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# EXPERIMENTAL STUDY ON PERVIOUS CEMENT AND PERVIOUS GEOPOLYMER CONCRETES USING SEA SAND AND SEAWATER

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**ABSTRACT:** Normal pervious concrete is a special type of concrete with high porosity, allowing water to percolate into the subgrade and using Portland cement. Pervious geopolymer concrete is also an environmentally friendly concrete using fly ash, blast furnace slag and kaolinite alkaline activator. However, all previous cement and geopolymer concretes are produced with normal sand and clean water. This study presents an experimental program on two types of concrete, viz. pervious cement concrete (PCC) and pervious geopolymer concrete (PGC), both made of sea sand and seawater. The compressive strength and hydraulic properties of those concretes have been investigated, showing that they have acceptable properties and a great potential to replace normal pervious concrete near coastal areas with low traffic density, viz., pavements, parking lots. It is possible to produce PCC and PGC made by sea sand and sea water achieving the compressive strength of cylinder samples greater than 17 MPa at a porosity of 24%.

*Keywords: Porous concrete, Geopolymer concrete, Fly ash, Sea sand, Sea water.*

## 1. INTRODUCTION

Pervious cement concrete (PCC) is known as no-or-very little fine aggregate and as a permeable concrete, allowing water to percolate into the sub-grade. It has been developed as an environmentally friendly material used in water purification, permeable pavement, and other applications in civil engineering. The void content of PCC is between 15% to 35% and the compressive strength is between 2.8 and 28.0 MPa with the water permeability from 2 to 12 mm/s [1]. The aggregate-to-binder ratio of cement based porous concrete is in the range of 4 to 6 by mass [2]. The common components of this concrete type include cement as a binder, coarse aggregates, water and admixure.

Another type of concrete, geopolymer concrete, has been studied and can replace partly the “conventional” concrete since it is an environmentally friendly material. It was introduced the first time by Davidovits [3] who proposed the use of kaolinite, alkaline activators, fly ash (FA) and blast furnace slag (BFS). In Vietnam, this type of concrete has also been studied by a number of researchers [4, 5], showing that GPC can be fabricated locally with good mechanical properties.

A number of studies on pervious geopolymer concrete (PGC) using normal sand and clean water have been done. Trung, Minh, Tung and Phuong [5] proposed a porous geopolymer concrete using normal sand, clean water, fly ash and blast furnace slag which can achieve the compressive cube strength greater than 23MPa. The average values of water permeability are in the range of 6.4 to 17.8 mm/s depending on the mix design. Sata, Wongsa and Chindaprasirt [6] studied the pervious geopolymer concrete using recycled aggregates (RA) and high-calcium fly ash as a source material. Two different types of RA, viz. crushed structural concrete member (RC) and crushed clay brick (RB) were tested, and then compared to natural coarse aggregate. The results indicate that both RC and RB can be used as recycled coarse aggregates for making PGC with acceptable properties. The geopolymer pervious concrete using natural coarse aggregate achieved the highest mechanical strength, while those using recycled aggregate from crushed structure concrete had the best water permeability. Sun, Lin, Vollpracht [7] researched on pervious concrete made of alkali activated slag and geopolymers. The effects of aggregate size and binder type on the physical properties of resultant pervious concrete were studied in terms of compressive strength, density, total porosity and water permeability. They concluded that the pervious concretes produced in the work were not only environmentally friendly, but also achieved higher mechanical properties and water permeability than cement pervious concretes. Azad, Anshul, Azad, Samarakoon, Yadav, Bherwani, and Gebremariam [8] studied the development of geopolymer pervious concrete (GPC). Different geopolymeric compositions were mixed with aggregates of 10 mm and 20 mm and using different binder to aggregate ratios. Compressive strength and flexural strength of the developed fly-ash based geopolymer concrete were 39.9 MPa and 2.2 MPa, respectively, and the void content was maintained up to 37.7%, while density was 1988.14 kg/m$^3$. Huang and Wang [9] studied the geopolymer pervious concrete which focused on its durability, such as freeze-thaw resistance, clogging, and raveling resistance. Geopolymer binder was prepared using metakaolin (MK) or fly ash (FA) with granulated blast furnace steel slag (GBFS) and used to fabricate pervious concrete. The strength and durability results show that the MK based pervious concrete exhibited superior performance in mechanical property and lowest mass loss (3%) after 70 cycles of freeze & thaw test. The FA based pervious concrete had about 10% higher splitting tensile strength and better raveling resistance than the PC based pervious concrete, but its freeze & thaw resistance was the lowest.

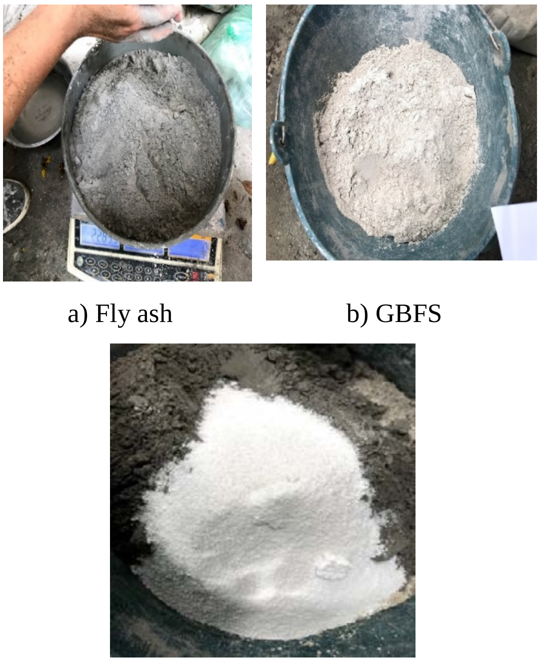
Tung, Trung and Thuan [4] studied the mechanical properties of geopolymer concrete made from sea sand and sea water. The results showed that compressive and tensile strengths of that concrete are not reduced against time. It opens a possibility to apply this type of concrete to civil works near coast areas. Hoa [10] studied the usage of fly ash, sea sand, sea water and fiber reinforced polymer rebars (FRP rebars) in civil works near coast and islands. The results showed that FRP rebars have not been corroded by the concrete made of sea sand and sea water.

It can be seen that there are very few studies on pervious concrete using sea sand and sea water. Therefore, this study focuses on producing two types of pervious concrete, viz. pervious cement concrete (PCC) and pervious geopolymer concrete (PGC), both made by sea sand and sea water. An experimental program was conducted to investigate mechanical and hydraulic properties of PCC and PGC.

## 2. MATERIALS

The raw materials used for PCC include cement But-son Vietnam PC40 with a specific gravity of 3.1 g/cm$^3$, complied with TCVN 2682:2009 [11], granulated blast furnace slag (GBFS) type S95 from Hoa Phat Metallurgy Factory with a specific gravity of 2.94 g/cm$^3$. The granulated blast-furnace slag was ground to reduce particle size of slag, resulting in an increase of concrete compressive strength [7]. The silica fume from Elkem supplier with a specific gravity of 2.20 g/cm$^3$ was adopted. The superplasticizer was ACE388 from Basf supplier with a specific gravity of 1.08 g/cm$^3$. The other materials were sea sand and sea water.

The raw materials of PGC include fly ash (FA), GBFS, alkali-activated materials (AAM or "activator"), coarse aggregate, fine aggregate (sea sand) and sea water. This study used low-calcium fly ash (class F) as defined by ASTM standard C618 [12] from Pha Lai Thermo-power Plant (Vietnam). Fig. 1 shows images of FA, BFS and activator, while chemical compositions of the materials are presented in Table 1. For PCC, silica fume (SF) was used to ensure the strength of the binder; while for PGC, GBFS was used to take part more effectively in the polymerization process.



a) Fly ash b) GBFS

c) Activator (AAM)

Fig. 1 FA, GBFS and AAM

Coarse aggregate was fine stone with the grade complied with the requirements of ASTM C29 [13]. The stone size for all design mixes was from 5 to 10mm with the properties shown in Table 2.

Table 1 Chemical composition of materials (%)

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $CaO$ | $MgO$ |
|---|---|---|---|---|---|
| Cement | 22.58 | 5.72 | 3.45 | 61.23 | 0.65 |
| GBFS | 34.52 | 12.38 | 0.66 | 41.54 | 7.25 |
| FA | 56.25 | 20.04 | 6.60 | 1.90 | 1.30 |
| SF | 93.45 | 0.92 | 0.52 | 1.57 | - |
| | $TiO_2$ | $SO_3$ | $Na_2O$ | $K_2O$ | % of mass loss when heating |
| Cement | - | - | - | - | 1.71 |
| GBFS | - | - | 0.43 | 0.24 | 0.96 |
| FA | 0.40 | 0.58 | - | 2.49 | 9.52 |
| SF | - | - | - | - | 4.20 |

Table 2 Properties of coarse aggregate

| *No.* | *Item* | *Unit* | *Value* |
|---|---|---|---|
| 1 | Unit weight | g/cm$^3$ | 2.72 |
| 2 | Bulk density | kg/m$^3$ | 1620 |
| 3 | Void content | % | 41.0 |
| 4 | Mud & dust content | % | 0.12 |
| 5 | Crushing value | % | 5.0 |

The fine aggregare (sea sand) was taken from Do Son beach, Hai Phong city. The sea sand was dried and the properties were tested following TCVN 7572:2006 [14]. The results are shown in Table 3.

Table 3 Properties of fine aggregate (sea sand)

| *No.* | *Item* | *Unit* | *Value* |
|---|---|---|---|
| 1 | Unit weight | g/cm$^3$ | 2.673 |
| 2 | Density | g/cm$^3$ | 2.591 |
| 3 | Fineness modulus | - | 2.104 |
| | Content of particle size < 0.14 mm | % | 1.18 |
| | Content of particle size > 5 mm | % | 0.02 |
| 4 | Mud & dust content | % | 0.86 |
| 5 | Content of ion clo ($Cl^-$) | % | 0.007 |

Water used in this study was sea water taken from Do Son beach, Hai Phong city. This type of water includes mostly ion $Cl^-$, $Na^+$, $SO_4^{2-}$, $K^+$, $Mg^+$ in which the ion content of $Cl^-$, $Na^+$ is about 88% of mass as dissolved salt NaCl. The chemical composition of sea water is shown in Table 4.

Table 4 Chemical composition of sea water

| Sea water | *pH index* | *$Cl^-$ (g/l)* | *$Ca^+$ (g/l)* | *$Mg^+$ (g/l)* |
|---|---|---|---|---|
| Do Son beach | 7.5 | 16.4 | 0.34 | 1.08 |
| Sea water | *$SO_4^{2-}$ (g/l)* | *$K^+$(g/l)* | *$Na^+$(g/l)* | |
| Do Son beach | 2.1 | 0.12 | 9.17 | |

The alkali-activated material (AAM) is recognized as a good alternative to ordinary Portland cement (OPC). There are two types of activator as one-part or "just add water" AAM and the conventional two-part AAM [15]. This study used one-part AAM and supplied by APTES Pty – Australia. This activator, namely M-activator, in a solid state as a white powder is a form of sodium silicate holding *n* water molecules ($Na_2SiO_3.nH_2O$) (see Fig. 1(c)). The solid activator is dryly mixed with FA and BFS before they are dissolved in water to create the binder. This dry-state activator has many advantages such as easy to maintain and transport, uniformly contact between FA-BFS and activator to increase the quality of GPC.

## 3. CONCRETE MIX DESIGN AND EXPERIMENTAL METHOD

The experimental program was conducted at the Laboratory of Construction Testing and Inspection, Hanoi University of Civil Engineering in 2021. The aim was to investigate the relationships between the target porosity, water permeability, and compressive strength. The target cylinder compressive strength of concrete was 16 MPa and the porosity of 20% at least.

### 3.1 Mix Design

The aggregate proportion was chosen based on the test method in standard ASTM C29 [13]. This method allows to determine the bulk density value necessary for many methods of selecting proportions for concrete mixtures. Hence, the design mixures for both PCC and PGC were determined firstly by the recommendations from the standard ACI 211.3R-02 [16]. The mixes were then adjusted by the experiment. The procedure was as follows: (i) choose the required water permeability factor, then determine the void content; (ii) calculate the aggregate content; (iii) choose the water/binder ratio, then calculate the water content; (iv) calculate the binder content; (v) calculate the cement and admixture contents. In this study, the size of coarse aggregate ranges from 5 to 10mm.

*3.1.1 Pervious cement concrete (PCC)*

The binder paste included coarse aggregate, sea sand, cement, FA, SF and sea water. The content of sea sand was studied with three different values as 4%, 7% and 10% of the content of coarse aggregate. The sand content was determined by trial-and-error so that the target cylinder compressive strength and the porosity could be achieved. The calculated design mix is shown in Table 5.

The specimens were cast in the 100×200 cylinders for the compression tests and for the water permeability tests. After casting, the specimens were cured in the laboratory in air. For each design mix, six groups of 3 samples were cast, including five groups to determine the compressive strength at 3, 7, 28, 60 and 120 days (180 samples in total), one group for permeability test (36 samples in total).

*3.1.2 Pervious geopolymer concrete (PGC)*

The pervious geopolymer concrete contains coarse aggregate, sea sand, FA, GBFS, and activator. As the previous study [5], to balance between the strength and the porosity, it requires to use a little of fine aggregate.

Table 5 Mix design for PCC

| *No.* | *Denote* | *Coarse aggregate, kg* | *Sea sand, kg* | *Cement, kg* | *FA, kg* | *SF, kg* | *Sea water, kg* | *Plasticizer, kg* |
|---|---|---|---|---|---|---|---|---|
| 1 | S0/r15 | 1574 | 0 | 297 | 84.8 | 42.4 | 93.3 | 1.7 |
| 2 | S0/r20 | 1574 | 0 | 237 | 67.8 | 33.9 | 74.6 | 1.4 |
| 3 | S0/r25 | 1574 | 0 | 178 | 50.8 | 25.4 | 55.8 | 1.0 |
| 4 | S4/r15 | 1574 | 63 | 269 | 76.8 | 38.4 | 84.4 | 1.5 |
| 5 | S4/r20 | 1574 | 63 | 209 | 59.8 | 29.9 | 65.7 | 1.2 |
| 6 | S4/r25 | 1574 | 63 | 150 | 42.7 | 21.4 | 47 | 0.9 |
| 7 | S7/r15 | 1574 | 110 | 248 | 70.8 | 35.4 | 77.8 | 1.4 |
| 8 | S7/r20 | 1574 | 110 | 188 | 53.7 | 26.9 | 59.1 | 1.1 |
| 9 | S7/r25 | 1574 | 110 | 129 | 36.7 | 18.4 | 40.4 | 0.7 |
| 10 | S10/r15 | 1574 | 157 | 227 | 64.7 | 32.4 | 71.2 | 1.3 |
| 11 | S10/r20 | 1574 | 157 | 167 | 47.7 | 23.9 | 52.5 | 1.0 |
| 12 | S10/r25 | 1574 | 157 | 107 | 30.7 | 15.4 | 33.8 | 0.6 |

*Note: the design mix S0/r15 means the content of fine aggregate is 0%, the design porosity is 15%.*

Total volume of the binder paste plays an important role in concrete compressive strength. However, the more it increases, the more water permeability coefficient and porosity reduce. It is important to find a balance point to achieve the desired target. The total volume of the binder paste of geopolymer $V_H$ includes *FA*, *GBFS* and *W* (water) as shown in Eq. (1).

$$V_H = (FA + GBFS)/2780 + \left[\left(W/(FA+GBFS)\times(FA+GBFS)/1000\right)\right](m^3) \quad (1)$$

The ratio of *W*/(*FA*+*GBFS*) is the key factor to ensure compressive strength and porosity of porous geopolymer concrete. If this ratio is too high, bonding between geopolymer paste and aggregate will be reduced. If this ratio is low, workability of concrete mixtures cannot be achieved. As found by the authors [4, 5], the ratio of *W*/(*FA*+*GBFS*) should be in the range of 0.25 to 0.35, resulting in balance of the compressive strength and workability. This range is adopted in this study.

Two design mixes were tried and tested as shown in Table 6. The design mixes were then achieved by varying the content of FA, GBFS and the amount of alkali activator (ACT). The percentage of ACT over the binder is kept at 8%. This is the most effective amount of ACT as previous study [4].

The specimens were cast in the 100×200 cylinders for the compression tests and for the water permeability tests. After casting, the specimens were cured in the laboratory in air. For each design mix, six groups of 3 samples were cast, including five groups to determine the compressive strength at 3, 7, 28, 60 and 120 days (30 samples in total), one group for permeability test (6 samples in total).

Table 6 Mix design for PGC

| *N°* | *W / (FA+GBFS)* | *(FA+GBFS) / Coarse aggregate* | *Binder composition* | |
|---|---|---|---|---|
| | | | *FA (kg)* | *GBFS (kg)* |
| *GPC1* | 0.22 | 0.203 | 80 | 240 |
| *GPC2* | 0.22 | 0.254 | 100 | 300 |

| *N°* | *Sea water (kg)* | *Coarse aggregate (kg)* | *Sea sand (kg)* | *ACT (kg)* | *ACT / Binder* |
|---|---|---|---|---|---|
| *GPC1* | 70 | 1574 | 157 | 32 | 8% |
| *GPC2* | 88 | 1574 | 63 | 40 | 8% |

It is noted that this study used the solid activator AAM which was dryly mixed with FA and BFS before being dissolved in water to create the binder. Thus, the procedure to produce GPC is quite similar with that of OPC.

After removal, the porous geopolymer concrete specimens were left in the laboratory conditions (temperature of about 25°C – 28°C, air humidity of 80%) until the test date. The specimens after demolding and curing are shown in Figs. 2 and 3.

### 3.2 Testing Procedure and method

#### *3.2.1 Porosity test*

To determine porosity of pervious concrete, the procedure stipulated in ASTM C1754 [13] is adopted. The samples are of 100mm diameter and 200mm high. Firstly, the sample volume $V_o$ ($cm^3$) was calculated. The samples were submerged into water for 24 hours to measure the mass under water $M_1$ (g). The samples were then taken out and dried using the drying cabinet up to 105ºC during 24h. The dry mass $M_2$ (g) of the samples can be determined. The porosity can be determined by Eq. (2), where $\rho_w$ is water density (g/cm$^3$).

$$n = \left(1 - \frac{M_2 - M_1}{\rho_w V_0}\right) \times 100\% \qquad (2)$$

Fig. 2 Porous cement samples

Fig. 3 Porous GPC samples

*3.2.1 Water permeability test*

The water permeability factor can be determined based on the Darcy’s law. The cylinder sample (100*D*×200*H*) was used. After casting of 24 hours, the sample was demolded and wrapped by plastic to avoid water passing through. It was then put into the test pipe and closed at both ends by mortar. Water was filled in up to $H_1$ and stoped when the water level was stable. The valve was opended and the time when the water level reduced from $H_1$ to $H_2$ was recorded. The test setup is shown in Fig. 4. The water permeability can be determined by Eq. (3).

$$K_p = \left(\frac{A \times L}{F \times t}\right) \times \ln \frac{H_1}{H_2} \quad (mm/s) \qquad (3)$$

where $A$ is cross-sectional area of pipe, mm$^2$; $L$ is specimen length, mm; $F$ is cross-section area of the specimen, mm$^2$; $t$ is time of water collection, corresponding to the time when the water column reduces from $H_1$ to $H_2$, s; $H_1$ is the initial height of water column (1310 mm); $H_2$ is the height of water column after permeability (880 mm).

*3.2.1 Compressive strength*

The compressive strength is determined according to the standard ASTM C39 [17], with the cylinder sample of 100*D*×200*H* (mm).

## 4. RESULTS AND DISCUSSION

### 4.1 Porosity and Water Permeability

The cylinder samples of 100*D*×200*H* were used to determine the porosity, density, permeability and the compressive strength at 3, 7, 28, 60 and 120 days. Table 7 shows the average results of both PCC and PGC.

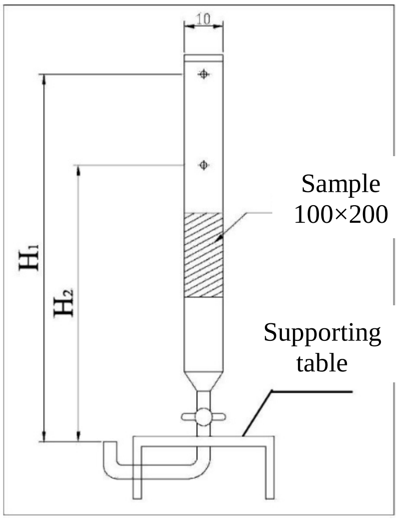



Fig. 4 Schematic of water permeability test

The actual porosity of both types of concrete was determined according to ASTM C138 as mentioned in section 3.2(a). For PCC, all the design mixes have the actual porosity higher than the design values from 1.2% to 2.9%. PGC1 achieved a very high value of porosity (33%), but a low compressive strength at 28 days (12.7 MPa) which was lower than the target. Therefore, PGC2 was adjusted by increasing the content of FA and BFS and reducing the content of sand. As a result, the compressive strength at 28 days can be achieved 17.4 MPa.

Fig. 5 shows the relationship between the permeability and the target porosity. It can be seen that the water permeability depends significantly on the design porosity. Increasing the porosity, the permeability will increase significantly.

Table 7 Results of PCC and PGC

| No. | Denote | Porosity, % | Density, $kg/m^3$ | Permeability, mm/s | Compressive strength, MPa | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 3 days | 7 days | 28 days | 60 days | 120 days |
| 1 | S0/r15 | 16.2 | 1924 | 3.7 | 20.1 | 24.1 | 26.3 | 24.5 | 24.1 |
| 2 | S0/r20 | 21.4 | 1864 | 6.2 | 16.7 | 20.2 | 22.2 | 20.6 | 20.3 |
| 3 | S0/r25 | 26.3 | 1786 | 9.9 | 13.4 | 16.2 | 17.8 | 15.4 | 15.3 |
| 4 | S4/r15 | 16.8 | 1943 | 4.2 | 18.8 | 22.4 | 24.5 | 22.8 | 22.4 |
| 5 | S4/r20 | 21.9 | 1883 | 6.8 | 16.1 | 18.8 | 20.4 | 18.9 | 18.7 |
| 6 | S4/r25 | 26.9 | 1813 | 10.2 | 12.4 | 12.8 | 14.4 | 13.3 | 13.1 |
| 7 | S7/r15 | 17.0 | 1955 | 4.6 | 17.2 | 20.4 | 22.3 | 20.6 | 20.4 |
| 8 | S7/r20 | 22.4 | 1897 | 7.1 | 14.4 | 16.8 | 18.0 | 16.8 | 16.5 |
| 9 | S7/r25 | 27.1 | 1818 | 10.4 | 10.4 | 11.2 | 12.2 | 11.3 | 11.1 |
| 10 | S10/r15 | 17.3 | 1962 | 4.9 | 15.2 | 17.6 | 19.4 | 17.9 | 17.7 |
| 11 | S10/r20 | 22.4 | 1903 | 7.6 | 14.4 | 16.0 | 17.4 | 16.1 | 16.2 |
| 12 | S10/r25 | 27.9 | 1826 | 10.7 | 10.1 | 10.6 | 11.6 | 10.7 | 10.2 |
| 13 | PGC1 | 33.0 | 1758 | 11.8 | 6.7 | 11.0 | 12.7 | 13.1 | 14.0 |
| 14 | PGC2 | 24.5 | 1806 | 15.2 | 7.1 | 11.4 | 17.4 | 18.0 | 19.0 |

When the porosity increases from 15% to 20%, the permeability will increase at a rate of 0.5 $mm.s^{-1}$/1% of porosity; and when the porosity increases from 20% to 25%, the changing rate of permeability is 0.9 $mm.s^{-1}$/1% of porosity.

At a similar target porosity, if the content of sand is increased the permeability is also rised slightly. At the design porosity of 15%, without sand the permeability is 3.7 mm/s; with 7% of sand the permeability is 4.6 mm/s (increased about 24%).

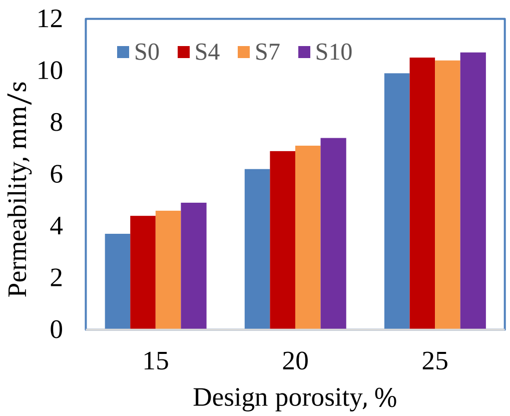



Fig. 5 Relationship between permeability and design porosity of PCC

## 4.2 Density

Fig. 6 shows the relationship between the density and the target porosity for PCC, while that relationship for PGC is presented in Fig. 7. The density of PCC varies from 1786 $kg/m^3$ to 1962 $kg/m^3$ and is inversely proportional to the design porosity. At the porosity of 20%, the density is 1864 $kg/m^3$ (about 70% of the normal concrete weight). At a predetermined target porosity, when the sand content is increased, the density will be increased. For PGC, the density is 1758 $kg/m^3$ at the actural porosity of 33%; and 1806 $kg/m^3$ at the porosity of 24.5%. The development trend is similar to PCC.

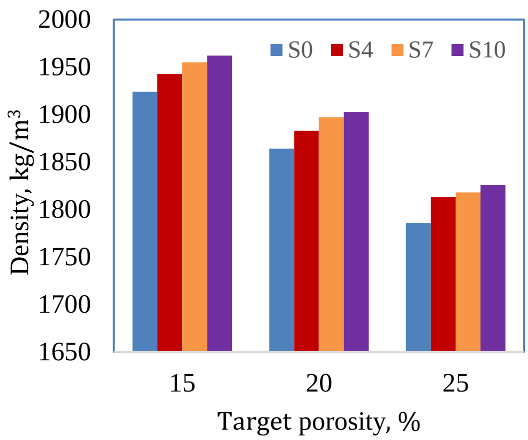



Fig. 6 Density - target porosity relationship of PCC

## 4.3 Compressive strength

Figs. 8 to 11 show the compressive strength of PCC with 0%, 4%, 7% and 10% of the fine aggregate (sea sand) up to 120 days. Figs. 12 to 14 show the compressive strength of PCC with 15%, 20% and 25% of porosity.

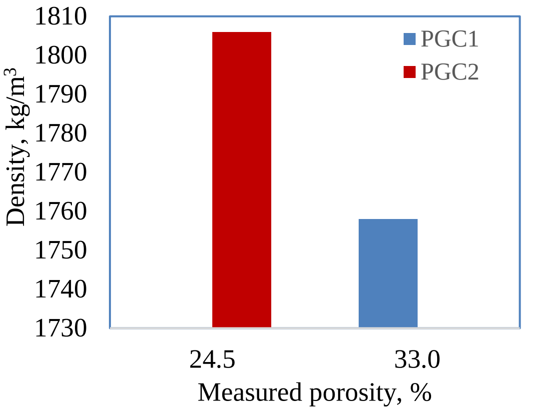



Fig. 7 Density - measured porosity relationship of PGC

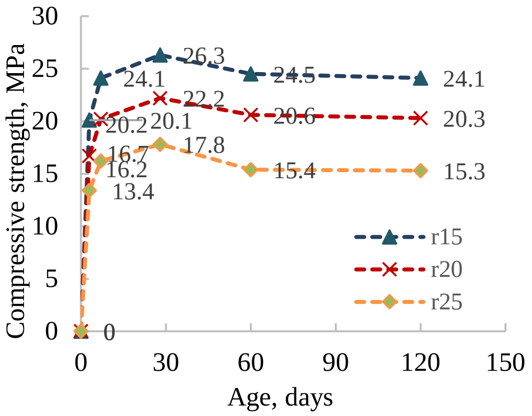



Fig. 8 Compressive strength of PCC (0% of sand)

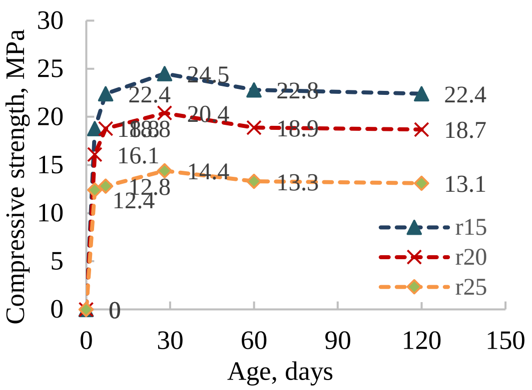



Fig. 9 Compressive strength of PCC (4% of sand)

It is evident that as the porosity increases, the compressive strength decreases. When the target porosity is chosen to be higher, the coarse aggregate content is kept constant and the binder content (cement and water) is reduced. Connection between coarse aggregates becomes weaker, as a result the compressive strength will be lower. The reduction rate is greater as the porosity increases. When the porosity changes from 15% to 20%, the rate is 0.75 MPa/1% of porosity, but when it changes from 20% to 25%, the rate is faster, 1.16 MPa/1% of porosity.

The compressive strength at the early age is fairly high. The 3-day strength achieves about 80% of the 28-day strength; and the 7-day strength achieves 91% of the 28-day strength. It is because when the concrete has a high porosity, water can contact more efficiently with coarse and fine aggregates, and ion $Cl^-$ in sea water has a benificial effect on the concrete hardening at the early ages.

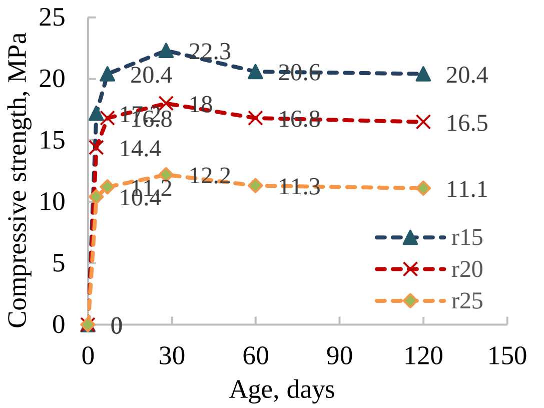



Fig. 10 Compressive strength of PCC (7% of sand)

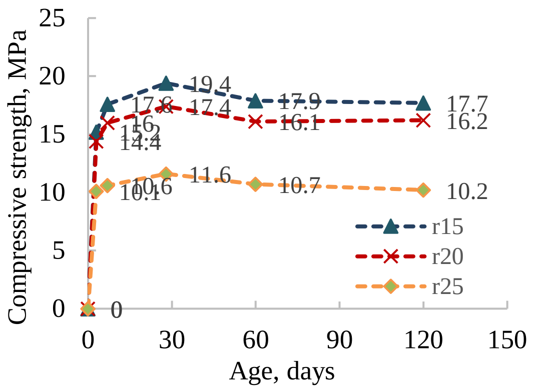



Fig. 11 Compressive strength of PCC (10% of sand)

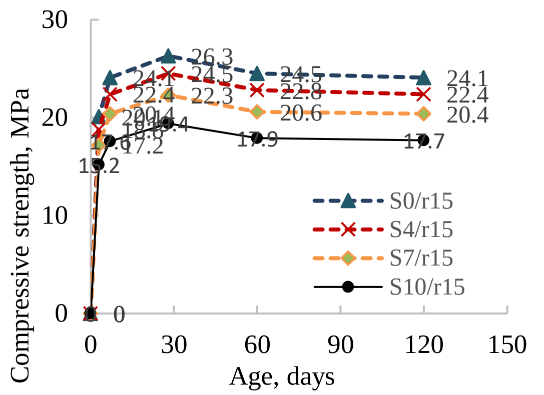



Fig. 12 Compressive strength of PCC (15% of porosity)

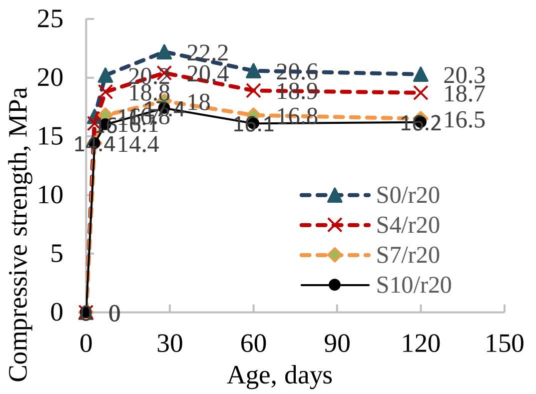



Fig. 13 Compressive strength of PCC (20% of porosity)

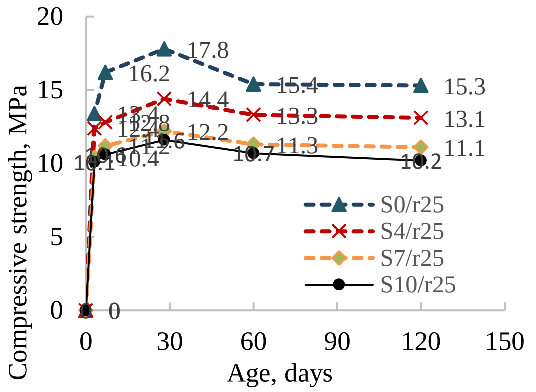



Fig. 14 Compressive strength of PCC (25% of porosity)

However, the strength at 60-day and 120-day reduces which may cause by the reaction between salts $SO_4^{2-}$ in sea sand / sea water and $Ca(OH)_2$ producing salts $CaSO_4$. That salt reacts constinuously with $C_3A$ making the ettringite which is harmful for cement binder, leading to the strength reduction [4]. The reduction is faster between 30 to 60 days, then it becomes slower and stable. This requires more studies in future.

As shown in Figs. 12 to 14, at a similar porosity, if the content of sea sand is increased from 0% to 10% by reducing the content of cement and additives, the concrete strength is decreased since the strength of binder is reduced. At a porosity of 20%, if the sand content is 0%, the 28-day concrete strength reaches 22.2 MPa. If the sand content is 10%, the strength is only 17.4 MPa (a reduction of 20%).

Fig. 15 shows the development of compressive strength of PGC with time. PGC1 with a porosity of 33% only reaches a 28-day strength of 12.7 MPa, while PGC2 with a porosity of 24.5% attains a 28-day strength of 17.4 MPa (37.9% higher). It is observed that the strength of GPC made by sea sand and sea water does not reduce according to time since properties of polymer may not be affected by the $SO_4^{2-}$ and $Cl^-$ ions which causes concrete corrosion. The strength is still developed from 28 days to 120 days, similar to previous study of the authors [4]. This is the significant advantage of geopolymer concrete. Thus, it can be applied for civil works near sea areas.

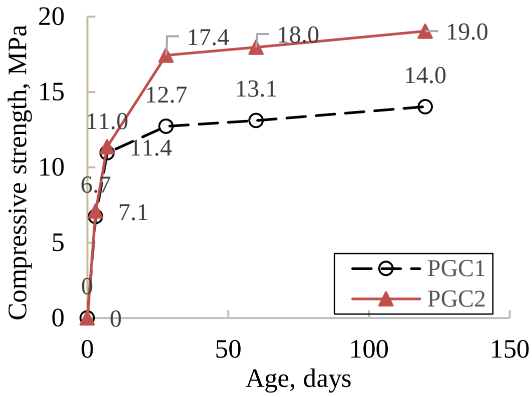



Fig. 15 Compressive strength of PGC

## 5. CONCLUSIONS

This paper presents an experimental program on two proposed types of porous concrete (pervious cement concrete and pervious geopolymer concrete) made of sea sand and sea water. The porosity, water permeability, density, compressive strength and the relationships between these factors have been studied. The following conclusions can be withdrawn:

- For *pervious cement concrete*, at a similar design porosity, if the content of sea sand is increased by reducing the content of cement and additives, the concrete compressive strength is decreased. That strength develops very fast at the early stage, reaching 80% after 3 days; however, it will reduce after reaching the maximum value at 28 days caused by corrosion of salt $SO_4^{2-}$ in sea sand / sea water.
- For *pervious geopolymer concrete*, the compressive strength of GPC made by sea sand and sea water does not reduce according to time since properties of polymer may not be affected by the $SO_4^{2-}$ ion [4]. This is the significant advantage of geopolymer concrete.
- It is possible to produce pervious cement and pervious geopymer concretes made of sea sand and sea water which can achieve the compressive cylinder strength greater than 17 MPa at a porosity of 24%.

The positive results of this research can be considered as a basis for the application of these concrete types in the civil works near sea areas such as roads, pavement, car parks.

## 6. ACKNOWLEDGMENTS

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