Water Absorption Capacity of Low Calcium Fly Ash and Slag based Geopolymer Concrete

T Srinivas[1] and Dr. N V Ramana Rao[2]

Abstract: An experimental investigation on effect of water absorption capacity of geopolymer concrete is outlined in this paper. The water absorption capacity, volume of permeable voids and apparent porosity tests were performed on the samples of controlled concrete of standard grades (M30 & M50) and equivalent grades of geopolymer concrete (G30 & G50) to assess the enhancement of part of permeation properties of geopolymer concrete. The results showed that absorptivity, volume of permeable voids and apparent porosity of geopolymer concrete are lower than the corresponding characteristics of controlled concrete. The study of porosity is fundamental for understanding phenomena of water transport within pore structure and interactions between concrete and water. Water can penetrate a solid because there are interconnected channels (pores) inside the solid that facilitate its transportation.The long-term durability of concrete is affected to a large extent by its permeability. Therefore, the permeation properties, rather than mechanical properties, are the important factors to study in relation to concrete durability. As a consequence, a considerable effort has to be directed toward investigation of such properties in the present study.

Keywords: Fly Ash, Geopolymer Concrete, GGBS, Water Absorption Capacity and Volume of Permeable Voids

I. Introduction

Reinforced concrete structures are exposed to harsh environments, yet often expected to last with little or no repair or maintenance for long periods of time. To do this, a durable structure needs to be produced. One of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction in the strength, serviceability, and aesthetics of the structure. This may lead to early repair or premature replacement of the structure. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of the reinforcing steel bar by using relatively impenetrable concrete. Capillary absorption, hydrostatic pressure, and diffusion are the means by which chloride ions can penetrate concrete.

Most building materials, both natural (stones) and artificial (bricks, cement mortar and concrete), contain a certain volume of empty space which is distributed within the solid mass in the form of pores, cavities, and cracks of various shapes and sizes.

The total sum of these empty spaces is called porosity, a fundamental characteristic of building construction material that affects its physical properties (mechanical strength, durability, etc.).The knowledge of their pore structure is an important parameter for characterizing building materials in predicting their behavior under weathering conditions and for evaluating the degree of deterioration and establishing the effectiveness of conservation treatments of their surfaces. The percentage distribution of pores of differing radius within the material is an extremely important parameter for the evaluation of its behaviour when in contact with water. The size of the pores, their distribution and geometry are fundamental factors in determining the properties of materials and their suitability for building applications. One of the main causes of deterioration is the interaction between water and the porous structure. Concrete can be viewed as a porous composite material due to the presence of pores and unfilled voids caused by improper grading of aggregates, lack of enough cement paste, incomplete compaction, bleeding, by air entraining, if used, and inadequate degree of hydration of cement. Perviousness of concrete, like other porous materials, is expressed in terms of permeability, which is defined as the rate at which water or other fluids can penetrate through concrete under a pressure head. Permeability is regarded as an important material property for concrete construction, as its affects the durability of concrete exposed to aggressive environments. Permeability of concrete is not a function of porosity alone, it depends on the porosity, pore size and distribution, and tortuosity of pore channels in concrete (Neithalath et al. 2003).

II. Experimental Programme

A. General

This paper presents an experimental data on the water absorption capacity, volume of permeable voids and apparent porosity tests were then performed on the samples of controlled concrete of standard grades (M30 & M50) and equivalent grades of geopolymer concrete (G30 & G50), to assess the enhancement of part of permeation properties of geopolymer concrete. The mix proportions are given in table 1 and 2.The alkaline solution used for the present study is combination of sodium silicate (Na_2Sio_3) and sodium hydroxide. The ratio of Na_2SiO_3 to NaOH is 2.5 and SiO_2 to Na_2O is 2.09 has been used since the compressive strength is maximum at these ratios. The cubes of size 100mm×100mm×100mm were cast and after one day rest period, the specimens were cured in an oven at 60°C for 24

[1]Research Scholar, Department of Civil Engineering, JNTUH, Hyderabad, Telangana, India –500085

[2]Professor, Department of Civil Engineering, JNTUH, Hyderabad, Telangana, India –500085

hours (OC) and the remaining period cured in sun light. After 28 days the specimens were tested for absorption capacity, volume of permeable voids and apparent porosity of both grades of controlled and geopolymer concrete are evaluated at different time intervals according to codal procedures and the results are studied and compared with the controlled concrete.

TABLE I: MIX PROPORTIONS FOR G30 GRADE OF GEOPOLYMER CONCRETE

Grade of GPC		G30
Fly ash (Kg/m^3)	307.7	362
GGBS (Kg/m^3)	54.3	
Fine Aggregate (Kg/m^3)		682.6
Coarse Aggregate (Kg/m^3)		1184.4
NaOH solids out of 46.54 Kg/m^3 for 12 Molarity concentration in Kg/m^3		16.80
Na_2SiO_3 (Kg/m^3)		116.36
Extra water (Kg/m^3)		20
Super plasticizer (GLENIUM B233)@ 1% (Kg/m^3)		3.62
Ratio of mix proportions		1:1.89:3.27
Liquid/binder ratio		0.45
Workability (mm)		50

TABLE II: MIX PROPORTIONS OF CONTROLLED CONCRETE EXPRESSED AS EQUIVALENT PROPORTIONS OF GPC

Grade of Concrete	M30
Cement (Kg/m^3)	362
Fine Aggregate (Kg/m^3)	682.6
Coarse Aggregate (Kg/m^3)	1184.4
Super plasticizer (GLENIUM)@1% (Kg/m^3)	3.62
Ratio of mix proportions	1:1.89:3.27
W/C ratio	0.45
Workability (mm)	50

TABLE III: MIX PROPORTIONS FOR G50 GRADE OF GEOPOLYMER CONCRETE

Grade of GPC		G50
Fly ash (Kg/m^3)	348.5	410
GGBS (Kg/m^3)	61.5	
Fine Aggregate (Kg/m^3)		554.4
Coarse Aggregate (Kg/m^3)		1293.6
NaOH solids out of 46.86 Kg/m^3 For 16 Molarity concentration in Kg/m^3		20.81
Na_2SiO_3 (Kg/m^3)		117.14
Extra water (Kg/m^3)		45
Super plasticizer (GLENIUM)@ 1.5% (Kg/m^3)		6.15
Ratio of mix proportions		1:1.35:3.16
Liquid/binder ratio		0.40
Workability (mm)		50

TABLE IV: MIX PROPORTIONS OF OPC CONTROLLED CONCRETE EXPRESSED AS EQUIVALENT PROPORTIONS OF GPC

Grade of Concrete	M50
Cement (Kg/m^3)	410
Fine Aggregate (Kg/m^3)	554.4
Coarse Aggregate (Kg/m^3)	1293.6
Super plasticizer (GLENIUM)@1.5% Kg/m^3)	6.15
Ratio of mix proportions	1:1.35:3.16
W/C ratio	0.40
Workability (mm)	50

B. Water Absorption Capacity Test

As per ASTM C642 (13) "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete", this test measures the water absorption rate and the maximum water absorption capacity. The total quantity of water absorbed is related to the total open porosity, while the kinetics of the process depends principally on the distribution of the pore sizes. The maximum quantity of water absorbed by a material at room temperature and pressure under conditions of saturation is expressed as a percentage of the dry mass of the sample. This test also measures the capillary rise of water, the most common form of liquid water migration in concrete. It is inversely proportional to the diameter of the pores; the smaller the diameter the greater the capillary absorption. Absorption is the capacity of a sample to hold water.

B.1. Procedure

1. Concrete cube samples of size 100 x 100 x 100 mm are casted and cured for 28 days for testing.
2. Wash the samples in the deionized water before beginning this test in order to eliminate powdered material from the surface. Dry the samples in the oven for 24 hours at 60°C (this relatively low drying temperature will prevent the deterioration of organic substances in the case of treated samples).
3. Weigh the samples. Repeat the drying process until the mass of the each sample is constant, that is, until the difference between 2 successive measurements, at an interval of 24 hours, is no more than 0.1% of the mass of the sample.
4. Once the samples have been completely dried and the constant mass recorded (m_o), place them in a container or beaker, on a base of glass rods and slowly cover with deionized water until they are totally immersed with about 2 cm of water above them.
5. At programmed intervals of time, take each sample out of the container, blot it quickly with a damp cloth to remove surface water, and then record the mass of the wet samples (m_i) and the time of measurement on the data sheet.
6. Re-immerse the samples in water and continue measuring until the difference in weight between 2 successive measurements at 24-hour intervals is less than 1% of the amount of water absorbed
7. At this point, take the samples out of the water and dry them again in an oven at 60°C until they have reached constant mass (as above). Record this value (m_d) on the data sheet. Proceed with the calculations.

a) At each interval, the quantity of water absorbed with respect to the mass of the dry sample is expressed as:

$$M_i\% = 100 \text{ x } (m_i - m_o)/m_o$$

Where m_i = weight (kg) of the wet sample at time t_i; m_o = weight (kg) of the dry sample

b) Record these values on a data sheet and on a graph as a function of time.

c) From the recorded data sheet, calculate the water absorption capacity (WAC) as shown below:

$$WAC = 100 \text{ x } (m_{max} - m_d)/m_d$$

Where m_{max} = the mass (kg) of the sample at maximum water absorption

m_d = the mass (kg) of the sample after re-drying at the end of the test

The length of the intervals during the first 24 hours depends on the absorption characteristics of the materials. concrete samples should be weighed a few minutes after immersion, and then at increasing intervals (15 min, 30 min, 1 hour, etc.) for the first 3 hours. All samples should then be weighed 8 hours after the beginning of the test and then at 24- hour intervals until the quantity of water absorbed in two successive measurements is not more than 1% of the total mass.

The following equation was used to find the apparent porosity.

$$\text{Apparent porosity } \% = [(M_w - M_d)/(M_w - M_s)] \times 100$$

Where M_w = weight of saturated specimen (after immersion in water for 48 hours, it is removed and surface dried),

M_d = Weight of specimen after oven drying and M_s = weight of specimen while suspended in water As per ASTM C642, the Volume of permeable voids (VPV) was evaluated using the formula:

Volume of permeable pore space in concrete (%) = $(1 - SG_b / SG_a) \times 100$

Where

Concrete bulk dry specific gravity (SG_b) = $M_d / (M_w - M_s)$

Concrete apparent specific gravity (SG_a) = $M_d / (M_d - M_s)$

Concrete bulk dry specific gravity considers both permeable and impermeable voids where as apparent specific gravity considers only impermeable voids.

III. Test Results

TABLE V: WATER ABSORPTION AT DIFFERENT TIME INTERVALS OF CONTROLLED CONCRETE FOR DIFFERENT GRADES

Measurement Intervals t_i (min)	Controlled Concrete			
	M30		M50	
	m_o= 2.50 kg		m_o= 2.55 kg	
	m_i(kg)	M_i(%)	m_i(kg)	M_i(%)
0	2.50	0.00	2.55	0.00
15	2.52	0.80	2.57	0.78
30	2.60	4.00	2.60	1.96
60	2.61	4.40	2.62	2.75
90	2.62	4.80	2.63	3.14
180	2.63	5.20	2.64	3.53
480	2.63	5.20	2.65	3.92
1440	2.64	5.60	2.65	3.92
2880	2.64	5.60	2.65	3.92

TABLE VI: WATER ABSORPTION AT DIFFERENT TIME INTERVALS OF GEOPOLYMER CONCRETE FOR DIFFERENT GRADES

Measurement Intervals t_i (min)	Geopolymer Concrete			
	G30		G50	
	m_o= 2.29 kg		m_o= 2.35 kg	
	m_i(kg)	M_i(%)	m_i(kg)	M_i(%)
0	2.29	0.00	2.35	0.00
15	2.31	0.87	2.36	0.43
30	2.33	1.75	2.38	1.28
60	2.36	3.06	2.39	1.70
90	2.38	3.93	2.42	2.98
180	2.40	4.80	2.43	3.40
480	2.40	4.80	2.44	3.83
1440	2.41	5.24	2.44	3.83
2880	2.41	5.24	2.44	3.83

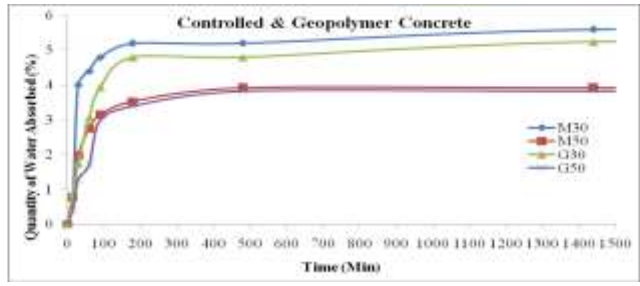

Fig 1: Plot showing amount of water absorption with time for different grades of controlled and geopolymer specimens

TABLE VII: WATER ABSORPTION CAPACITY (WAC), VOLUME OF PERMEABLE VOIDS AND APPARENT POROSITY OF CONTROLLED AND GEOPOLYMER CONCRETE SPECIMENS FOR DIFFERENT GRADES

	Controlled Concrete		Geopolymer Concrete	
	M30	M50	G30	G50
m_{max} (kg)	2.64	2.65	2.41	2.44
m_d (kg)	2.49	2.58	2.36	2.40
m_s (kg)	1.50	1.67	1.48	1.55
Water Absorption Capacity (WAC) (%)	6.02	2.71	2.11	1.67
VPV	13.49	7.39	5.22	4.61
Apparent porosity (%)	13.16	7.14	5.38	4.49

TABLE VIII: DURABILITY CLASSIFICATION AS PER ASTM C642

Classification	Volume of Permeable Voids (VPV) (% by volume)	Water Absorption Capacity (% by weight)
Excellent	<14	<5
Good	14-16	5-6
Normal	16-17	6-7
Marginal	17-19	7-8
Bad	>19	>8

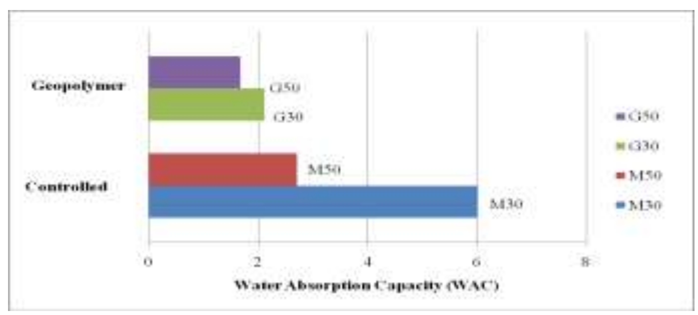

Fig 2: Water absorption Capacity and volume of permeable pore space of controlled and geopolymer concrete

IV. Conclusions

Based on present experimental investigations the following observations are drawn:

1. Water absorption capacity (WAC) of geopolymer concrete specimens for G30 & G50 grades are decreased by 64.9% and 38.38% respectively when we compare to respective grades of controlled concrete because of dense pore structure in geopolymer concrete.
2. Volume of permeable voids of geopolymer concrete specimens for G30 & G50 grades are decreased by 61.3% and 37.62% respectively when we compare to respective grades of controlled concrete because of dense pore structure in geopolymer concrete.

3. An apparent porosity of geopolymer concrete is decreased in both the grades as compared to controlled concrete; this indicates that the durability of geopolymer concrete can be more than controlled concrete.
4. It was observed that the water absorption capacity and volume of permeable voids are decreased as grade of concrete is increased in both geopolymer and controlled concrete.

REFERENCES

[1] D.W. Law, A.A. Adam, et al., Long term durability properties of class F fly ash geopolymer concrete, Mater. Struct. 48 (3) (2014) 1–11.

[2] Claisse, P. A. (1997). "Absorption and Sorptivity of Cover Concrete." Journal of Materials in Civil Engineering, 9(3), 105-110. https://doi.org/10.1061/(ASCE)0899-1561(1997)9:3(105)

[3] Khan, M.I., 2003, "Permeation of High Performance Concrete" Journal of Materials in Civil Engineering, ASCE, Vol. 15, pp. 84-92. https://doi.org/10.1061/(ASCE)0899-1561(2003)15:1(84)

[4] AS, Methods of Testing Concrete – Determination of Water Absorption and Apparent Volume of Permeable Voids in Hardened Concrete, Standards Australia, 1999.

[5] ASTM C642 (1993) Standard Test Method for Specific Gravity, Absorption, and voids in Hardened concrete. American Standard of testing Materials, 1982, pp.395- 97.

[6] German Standard DIN 52 617:1987 (1987). Determination of the water absorption coefficient of construction material.

[7] Parrott, l.j., "Variations of water absorption rate and porosity with depth from an exposed concrete surface: Effects of exposure conditions and cement type", Cement and Concrete Research, Vol. 22, pp. 1077-1088, 1992. https://doi.org/10.1016/0008-8846(92)90038-W

[8] AS, Methods for Sampling and Testing Aggregates, Method 5: Particle Density and Water Absorption of Fine Aggregate, in AS (Australian Standards), Standards Australia, Australia, 2000. pp. 1–8.