2nd International Conference on Current Research Trends in Engineering and Technology
© 2018 IJSRSET | Volume 4 | Issue 5 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Performance Assessment of Pervious Geopolymer Concrete using Metakaolin

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ABSTRACT

Pervious concrete made from geopolymer has some advantages over cementitious pervious concrete in strength as well as in abrasion. It also helps in reducing emission of carbon dioxide in environment. Metakaolin is used as a prime material to produce Pervious Geopolymer Concrete (PGC). In this study, nine different mixes are experimented to check its workability, porosity, permeability and compressive strength. Each mix has different proportion of alkaline liquid (AL) to binder (B) ratio (varying between 0.35, 0.40 and 0.45) and Sodium silicate (Na_2SiO_3) to Sodium hydroxide (NaOH) ratio (varying between 2.5, 2.0 and 1.5) and two different sizes of aggregates ere used, i.e., 4.75-10 mm and 10-20 mm. PGC is cured at elevated temperature of 60˚C for 24 hours after casting. NaOH solution having 16M and Na_2SiO_3 are used as alkaline activators to produce PGC. Specimens are tested after 7 days and 28 days. Up to 21 MPa strength can be achieved with designed porosity range of 20-25%.

Keywords : Alkaline liquid, Geo-polymer concrete, Metakaolin, Permeability, Pervious Concrete, Porosity

I. INTRODUCTION

A concrete that holds high water permeability compared to normal concrete and contains continues voids is known as pervious or permeable concrete. "No-fine concrete" is another term generally used for pervious or porous concrete. It is generally consisting of coarse aggregate, admixture, binder and water. But, in some cases, fine aggregates up to 10% is also used to increase compressive strength of pervious concrete.

Due to expansion of urban area, problems related to runoff management have turned out to be more challenging. This issue has increased the recent interest in pervious concrete pavements. It has some limitation due to its lower compressive strength, clogging and abrasion.

Conventionally, Portland Cement Concrete (PCC) is used for construction of pavements. Increased water runoff in drainage systems, overburdening of infrastructure and cause of excessive flooding in built-up areas are the main problems arises due to impervious nature of PCC pavements. Pervious concrete made of geopolymers has a solution of all the above defined problems.

Pervious concrete is a concrete with significantly high porosity and permeability compared to normal concrete as it has been mainly developed for draining water from precipitation.

There are some advantages of Pervious Geopolymer Concrete (PGC) as it helps in reducing possibilities of flooding specially in urban areas, by allowing storm water into the ground, it helps to replenish aquifers, groundwater and retains storm water, so that retention ponds are not needed for parking lots. It allows air and water to penetrate to the roots of plants and trees within parking areas. It reduces the requirement of watering by improving the quality of landscaping. As it has open interconnected air void structure, it helps in reducing tire noise. It also has less costly repair works than black top. PGC allows water to flow freely through the surface which reduces glare, especially at night.

It also has some disadvantages too, i.e., High maintenance requirement, Risk of clogging if improperly installed and poorly maintained, Runoff from adjacent areas into pervious concrete may also cause clogging, Low strength due to high porosity, Limited use as a load bearing unit due to its low strength.

The main objectives of the study are; (i) to investigate the suitability of Metakaolin based geo-polymer as an alternative to pervious cement concrete, (ii) to study abrasion resistivity of Metakaolin based geo-polymer pervious concrete compared to pervious cement concrete, (iii) to compare the strength and durability aspects of Geopolymer pervious Concrete made from Metakaolin and Fly ash, and (iv) to evaluate compressive strength with desired porosity.

II. METHODS AND MATERIALS

To accomplish the objectives of the study, nine different mixes are designed and casted for various tests. These nine mixes have different combinations of Alkaline liquid to binder ratios (AL/B) and sodium silicate to sodium hydroxide ratios (NS/NH) as shown in Table I below. It also shows proportions of various mixes.

In this study, American concrete institute's report on pervious concrete (ACI 522R-10) [1] is used to design mix proportion of pervious geo-polymer concrete. This mix design is based on porosity and 20% porosity is assumed and mix designed is prepared for the same in this study.

Table I Mix Proportion of PGC

Mix	NS/NH	Alkaline/Binder	NaOH	Aggregate		Na_2SiO_3	Binder	Water
			kg	10-20 mm	10	kg	kg	Kg
			(All parameters are in kg)					
M1	2.5	0.35	1.27	38.59	38.59	3.17	12.68	4.44
M2		0.4	1.38	38.59	38.59	3.44	12.04	4.21
M3		0.45	1.47	38.59	38.59	3.68	11.46	4.01
M4	2	0.35	1.48	38.59	38.59	2.96	12.71	4.45
M5		0.4	1.61	38.59	38.59	3.22	12.06	4.22
M6		0.45	1.72	38.59	38.59	3.45	11.48	4.02
M7	1.5	0.35	1.78	38.59	38.59	2.67	12.73	4.46
M8		0.4	1.94	38.59	38.59	2.9	12.09	4.23
M9		0.45	2.07	38.59	38.59	3.11	11.52	4.03

Curing of PGC is done at an elevated temperature of 60 °C for 24 hours [2] and then to avoid effect of atmospheric moisture, all the specimens are wrapped in plastic bags till the day of testing.

Various materials used for making PGC is listed below with their properties.

A. Metakaolin

A clay mineral kaolinite's dehydroxylated form is known as Metakaolin. The particle size of metakaolin (8-12 μm) is smaller than cement (16-22 μm) particles, but not as fine as silica fume (≤1 μm). Figure 1 shows metakaolin used for this study and Table II shows chemical and physical properties of metakaolin.

Table II Properties of Metakaolin

Properties	Mineral	Value
Chemical Properties	Al_2O_3	43 %
	SiO_2	53 %
	CaO	0.1 %
Physical Properties	Specific Gravity	2.55
	Bulk Density	2640 kg/m^3

Figure 1 Metakaolin

B. Alkaline Liquid

NaOH of molarity 16M is used to produce GPC and brought in flakes form as shown in Figure 2.

Figure 2 Sodium Hydroxide flakes

Sodium silicate used to produce GPC is made by Ricasil industries, GIDC, Anand in composition as shown in Table III below. Figure 3 shows real image of sodium silicate used in this study.

Table III Properties of Sodium Silicate

Properties	Mineral	Value
Chemical	Na_2O	15.9 %
Properties	SiO_2	31.4 %
	H_2O	52.7 %
Physical Properties	Specific Gravity	1.6
	Molecular	184.04
	weight	102 °C
	Boiling point	Light
	Colour	yellow
	Appearance	Liquid (gel)

Figure 3 Sodium Silicate gel

C. Aggregates

Many researchers concluded that use of fine aggregates in pervious concrete up to 20% increases its compressive strength, but it also affects its permeability as porosity decreases [3]. In this study, two different sizes of aggregates are used, i.e., 50% of size 4.75-10 mm and 50% of size 10-20 mm natural river aggregates are used. Table IV shows physical properties of coarse aggregate that are used in mix design in this study.

Table IV Properties of Aggregates

Properties	Mineral	Value
Physical Properties	Specific Gravity Water absorption Fineness modulus	2.59 1.5% 7.15

III. RESULTS AND DISCUSSION

As discussed above, total of nine mixes are casted and tested for different properties like permeability, porosity, compression and abrasion. These different tests are listed below.

A. Compression Test and Density

Pervious concrete is tested by Compression testing machine (CTM) having capacity of 2000 kN, as described in IS:516-1959[4]. To cast specimens for compression test, 150×150×150 mm moulds of cubes are used and tested after 7 and 28 days. The load intensity is limited to 5.2 kN/s as per IS:516-1959.

Table V shows average compressive strength and average density of all nine mixes measured before testing them in CTM. The highest compressive strength is found with AL/B ratio of 0.4 as shown in Figure 4. All the densities are around 2100 kg/m^3 with highest of M6 and lowest of M4.

Table V Average compressive strength and density of PGC

Mix	Compressive Strength (MPa)		Average Density (kg/m^3)
	7 Days	28 Days	
M1	8.43	12.96	2090.37
M2	11.24	17.63	2120.59
M3	10.57	9.33	2071.31
M4	9.57	16.07	2015.41
M5	13.05	21.78	2100.64
M6	12.02	18.15	2129.48
M7	6.91	8.81	2021.04
M8	13.6	21.26	2057.88
M9	11.43	19.7	2093.93

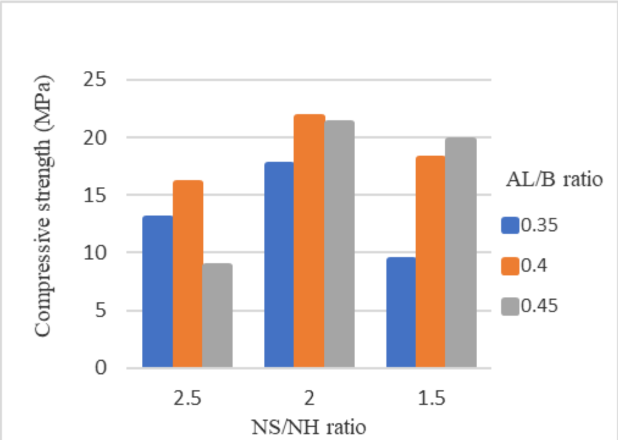

Figure 4 Compressive strength comparison

B. Porosity and Permeability

As porosity is directly related to strength and permeability of concrete, it is important to measure porosity of PGC. Cylindrical specimens of size 150 mm diameter and 300 mm height are casted to measure porosity of PGC. Montes et al. [5] has developed a method to measure porosity of concrete in 2005, the same is used in this study with following equation.

$$P = \left(1 - \frac{W_2 - W_1}{\rho_w \times V}\right) \times 100\ \%$$

where,

P = Porosity, %

W_1 = Weight under water, kg

W_2 = Air-dried weight, kg

ρ_w = Density of water, kg/m^3

V = Volume of specimen, m^3

Permeability is measured by Falling head method as described in IS:2720 (Part-17) (1986) [6]. Above tested cylindrical specimen is then placed in the setup as shown in Figure 5 and permeability is measured using 300 mm head loss. To calculate permeability Darcy's law [7] is used as shown below.

$$K = \frac{A_1 \cdot L}{A_2 \cdot t} \log \frac{h_2}{h_1}$$

where,

K = Water permeability coefficient, mm/s.

A_1 = Cross sectional area of specimen, mm^2

A_2 = Cross sectional are of specimen tube, mm^2

L = Length of specimen, mm

t = time, s

h_2 = Final water head, mm

h_1 = Initial water head, mm

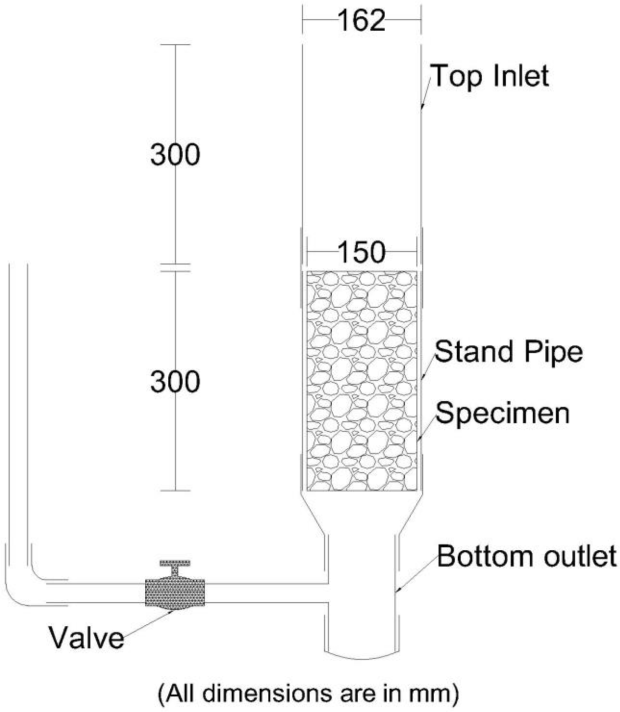

Figure 5 Permeability Set-up [8]

Porosity and permeability of PGC is listed below in Table VI. Mix M9 gives highest permeability as it has the highest porosity. Figures 6 & 7 show that NS/NH ratio of 1.5 gives higher permeability and porosity respectively.

Table VI Porosity and Permeability of PGC

Mix	Porosity (%)	Permeability (mm/s)
M1	23.94	9.92
M2	21.49	9.39
M3	21.68	9.54
M4	24.7	10.02
M5	22.06	9.62
M6	23.19	9.96

M7	22.81	9.77
M8	22.43	9.86
M9	24.13	10.45

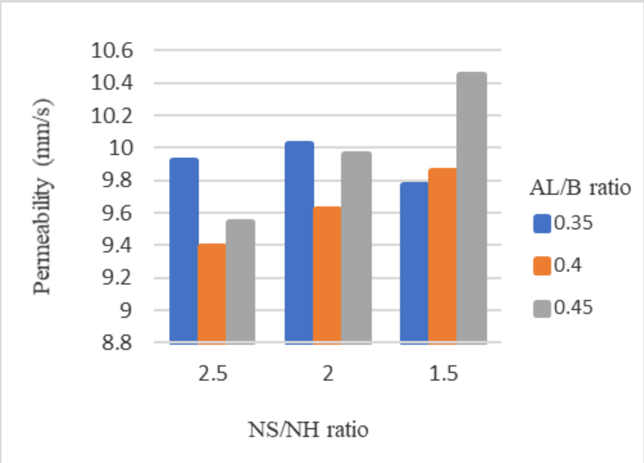

Figure 6 Permeability of PGC

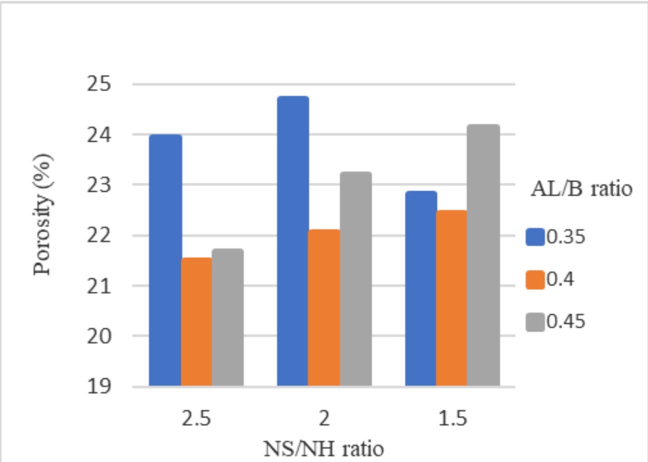

Figure 7 Porosity of PGC

C. Cantabro Abrasion Test

Abrasion resistance must be checked for pervious concrete as it is mainly going to be used in pavements either in parking lots or on the roads. In this study, abrasion loss is obtained by using Cantabro test, which is conducted in Los Angeles (LA) abrasion machine without steel balls. To test PGC for abrasion loss, three specimens of size 70×70×70 mm is casted for each mix and tested. All three specimens are then weighed (W_1) together before test. These specimens are placed together inside the machine, then the machine is rotated 500 times at a rate of 30 rpm. After the loose debris passing through 25 mm sieve is removed and discarded, the final mass (W_2) of the specimens is recorded by weighing the mass retained on sieve. The percentage of mass loss is calculated by the following equation.

$$Cantabro\ Mass\ Loss = \frac{W_2 - W_1}{W_1} \times 100\ \%$$

Figure 8 shows Cantabro mass loss of all nine mixes. It is clear from chart below that M5 and M8 has the lowest mass loss, which has higher compressive strength as shown in Table V. Figure 9 shows that AL/B ratio of 0.4 give less percentage loss.

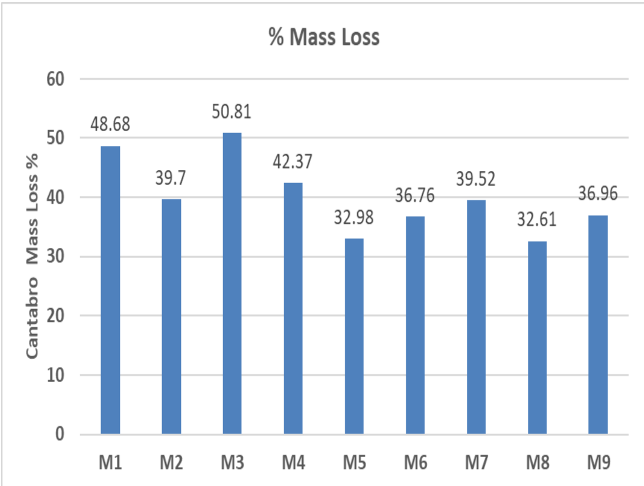

Figure 8 Percentage Mass Loss

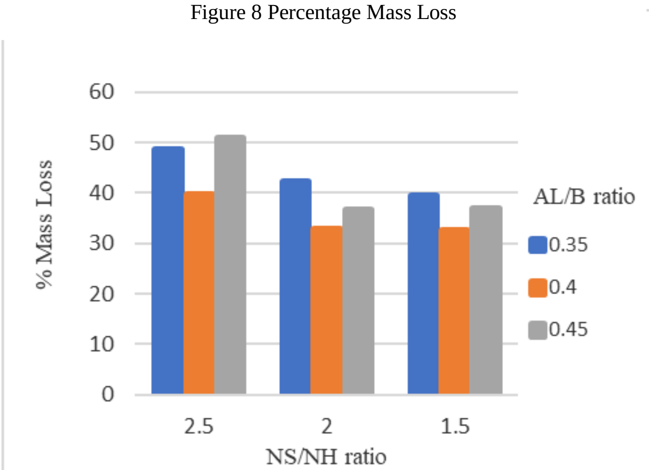

Figure 9 Comparison of Mass Loss (%)

IV. CONCLUSIONS

Compression, porosity, permeability and abrasion resistance, etc. are tested on PGC with different AL/B and NS/NH ratios. Based on the test results and discussion, following conclusions are drawn.

1. The compressive strength is found higher with AL/B ratio of 0.4 with all three NS/NH ratios. All these three mixes have higher density.

2. Although highest porosity of 24.7% is found at NS/NH ratio of 2, NS/NH ratio of 1.5 gives the higher permeability than two others.

3. Abrasion loss of PGC is lower in mixes with AL/B ratio of 0.4, while Al/B ratio of 0.35 gives the higher mass loss in abrasion.

4. To get higher compressive strength and lower abrasion loss with desired porosity and permeability of PGC, AL/B ratio and NS/NH ratio has to be 0.4 and 2.0, respectively.

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