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Geopolymer binder for pervious concrete

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Research Paper

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Construction of pervious concrete (PC) pavements is an exclusive and efficient measure for solving environmental problems while also contributing to sustainability. Pervious concrete enables rainwater to percolate into soil thus reducing the storm water runoff and assisting in ground water recharge. It is used for the construction of pedestrian pathways, parking lots, and in various other applications. During the research, the content of coarse aggregate grains in geopolymer binder was varied in order to investigate pervious concrete properties. It was established that pervious concrete with geopolymer binder containing fly ash meets requirements set in regulations, and that it can be used for sustainable pavement construction.

Key words:

pervious concrete, macrostructure, cohesion, geopolymer, binder, fly ash

Prethodno priopćenje

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Geopolimerno vezivo za propusni beton

Nogostup od propusnog betona (PC) ekskluzivna je i efikasna mjera za rješavanje ekoloških problema i pridonosi održivosti. Omogućava kišnici da se procijedi u tlo smanjujući time mogućnost razlivanja i pomažući u dopunjavanju razina podzemnih voda. Koristi se za izgradnju pločnika, parkirališnih površina kao i za ostale mnoge primjene. Prilikom provedbe istraživanja variralo se s veličinom zrna krupnog agregata u geopolimernom vezivu kako bi se procijenila svojstva propusnog betona. Utvrđeno je da geopolimerno vezivo za propusni beton s letećim pepelom zadovoljava zahtjeve postavljene pravilnicima i može se koristiti za izgradnju održivih pločnika.

Ključne riječi:

propusni beton, makrostruktura, kohezija, geopolimer, vezivo, leteći pepeo

Vorherige Mitteilung

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Geopolymeres Bindemittel für den durchlässigen Beton

Ein Fußweg aus dem durchlässigen Beton (PC) ist eine exklusive und effiziente Maßnahme für die ökologischen Probleme, und sie trägt der Nachhaltigkeit bei. Diese Maßnahme ermöglicht, dass das Regenwasser in den Boden fließt, womit die Möglichkeit der Zerfließung/Vergießung gemindert wird. Der durchlässige Beton ist auch bei der Ergänzung von Ebenen der Grundwasser behilflich. Dieser Beton wird auch für den Bau von Fußwegen, von den Parkplatzflächen, sowie für viele andere Bauten angewendet. Bei der Durchführung von Forschungen gab es Variationen mit der Korngröße des groben Aggregats im geopolimeren Bindemittel, damit die Eigenschaften des durchlässigen Betons eingeschätzt werden können. Es wurde festgestellt, dass das geopolymeres Bindemittel für den durchlässigen Beton mit der fliegenden Asche die Anforderungen erfüllt, welche mit den Dienstvorschriften festgelegt wurden, und dieses Mittel kann für den Bau von nachhaltigen Fußwegen genutzt werden.

Schlüsselwörter:

der durchlässige Beton, Makrostruktur, Kohäsion (Bindigkeit), Geopolymer, Bindemittel, fliegende Asche

1. Introduction

Infrastructure developments in cities have resulted in streets full of impermeable concrete pavements that do not allow water to pass through. There is therefore a pressing need to create pavements of permeable nature. Pervious concrete pavement is the best choice for permeable pavement construction that allows water to penetrate, which leads to proper ground water recharge. Pervious concrete is mainly composed of cement, coarse aggregates, and water, with little to no fine aggregates. It is used in parking lots, pedestrian pathways, swimming pool decks, less-trafficked roads, etc. [1-3]. In general, pore size of pervious concrete ranges from 2 mm to 8 mm in diameter, with the void content ranging between 15 % and 35 %, and the compressive strength of pervious concrete varying between 2.8 MPa and 28 MPa [4]. Concrete is the most widely used construction material in the world, and Ordinary Portland Cement (OPC) is a major ingredient of concrete. Concrete takes second position after water based on global usage. When there is demand for concrete, there is obviously also demand for Portland cement. On the other hand, the production of Portland cement results in CO₂ gas emissions to the atmosphere, which has become a major concern in climate change due to global warming [5]. As per statistics, as much as 7 % by weight of total carbon dioxide emissions is generated by cement producing industries. Therefore, proper recycling and reusing of waste/by-product materials helps in protecting environment. Many investigations have been carried out to address these issues by developing alternate binders instead of Portland cement using several waste/by product materials such as fly ash, ground granulated blast furnace slag, silica fume, rice husk ash, etc. [6].

In 1978, Joseph Davidovits made an attempt to form geopolymer binder by mixing inorganic polymeric material (alkaline solution) with another source material. Alkaline solution can be based on sodium or potassium. Geopolymer technology ranks among the new technologies through which attempts are made to reduce the use of Portland cement in concrete, and reduce environmental footprint. [7]. Several studies have been carried out by varying alkaline liquid/solids (L/S) ratios and sodium hydroxide (NaOH) concentrations termed as molarity (M). These studies reveal information on strength properties, permeability properties, and influence of NaOH concentrations in concrete. Studies in this field have also focused on the total void ratio, water permeability coefficient and compressive strength of pervious geopolymer concrete with the use of recycled aggregates. Furthermore, it has been established that pervious concrete mixture can be produced with acceptable permeability and strength through the combination of latex and sand [8-14]. Comprehensive studies have also been carried out by using geopolymer with various source materials that are rich in silica and alumina in reinforced cement concrete. However, limited studies have been carried out using fly ash based geopolymer in the applications of pervious concrete.

The main objective of the present research is to investigate performance of the fly ash based geopolymer (GP) binder pervious concrete by studying physical, mechanical, and other relevant properties using various sizes of coarse aggregates.

2. Experimental work

2.1. Materials

Ordinary Portland Cement (OPC), grade 53, conforming to IS 12269-2013, was used in the present work. Fly ash of Class 'F' conforming to IS 3812-2003 was obtained from the Mettur Thermal Power Station, Mettur, India. The specific gravity of fly ash was determined as 2.30. X-ray diffraction (XRD) spectra portray that fly ash possesses huge scattered peak at about 20-30° (2θ max) as indicated in Figure 1. It shows the presence of crystalline phases of quartz, calcite, feldspar, and mullite, in the matrix of aluminosilicate glass. Furthermore, the SEM image of fly ash, shown in Figure 2, illustrates that the particles are almost spherical in shape. The SEM and XRD analyses have been conducted at Karunya University, Coimbatore. To prepare alkaline solution, sodium hydroxide (NH) in the form of flakes, and sodium silicate (Na₂SiO₃) solution in liquid form, were procured from Coimbatore, India. Coarse aggregates (crushed blue granite metal) measuring 6.3 mm, 8 mm, 10 mm and 12.5 mm in size, were collected from a local material supplier company.

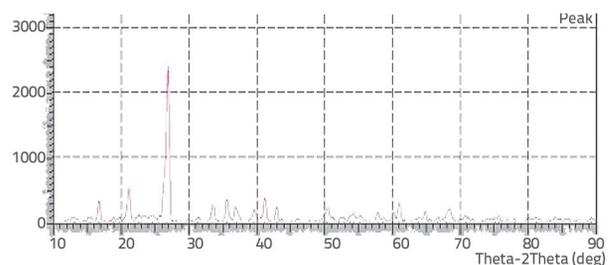


Figure 1. X-ray diffractogram of fly ash

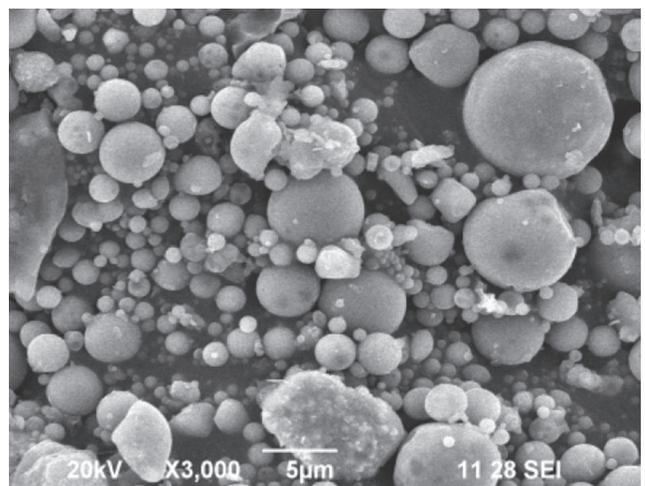


Figure 2. SEM image of fly ash

2.2. Fly ash based Geopolymer binder

Fly ash based geopolymer binder paste was prepared by selecting Na₂SiO₃/NaOH ratio as 2 and liquid to solid ratio as 0.4. The molarity of NaOH was chosen as 8. After preparing the paste, it was cast in cube moulds measuring 70.6 mm x

70.6 mm x 70.6 mm. The cast specimens were demoulded after 24 hours and kept for ambient curing over a period of 28 days to attain sufficient strength. Moreover, XRD and SEM analysis was conducted on the samples at Karunya University, Coimbatore, to study the polymerization behaviour. The corresponding results are presented in figures 3 and 4. XRD pattern of GP mix has a very scattered peak at about 20-30° (2θ max). The presence of crystalline phase in the fly ash, such as mullite, quartz, magnetite and sodalite, was observed through XRD analysis and, because of the activation process by alkaline solution, there was a slight shifting of hump in diffractogram graph (16°-22° and 25°-30°), which indicates formation of zeolites that help in geopolymerisation reaction [17,18]. The SEM analysis revealed dense gel-like substances and, at the surface of geopolymer, small zeolite crystals and N-A-S-H gel. The spherically shaped substance in the SEM image points to the presence of unreacted fly ash particles in the geopolymer blend.

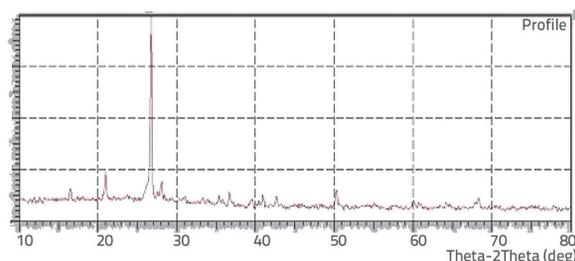


Figure 3. X-Ray Diffractogram of fly ash based GP binder

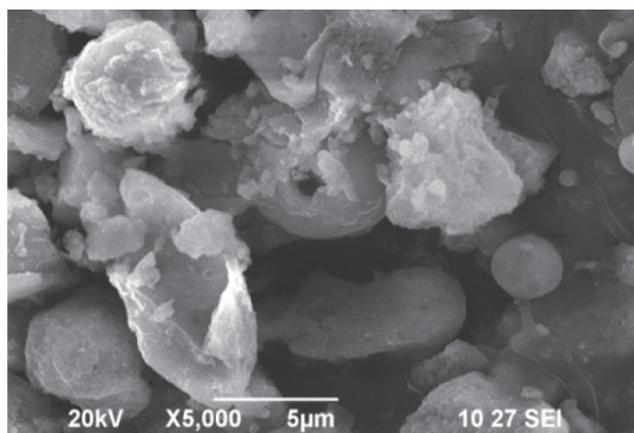


Figure 4. SEM image of fly ash based GP binder

Table 2. Mix proportion for various GP binder PC

Mix ID	Fly ash [kg/m ³]	Coarse aggregate [kg/m ³]	Alkaline solution [kg/m ³]		L/S ratio
			NaOH	Na ₂ SiO ₃	
GP _{6.3}	475	1570	63.3	126.6	0.4
GP ₈	454	1500	60.5	121.0	
GP ₁₀	421	1390	56.1	112.2	
GP _{12.5}	412	1360	54.9	109.8	

2.3. Mix proportion

The aggregate to solid ratio (A/S) was taken to be 3.3 by weight with the constant liquid ratio (Na₂SiO₃/NaOH) of 2 and liquid to solid ratio (L/S) of 0.4. The molarity of NaOH was chosen as 8. Extreme care was taken during preparation of alkaline solution. By using an ordinary Portland cement (OPC) binder, conventional control mix was prepared and the mix proportion was determined as shown in Table 1. The mix proportion determined for the fly ash based geopolymer binder (GP) is presented in Table 2. The mix ID 'OPC' and 'GP' represent the ordinary Portland cement binder mix and the fly ash based geopolymer pervious concrete mix, while the suffix denotes the size of aggregate used in the mix.

Table 1. Mix proportion for various OPC binder PC

Mix ID	OPC [kg/m ³]	Coarse aggregate [kg/m ³]	Water [kg/m ³]	W/B omjer
OPC _{6.3}	475	1570	166.2	0.35
OPC ₈	475	1500	158.9	
OPC ₁₀	421	1390	147.3	
OPC _{12.5}	412	1360	144.2	

3. Tests

Properties such as compressive strength, splitting tensile strength, flexural tensile strength, permeability, porosity, abrasion resistance, and chemical resistance, of OPC and GP binder pervious concrete were determined.

3.1. Mechanical properties

The compressive strength of specimens was determined as per guidelines mentioned in IS 516-1959. A total of 72 cube specimens (100 mm x 100 mm x 100 mm) were made for all the mixes with different binders for compression testing. In the case of the splitting tensile strength, 72 cylindrical specimens measuring 150 mm in diameter and 300 mm in height were used, and the test was conducted as per IS 5816 - 1999 procedure. A total of 72 prismatic specimens measuring 100 mm x 100 mm x 500 mm were used to determine flexural tensile strength, and the test procedure was conducted as per IS 516-1959. After 24

hours, 'GP' mix specimens were demoulded and cured under ambient temperature to achieve sufficient strength. Water curing was done for the OPC mix pervious concrete specimens. An average of three specimens was tested for each mix to study mechanical properties at 7, 28, and 56 days.

3.2. Physical properties

3.2.1. Permeability test

The permeability test was conducted at the age of 28 days using the falling head permeability apparatus as per guidelines given in ASTM C1701/M. The falling head permeability apparatus was fabricated in concrete laboratory of K.S.R. college of Engineering, Tiruchengode, Tamil Nadu. A schematic view of test setup is given in Figure 5.

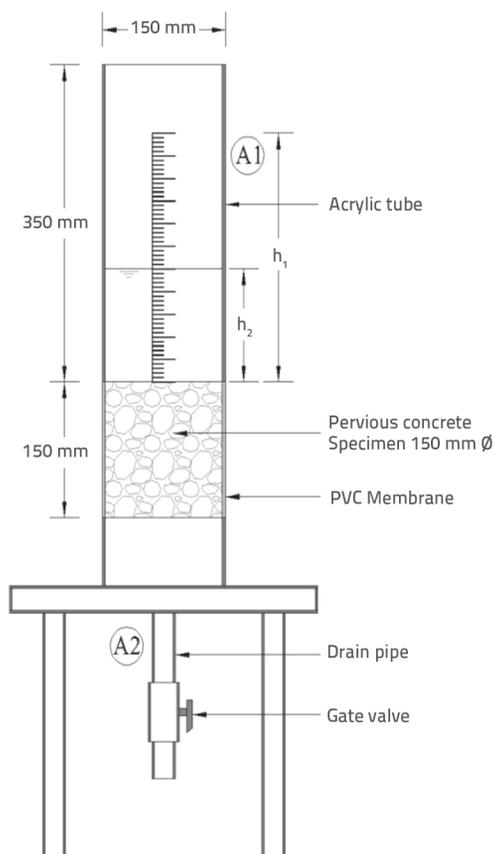


Figure 5. Falling head permeability test setup

A total of 24 cylindrical specimens measuring 150 mm in diameter and 150 mm in height were made and placed in between the PVC pipe and acrylic pipe. The side face of cylindrical specimen was firmly covered using PVC membrane in order to stop horizontal flow of water. A drain valve was attached at the bottom of the PVC pipe. Water was allowed to pass through cylindrical specimen by keeping the drain valve open so that the air locks present inside the specimen can be removed. The

acrylic pipe was filled up to initial head by closing the drain valve. After opening the valve, the time (t) taken for the water to flow from initial head to final head (h_1 to h_2) was noted by using the measuring scale attached to acrylic pipe. Applying the Darcy's law, the coefficient of permeability (k) was calculated as shown in Eq. (1):

$$k = \frac{A_1 l}{A_2 t} \log\left(\frac{h_2}{h_1}\right) \tag{1}$$

Where, A_1 and A_2 are the cross sectional areas of the specimen and drain pipe.

3.2.2. Porosity test

A total of 24 cube specimens measuring 70.6 mm x 70.6 mm x 70.6 mm were cast to determine the porosity percentage of various binder pervious concrete. This test was conducted as indicated by Lian and Zhuge [22]. The percentage of porosity in concrete specimen was determined according to Eq. (2):

$$\text{Porosity [\%]} = \frac{V_T - V_C}{V_T} \tag{2}$$

where, V_T is the total volume of the specimen in [mm³], and $V_T - V_C$ is the void space volume in [mm³].

3.3. Durability properties

3.3.1. Abrasion resistance test

A total of 24 cube specimens measuring 70.6 mm x 70.6 mm x 40 mm were cast to determine the abrasion resistance of pervious concrete. The test was carried out as per procedure defined in IS 1237- 2012. An average loss in specimen thickness was obtained according to Eq. (3):

$$t = \frac{(w_1 - w_2)V_1}{w_1 A} \tag{3}$$

where:

- t - average loss in thickness, [mm]
- w_1 - initial mass of specimen, [g]
- w_2 - final mass of abraded specimen, [g]
- v_1 - initial volume of specimen, [mm³],
- A - surface area of specimen, [mm²].

Also, percentage of wear can be determined using Eq. (4).

$$\text{Percentage of wear [\%]} = \frac{w_1 - w_2}{w_1} \tag{4}$$

3.3.2. Chemical resistance

A pervious concrete cube specimen measuring 100 mm x 100 mm x 100 mm was cast to determine chemical resistance to salt, sulphate, and acid attack on OPC binder and GP binder pervious

concrete. The specimens were immersed in the 3.5 % NaCl solution for salt attack, 5 % MgSO₄ solution for sulphate attack, and 2 % HCl solution for acid attack, separately in containers. After 180 days of chemical exposure, the parameters such as change in weight, change in compressive strength, and visual examination of the specimens, were observed.

4. Results and discussions

Properties such as compressive strength, splitting tensile strength, flexural tensile strength, dry density, permeability, porosity, abrasion resistance, and chemical resistance of OPC and GP binder pervious concrete were determined using different aggregate sizes and the results are discussed in great detail.

4.1. Compressive strength test results

The compressive strength test results of OPC and GP binder pervious concrete are presented in Table 3. The test results revealed that compressive strength of GP_{6.3} mix increased by 8.6 % when compared to conventional control mix OPC_{6.3}, 8.9 % increase in compressive strength was observed in GP₈ mix compared to the conventional control mix OPC₈. The compressive strength of GP₁₀ mix is by 9.7 % higher compared to OPC₁₀ mix. Furthermore, compressive strength of GP_{12.5} mix is by 19.2 % higher compared to OPC_{12.5} mix. It can be concluded from test results that GP binder exhibits higher compressive strength compared to the conventional control mix concrete. This can be attributed to the fact that the presence of rich silica and alumina in fly ash leads to formation of aluminosilicate gel during polymerisation process, which improves the compressive strength property [24, 25]. Regardless of aggregate size, 6.3 mm size aggregate shows higher compressive strength properties for both GP mix and conventional control mix concrete. When aggregate size increases, there is a gradual decrease in compressive strength of concrete. This is because the concrete made with smaller size aggregate shows lesser voids and thus becomes denser and achieves maximum compressive strength. It was also observed that smaller size aggregate has an increased specific surface area that promotes the binding property between aggregate phases [26].

An expression relating to compressive strength and aggregate size of OPC and GP binder pervious concrete was obtained and presented in Eq. (5) and Eq. (6).

OPC binder

$$f_{ck}(28) = -1,94 \cdot 10^{-2} ca^3 + 0,56 ca^2 - 6,53 ca + 45,76; \quad (5)$$

$$R^2 = 0,998$$

Fly ash based GP binder

$$f_{ck}(28) = -6,49 \cdot 10^{-3} ca^3 + 2,66 \cdot 10^{-1} ca^2 - 4,38 ca + 42,62; \quad (6)$$

$$R^2 = 0,999$$

where:

f_{ck} - compressive strength [MPa]

ca - size of coarse aggregate [mm].

4.2. Splitting strength test results

The splitting tensile strength results of fly ash based GP binder pervious concrete are presented in Table 3. Similar to compressive strength, the fly ash based geopolymer binder mix produces higher tensile strength property compared to the conventional control mix. The findings show that the splitting tensile strength of GP_{6.3} mix is by 7.0 % higher compared to that of the conventional control mix OPC_{6.3}. Furthermore, the splitting tensile strength of GP₈ mix is by 7.5 % higher when compared to OPC₈ mix. The splitting tensile strength property of GP₁₀ mix is by 10.1 % higher compared to the conventional control mix OPC₁₀. In addition, the splitting tensile strength is by 20.1 % higher in GP_{12.5} mix compared to the conventional control mix OPC_{12.5}. This may be due to the cohesiveness and rigidity of the geopolymer, resulting in an improved splitting tensile property of pervious concrete and, as discussed earlier, the polymerisation process and higher sodium silicate (Na₂SiO₃) to sodium hydroxide (NaOH) ratio increase the splitting tensile strength property [27]. The trend of compressive strength test results with respect to aggregate size is also presented. An expression relating to the splitting tensile strength and aggregate size of OPC and GP binder pervious concrete is developed and presented in Eq. (7) and Eq. (8).

OPC binder

$$f_{ct}(28) = -2,26 \cdot 10^{-3} ca^3 + 6,58 \cdot 10^{-2} ca^2 - 7,56 \cdot 10^{-1} ca + 5,14; \quad (7)$$

$$R^2 = 0,998$$

Fly ash based GP binder

$$f_{ct}(28) = -1,99 \cdot 10^{-3} ca^3 + 6,48 \cdot 10^{-2} ca^2 - 7,90 \cdot 10^{-1} ca + 5,49; \quad (8)$$

$$R^2 = 0,998$$

where:

f_{ct} - splitting tensile strength [MPa]

ca - size of coarse aggregate [mm].

4.3. Flexural tensile strength test

The flexural tensile strength test results of pervious concrete made with fly ash based GP binder are presented in Table 3. The fly ash based GP binder results are compared with those of the conventional control mix pervious concrete at the age of 28 days. It was observed that the flexural tensile strength of GP_{6.3} mix is by 2.1 % higher compared to the conventional control mix OPC_{6.3}. The flexural tensile strength of GP₈ mix is by 4.2 % higher compared to the OPC₈ mix. Furthermore, the flexural tensile strength of GP₁₀ mix is by 3.4 % higher compared to OPC₁₀ mix. GP_{12.5} has got 8.7 % higher flexural tensile strength than the OPC_{12.5} mix. The ratio

Table 3. Strength characteristics of OPC and fly ash based GP PC

Size of aggregates [mm]	Age [dani]	Compressive strength [MPa]		Split tensile strength [MPa]		Flexural tensile strength [MPa]		Dry density [kg/m ³] at 28 days	
		OPC	GP	OPC	GP	OPC	GP	OPC	GP
6.3	7	17.04	20.75	1.87	2.06	2.91	3.04	2060	2066
	28	22.05	23.95	2.42	2.59	3.33	3.40		
	56	23.52	25.12	2.58	2.78	3.55	3.61		
8	7	14.25	18.39	1.52	1.69	2.65	2.76	2038	2045
	28	19.53	21.27	2.14	2.30	3.12	3.25		
	56	21.23	22.78	2.28	2.52	3.23	3.34		
10	7	11.55	16.19	1.25	1.43	2.44	2.55	2030	2037
	28	17.24	18.92	1.89	2.08	2.95	3.05		
	56	18.62	20.25	2.02	2.23	3.02	3.14		
12.5	7	9.52	14.65	1.05	1.28	2.23	2.37	2015	2028
	28	14.05	16.75	1.54	1.85	2.63	2.86		
	56	15.83	17.83	1.75	1.95	2.85	2.96		

of alkaline solution to fly ash maintained at 0.4 contributes to considerable improvement in the flexural tensile strength property [28]. Obviously, smaller size aggregate shows higher flexural tensile strength when compared to larger size aggregates due to dense packing and enriched bonding. The relationship between the flexural tensile strength and aggregate size of OPC and fly ash based GP binder pervious concrete is given in Eq. (9) and Eq. (10).

OPC binder

$$f_{cr}(28) = -3,22 \cdot 10^{-3} ca^3 + 8,86 \cdot 10^{-2} ca^2 - 8,95 \cdot 10^{-1} ca + 6,25; \tag{9}$$

$$R^2 = 0,995$$

Fly ash based GP binder

$$f_{cr}(28) = 1,37 \cdot 10^{-3} ca^3 - 3,65 \cdot 10^{-2} ca^2 + 2,22 \cdot 10^{-1} ca + 3,10; \tag{10}$$

$$R^2 = 0,998$$

where:

- f_{cr} - flexural tensile strength [MPa]
- ca - size of coarse aggregate [mm].

4.4. Dry density

Dry density values of OPC binder and fly ash based GP binder are shown in Table 3. The test results revealed that an increase in aggregate size reduces the density property because when the size of aggregate increases it leads to an increase in the content of voids that cannot be entirely occupied by the aggregates and binder.

4.5. Penetration characteristics

The permeability and porosity values of OPC and GP binder pervious concrete are presented in Table 4.

Table 4. Penetration characteristics of OPC and fly ash based GP pervious concrete

Size of aggregates [mm]	Permeability, k [cm/s] at 28 days		Porosity [%] at 28 days	
	OPC	GP	OPC	GP
6.3	0.98	0.87	14.85	12.25
8	1.26	1.15	15.62	13.52
10	1.55	1.43	17.84	15.84
12.5	1.95	1.65	19.53	16.52

The coefficient of permeability of the OPC and GP binder pervious concrete ranges from 0.98 cm/s to 1.95 cm/s, and from 0.87 cm/s to 1.65 cm/s, respectively. It can be seen that the coefficient of permeability of GP_{6.3} mix is by 11.2 % lower when compared to the conventional control mix OPC_{6.3}. The coefficient of permeability of GP₈ mix is by 8.7 % lower compared to the conventional control mix OPC₈. In addition, 7.7 % lesser coefficient of permeability was observed in GP₁₀ mix as compared to the conventional control mix OPC₁₀. The coefficient of permeability of GP_{12.5} mix is by 15.4 % lower compared to OPC_{12.5} mix. It is evident that the fly ash based GP binder pervious concrete has lower coefficient of permeability than the conventional control mix concrete. This can be attributed to the fact that, when compared to conventional control mix, the alkaline liquid addition in the geopolymer binder mixture increases the paste content and reduces the void structures in the concrete, and makes the pervious concrete relatively dense [29]. This occurrence reduces the coefficient of permeability in the fly ash based GP binder compared to the conventional control mix. With respect to aggregate size, smaller size aggregate reveals a lower permeability range due to lesser

voids. An increase in the size of aggregate brings about a gradual increase in permeability property due to an increase in void ratio [30, 31].

The porosity of OPC and GP binder pervious concrete ranges from 14.85 % to 19.53 %, and from 12.25 % to 16.52 %, respectively. The results reveal that porosity of GP_{6.3} mix is by 17.5 % lower compared to OPC_{6.3}, while GP₈ mix shows 13.4 % lesser porosity when compared to the conventional control mix OPC₈. It can be observed that porosity of GP₁₀ mix is by 11.2 % lower compared to that of OPC₁₀ mix. In addition, porosity of GP_{12.5} mix is by 15.4 % lower compared to the conventional control mix OPC_{12.5}. The trend observed in permeability results is similar. As discussed earlier, formation of geopolymer binder with high adhesion property, due to alkaline solution percentage, decreases void formation and reduces pores in the structure of concrete. As to aggregate size, smaller size aggregate is characterized by lower porosity. Furthermore, it was noticed that an increase in the size of aggregate results in an increase in porosity due to lower packing effect between grains in aggregate matrix [32].

4.6. Relationship between various properties

The relationship between various properties such as the compressive strength, permeability, and porosity is clarified since these properties are closely related. This relative study helps in finding an optimum aggregate size for each mix with the corresponding compressive strength, porosity and permeability values. It can be seen in Figure 6 that an optimum aggregate size lies between 8 mm and 10 mm, and so the aggregate size of 9.5 mm can be preferred for OPC mix. With respect to the 9.5 mm size aggregate, the compressive strength stands at 18.6 MPa with porosity at 16.5 %, and permeability at 1.4 cm/sec. Figure 7 shows that an optimum aggregate size for GP mix also lies between 8 mm and 10 mm as in OPC mix and, hence, the aggregate size of 9.5 mm can be preferred. For the corresponding aggregate size, GP mix exhibits the compressive strength of 20.1 MPa, with 14.6 % porosity and 1.29 cm/sec permeability.

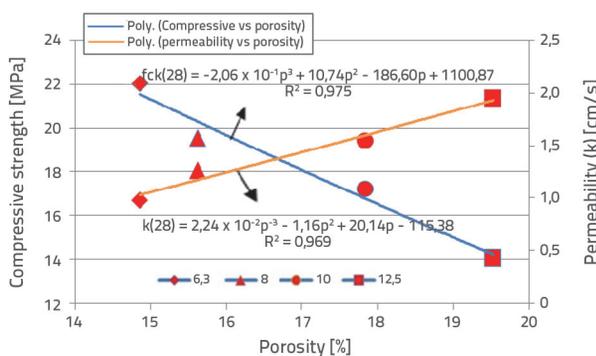


Figure 6. Relationship between “f_{ck}”, “p” and “k” – OPC

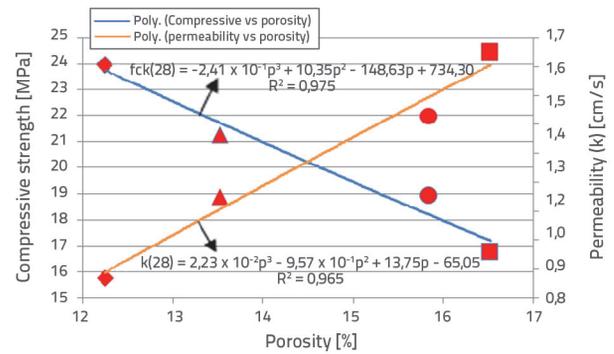


Figure 7. Relationship between “f_{ck}”, “p” and “k” – fly ash based GP

4.7. Abrasion resistance

The abrasion resistance of the horizontal pervious concrete surface was determined using the revolving disc method in which specimens are subjected to frictional forces by rubbing and grinding. The test was conducted on pervious concrete (PC) specimen measuring 70.6 mm x 70.6 mm x 40 mm. The percentage of wear in OPC and GP mix pervious concrete specimens was determined at the age of 28 days. The corresponding results are give in Table 5.

Table 5. Abrasion property of OPC and fly ash based GP binder pervious concrete

Aggregate size [mm]	Percentage of wear [%]		Loss in thickness [mm]	
	OPC	GP	OPC	GP
6.3	0.694	0.656	0.375	0.318
8	0.810	0.725	0.382	0.350
10	1.040	0.932	0.395	0.372
12.5	1.276	1.052	0.411	0.402

Test results show that GP mix specimens exhibit greater abrasive resistance compared to the conventional control mix OPC. The percentage of wear of GP mix specimens GP_{6.3}, GP₈, GP₁₀ and GP_{12.5} is by 5.5 %, 10.5 %, 10.4 % and 17.6 % lower compared to the respective aggregate sizes of the conventional control mix, as graphically presented in Figure 10. This can be attributed to the fact that higher fly ash content, with higher alkaline activator in GP mix, improves the abrasion resistance property of concrete. It is also obvious that abrasion resistance of GP mix is higher in all mixes due to its higher compressive strength. Many researchers agree that abrasion resistance is directly related to compressive strength. It has been established that the effect of abrasion reduces with an increase in compressive strength, splitting tensile strength, and flexural tensile strength of concrete [33]. As to loss in thickness, GP mix specimens show reduced thickness loss compared to the conventional control mix concrete. Results on the loss in thickness for OPC and GP mix pervious concrete specimens are graphically shown in Figure

11. When using different aggregate sizes, greater aggregate size leads to greater loss of wear and loss in thickness, as graphically presented in the same figure.

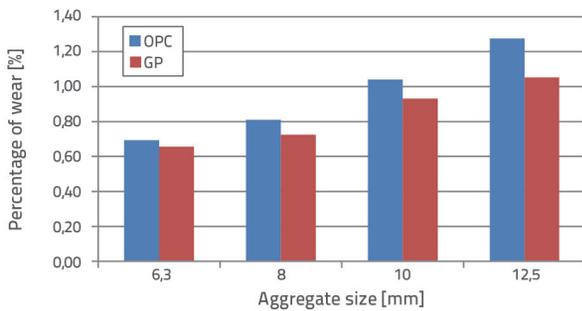


Figure 10. Percentage of wear in OPC and GP mix PC

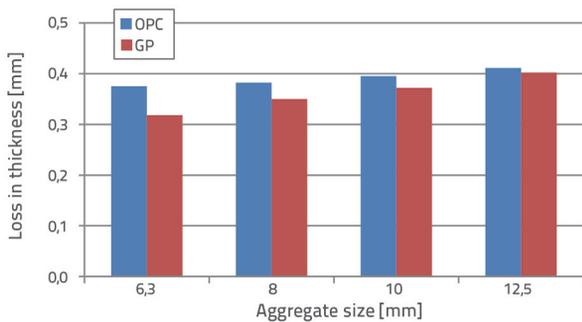


Figure 11. Loss in thickness of OPC and GP mix PC

4.8. Chemical resistance

Parameters such as visual observation, percentage of weight loss, and residual compressive strength, were observed for the specimens that were immersed in NaCl, MgSO₄ and HCl solutions for a period of 180 days. The result of percentage of weight retention against aggressive water solutions are graphically represented in figures 12-14. Visual observation of NaCl soaked specimens revealed that a little blending occurs at sharp edges of the GP mix and OPC mix specimens. This happens because the leaching of calcium compound from cement and fly ash reacts with chloride ions, which leads to blending. With respect to colour change, there was no change in colour of GP mix and OPC mix specimens when compared to the condition before specimens were soaked in NaCl solution.

In the case of immersion in MgSO₄ solution, white salt precipitation was observed in OPC mix because of replacement of calcium by magnesium to form Brucite (magnesium hydroxide) and magnesium hydroxide silicates. In GP mix, whitish layer development was noticed due to reaction of the leached sodium hydroxide with the atmospheric CO₂, later resulting in formation of a white layer of Na₂CO₃.

With respect to immersion in HCl acid solution, a slight reddish colour formed on the surface of the GP mix and OPC mix specimens. This can be attributed to the presence of iron (Fe₂O₃) in fly ash and hydrated cement matrix [34, 35].

Following exposure to NaCl, MgSO₄ and HCl solutions, GP mix specimens experienced relatively lesser weight loss at the age of 180 days compared to the conventional concrete mix. This can be attributed to the fact that dense microstructure property of GP mix restricts the chloride, sulphate and acid ion penetration in concrete, which leads to better performance in case of exposure to aggressive water attack [36-38].

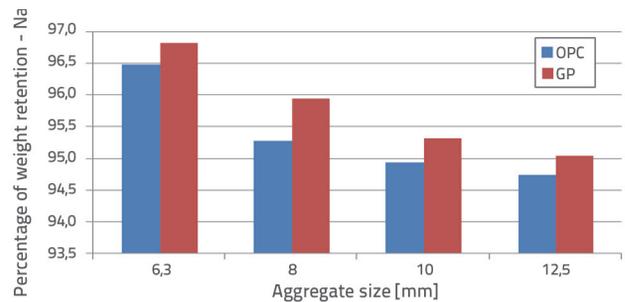


Figure 12. Percentage of weight retention against NaCl

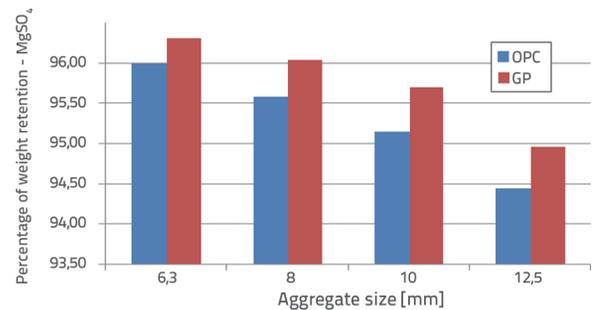


Figure 13. Percentage of weight retention against MgSO₄

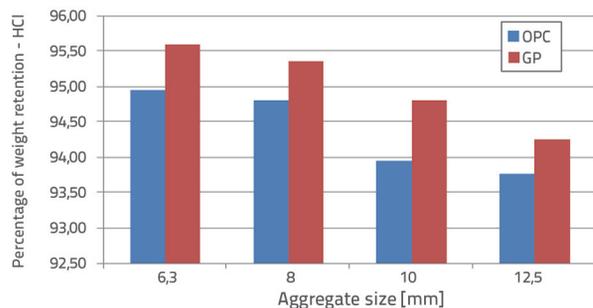


Figure 14. Percentage of weight retention against HCl

5. Conclusions

After determination of mechanical properties such as compressive strength, splitting tensile strength, and flexural strength, physical properties including permeability, porosity and dry density, and durability characteristics such as abrasion resistance and chemical resistance, the following conclusions can be made:

- It was established that pervious concrete made with fly ash based GP binder mix is characterized by higher mechanical strength. This can be attributed to the fact that the presence

of silica and alumina in fly ash plays a predominant role in the polymerization process that leads to formation of aluminosilicate gel, which is mainly responsible for enhancing mechanical strength properties.

- In addition, after comparison of all aggregate sizes, it was established that the mix prepared with smaller size aggregate showed better mechanical properties compared to the mix with larger size aggregate. This can be attributed to the fact that mixes made with smaller size aggregate show the denser packing effect than the mix made with larger size aggregate. Moreover, the use of smaller size aggregate increases the specific surface area and thus also increases the binding area, leading to better strength properties.
- The study of relationship between various physical properties confirmed that the aggregate size of 9.5 mm was

optimum for the fly ash based GP binder pervious concrete and conventional control mix OPC binder pervious concrete.

- Both OPC and GP pervious concrete mixes demonstrated better weight retention when exposed to the influence of chemical solutions. Therefore, pervious concrete made with OPC and fly ash based GP mixes can be used to enhance chemical resistance to salt, sulphate, and acid environment.
- In general, test results show that pervious concrete made with OPC and fly ash based GP binders can be recommended for use in pedestrian pathways, sidewalks, parking lots, and areas with medium traffic density.
- To conclude, pervious concrete made with fly ash based GP can be recommended for green projects as the usage of industrial by products like fly ash helps in minimizing waste materials and in controlling land disposal and environmental degradation.

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