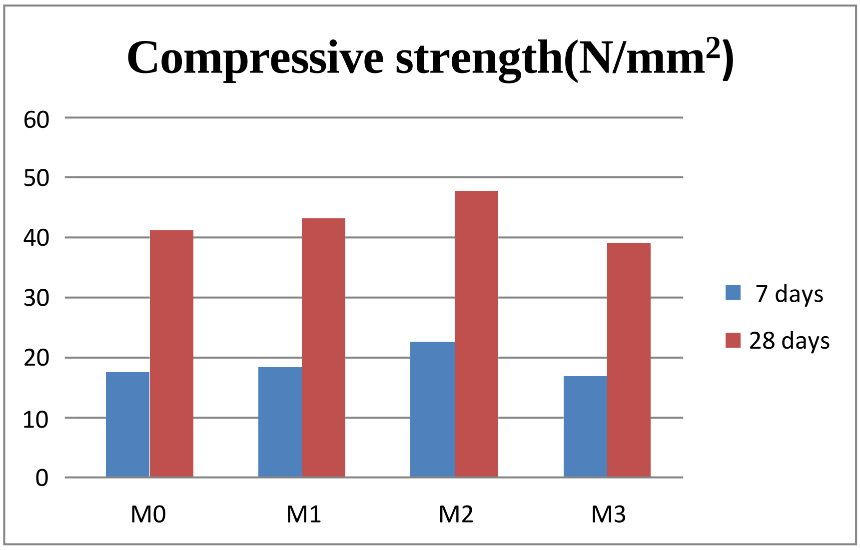


Fig. Compressive Strength Variation

4.2 Results for Abrasion resistance:

Table.10 Abrasion Resistance results for plain GPC Specimen

HOURS	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	4.650	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	0.150	2.12
72	13.940	9.934	4.006	.0.153	2.16

Table.11 Abrasion Resistance results for wollastonite & GGBS based GPC Specimens

HOURS	W air	W water	Vt	VLt	Avg. depth of abrasion(mm)
0	14.940	9.896	5.044	-	-
12	14.550	9.699	4.851	0.193	2.73
24	14.197	9.521	4.676	0.175	2.47
36	13.976	9.300	4.566	0.110	1.55
48	13.804	9.290	4.514	0.052	0.74
60	13.623	9.232	4.391	0.090	1.27
72	13.495	9.167	4.328	0.063	0.89

4.2 Sorptivity results for 150mmX150mmX150mm cubes:

Table.12 Sorptivity coefficients

Concrete Grade	15 min	30 min	60 min	120 min	180 min	240 min	300 min	360 min
PLAIN GPC 40	0.071	0.059	0.0574	0.051	0.041	0.039	0.037	0.031
Wollastonite Based GPC 40	0.045	0.042	0.034	0.024	0.026	0.02	0.045	0.024

V CONCLUSIONS:

From above Experimental work we can conclude that the Average Abrasion depth for plain GPC specimens is recorded as **15.84mm** and for ternary blended GPC specimens as **9.65 mm** which is much less than control mix.

Hence incorporation of wollastonite in GPC matrix gives good abrasive resistance. Sorptivity tests have concluded The Sorptivity coefficient **decreases** as the grade of concrete increases geopolymer concrete **increases.**

The wollostonite fly-ash & GGBS based GPC has performed better than plain geopolymer concrete mix. Sorptivity of low calcium fly ash geopolymer concrete is lower than the corresponding OPC concrete mixes. OPC concrete shows higher **capillary porosity** than Geopolymer concrete.

As the Sorptivity factor depends on water to geopolymer solid ratio the **lower ratio** can yield better results in both plain GPC and ternary blended GPC.

REFERENCES:

[1] G. Eason, B. Noble, and I.N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955.

[2] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[3] I.S. Jacobs and C.P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G.T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271-350 ASTM C 666 – 1997 “Standard Test Method for Resistance of Concrete for Rapid Freezing and Thawing”.

[4] Mehta, P. K. (1989). Pozzolanic and Cementitious By-Products in Concrete - Another Look. Paper presented at the third international conference on fly ash, silica fume, slag, and natural pozzolans in concrete, Trondheim, Norway

[5] KolliRamujee et al(2013). “Development of mix design for low calcium based Geopolymer concrete in Ordinary,standard and High strength grade concretes” Indian concrete Institute (ICI), Vol 14, issue no 2, pp 29-34.

[6] Davidovits, J. (2005). Geopolymer Chemistry and Sustainable Development. The Poly(sialate) Trminology : A Very Useful and Simple Model for the Promotion and Understanding of Green-Chemistry. In J. Davidovits (Ed.), Geopolymer, Green Chemistry and Sustainable Development Solutions (pp. 9-15). Saint-Quentin, France: InstitutGéopolymèr.

[7] R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.

[8] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740-741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[9] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.

[10] Shalika Sharma, Dr Hemant Sood Abrasion Resistance of Geopolymer Concrete at Varying Temperature. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 1 Ver. I (Jan. - Feb. 2016), PP 22-25.

[11] D.Hardjito, B. V. Rangan, "Development and properties of low- calcium fly ash based geopolymer concrete", Research Report GC 1, Faculty of Engineering, Curtin niversity of Technology, Perth, Australia, 2005.

About Authors:

K.**SAI PRASAD**

PG STUDENT (S.E) (CIVIL DEPT.) VNR VJIET

DR.KOLLI RAMUJEE (DEAN)
PROFESSOR & DEAN (CIVIL DEPT.) VNR VJIET