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Experimental Evaluation of Geopolymer Concrete Strength Using Sea Sand and Sea Water in Mixture

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Abstract

This paper presents the experimental strength evaluation of geopolymer concrete and ordinary concrete using sea sand and seawater in the mixture. A series of 30 cubic samples with a 150 mm side length and 12 rectangular specimens with a dimension of 100 × 100 × 400 mm (width × thickness × length) were cast and tested in this study. Specimens were divided equally into two groups. The first group of specimens was cast using geopolymer as the main binder (GPC), while the second group of samples was made using ordinary Portland Cement (OPC). While the compression tests were performed for specimens in two groups at the ages of 3, 7, 28, 60, and 120 days, the tensile tests were only performed for specimens at 7 and 28 days. The testing results revealed that the compression strength of GPC specimens using sea sand and seawater was significantly higher than that of OPC samples using the same type of salted sand and water. Besides, the use of sea sand and seawater for replacing river sand and fresh water in the production of GPC is feasible in terms of compressive strength since GPC produces a higher compressive strength than that of conventional concrete.

Keywords: Geopolymer Concrete; Portland Cement; Compression Strength; Tensile Strength; Seawater; Sea Sand.

1. Introduction

Concrete is a manmade material that consists of cement, coarse aggregate, and fine aggregate. The production of concrete requires a large amount of sand exploited from the river, which leads to serious environmental concerns such as instability of riverbanks or lowering of water aquifers [1, 2]. To eliminate the inverse effect, the restriction on digging river sand is imposed in many parts of the world, which has led to scarcity and increased the cost of river sand [3]. Thus, there is a need to utilize a substitute material to replace river sand in making concrete. One of the possible options is to utilize sea sand as an alternative replacement material for river sand in the production of concrete.

The problem arises when making OPC with sea sand and saltwater. Due to the high level of sodium chloride and magnesium sulfate in sea-origin products, the OPC using sea sand and seawater tends to degrade quickly [4, 5]. The main cause of this process is a chemical attack. Magnesium sulfate may attack most of all the constituents of hardened Portland cement paste, particularly the aluminate constituent [6]. Additionally, chloride promotes the corrosion process in steel, and alkalies may participate in the alkali-aggregate reaction. The potential solution to alleviate the issue is to use geopolymer concrete. Since no ordinary Portland cement is included in the GPC structure, GPC can eliminate the undesired effects of sodium chloride and magnesium sulfate contained in sea sand and ocean water on concrete [7].

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Geopolymer concrete is an environmentally friendly material that uses geopolymer to replace ordinary Portland cement as the main binder. One of the outstanding features of this green material is the ability to resist chemical attacks as well as fire resistance performance [8, 9]. The structure of geopolymer is formed by the chain and ring polymers with Si_4+ and Al_3+ in IV-fold coordination with oxygen (polysilanes). The practical formula of polysilanes is presented below:

$$Mn\ (-(SiO_2)_z - AlO_2)_n\ .\ wH_2O \quad (1)$$

where, z is 1, 2, or 3 or higher up to 32; M is a monovalent cation such as potassium or sodium, and n is a degree of polycondensation [10].

Research related to hardened properties of GPC has been intensively conducted. For example, Palomo et al. [11] studied the effect of combinations of alkaline liquids on the compression strength of GPC. It was found that the mixture of sodium silicate and sodium hydroxide provides the highest compressive strength of GPC. In another study, Gourley [12] recommended using materials with low calcium (ASTM Class F) to increase the compression strength of GPC. Xu and Van Deventer [13] compared the compression strength of GPC using potassium hydroxide and sodium hydroxide. It was concluded that GPC with potassium hydroxide has higher compression strength compared to that of GPC using sodium hydroxide.

Regarding the research on the compression strength of GPC concrete using sea sand as fine aggregate and seawater, Saranya et al. [14] stated a slightly higher 28-day compressive strength of GPC using FA-slag-based geopolymer, concretes activated with sodium silicate, and NaOH solution using sea sand compared to those with river sand. In another study, Etxeberria et al. [15] found that using seawater for concrete production increases the compressive strength at an early age compared to concrete made with fresh water. However, there was no difference in the compressive strength between the two types of concrete after one year. A similar conclusion was also found in a more recent study conducted by Yang et al. [16]. In this study, four types of GPC concrete with different sea sand and seawater combinations were cast and tested. Results from the study showed that the use of sea sand and seawater in GPC had a minimal effect on the strength of concrete. By contrast, Li et al. [17] reported a reduction of 21.48% in compressive strength of GPC using seawater and sea sand compared to that using freshwater and river sand. The statement was in line with a study by Shinde and Kadam [18], in which the strength of GPC using sea sand was reduced from 13.07% to 17.62% depending on the concentration of NaOH solution in the mixture.

Despite many studies related to the usage of sea sand and seawater to produce GPC concrete, there are still contradictory results regarding the effects of sea sand and saltwater on the compressive strength of GPC [14-24]. Some reported positive or no effects [14, 16] while others reported negative effects [17, 18]. Due to these contradictions, this study was conducted to examine the influences of sea sand and seawater on the compressive and tensile strength of GPC concrete. In addition, the usage of sea sand and seawater for producing concrete is still minimal even though those materials are abundant, especially, on the sea islands and remote coastal areas. The cost of construction in those areas increases significantly due to the transportation expense for the major materials (i.e., river sand and freshwater), which are only available at distance from the construction sites. To alleviate this drawback, there is a need to explore a feasible method of using available sea sand and seawater to replace freshwater and river sand in the concrete mixture.

As above discussed, the main objective of this study is to investigate the feasibility of using sea sand and seawater to produce GPC as well as to confirm the effects of those materials on the compressive strength of GPC and OPC. To achieve the goals, a series of GPC and OPC specimens using sea sand as the fine aggregate and seawater in the mixture was fabricated and tested. The compression strength of the test samples was measured at 3, 7, 28, 60, and 120 days. For the tensile strength, the tests were conducted at the age of 7 and 28 days. Additionally, the compression strength of the two types of concrete was compared to the strength of the M500 type specified in the current standard using river sand and OPC. Details are presented in the subsequent sections.

2. Experimental Setup

In this section, a short description of the principal materials used for fabricating both GPC and OPC specimens was presented. Furthermore, the information on the two mixtures for GPC and OPC was briefly reviewed. Finally, the test apparatus and procedure to conduct the compression and tensile test for the two types of test samples were also presented. The flowchart of the research methodology is presented in Figure 1, and details of these steps are provided in the subsequent section.

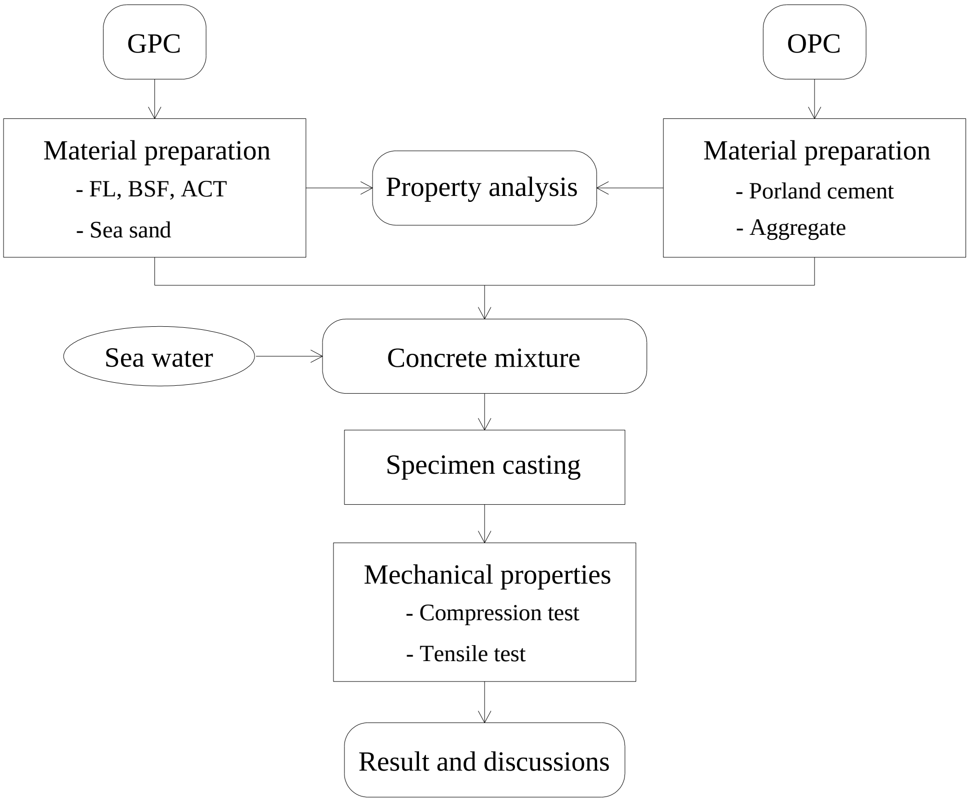


Figure 1. Flowchart of the research methodology

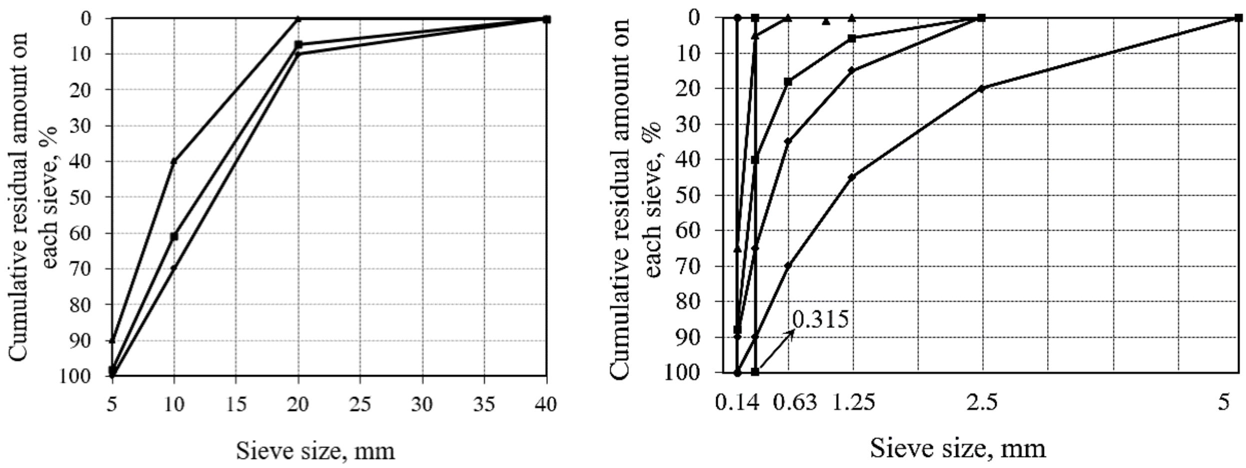
2.1. Material Preparation

Fly ash (FL) and Blast Furnace Slag (BFS) materials used in this study were collected from the disposal waste resultant from the burning of pulverized coal at the local plant. The specific surface area by Blaine of BSF is 4520 cm^2/g, with an average diameter of 7.63μm. The commercial liquid sodium silicate was used as an alkali activator for the GPC mix. The chemical composition of FA and BSF in terms of percentage by mass is listed in Table 1.

Table 1. Chemical composition of FA and BFS

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2
FA (%)	57.3	25.2	6.06	1.09	1.68	5.29	0.16	0.09	0.83
BFS (%)	43.7	12.9	1.47	28.7	6.29	1.22	0	1.35	0.84

Natural crushed rock with a maximum size of 40 mm was selected for coarse aggregate. The sea sand collected from the local beach with particle size less than 5 mm was chosen for fine aggregate. Details of sieve analysis TCVN 7572-2 [25] are presented in Figure 2, and the physical properties of aggregate are presented in Tables 2 and 3.



(a) Coarse aggregate (b) Fine aggregate

Figure 2. Grading curve for coarse and fine aggregate

Table 2. Sieve analysis results

Type	Sieve size (mm)	Cumulative retained (%)	Standards
Coarse aggregate	40	0	TCVN 7572-2 [25]
	20	8.2	
	10	50.3	
	5	95.5	
	< 5	100	
Fine aggregate	5	0	
	2.5	8	
	1.25	27.6	
	0.63	52.3	
	0.315	78.4	
	0.14	93.6	

Table 3. Physical properties of aggregate

Properties	Unit	Sea sand	Coarse aggregate
Specific gravity	g/cm^3	2.53	2.7
Dust content	%	1.62	0.77
Void	kg/m^3	43.3	46.3
Cl^- content	%	12×10^{-3}	-
SO_4^{2-} content	%	1.9×10^{-3}	-

Seawater used for the fabrication of the test specimens was collected directly from the ocean. The detailed chemical composition of seawater is presented in Table 4. It is worth noting that the substance in the ocean water with a concentration less than 0.1 g/l was not included in the table.

Table 4. Key chemical composition of seawater

pH	Cl^- (g/l)	Ca^+ (g/l)	Mg^+ (g/l)	SO_4^{2-} (g/l)	K^+ (g/l)	Na^+ (g/l)
6.8	15.3	0.3	1.1	2.4	0.35	8.5

2.2. Mixture Proportions

Seawater used for the fabrication of the test specimens was collected directly from the ocean. The detailed chemical. Two mixtures were identified in this study. The first one using by-product material from power plants for replacing cement was prepared for the GPC specimens. The GPC included a coarse aggregate, sea sand, activator, FA, BFS, and seawater. Solid sodium silicate with a composition of 75% SiO_2 and 23.3% Na_2O (by weight) and solid sodium hydroxide with a composite of 99.9% NaOH (by weight) was used as the alkaline activator (ACT). The ratio of sodium silicate to sodium hydroxide was equal to 2.5. The mixture proportion designed for 1m^3 GPC is listed in Table 5.

Table 5. Mixture proportions of GPC

Material	Quantity for 1m^3 GPC (kg)
BFS	255
FA	85
Sea sand	760
Coarse aggregate	1050
Seawater	165
ACT	68

The second mixture using ordinary Portland cement as the main binder was prepared for the OPC samples. Commercial cement type with physical properties listed in Table 6 was used. The mixture included Portland cement, sea sand, coarse aggregate, and seawater with a cement/water ratio of 2.65. The designated mixture proportion for 1m^3 OPC is presented in Table 7.

Table 6. Physical properties of Portland cement

Physical properties	Unit	Value
Specific gravity	g/cm^3	3.1
Specific surface (Blaine)	cm^2/g	3180
Compression strength 3 days	N/mm^2	23.1
Compression strength 7 days	N/mm^2	46.2

Table 7. Mixture proportions of OPC

Material	Quantity for $1m^3$ OPC (kg)
Cement	594.9
Sea sand	447
Coarse aggregate	1037
Seawater	224.5
C/W ratio	2.65

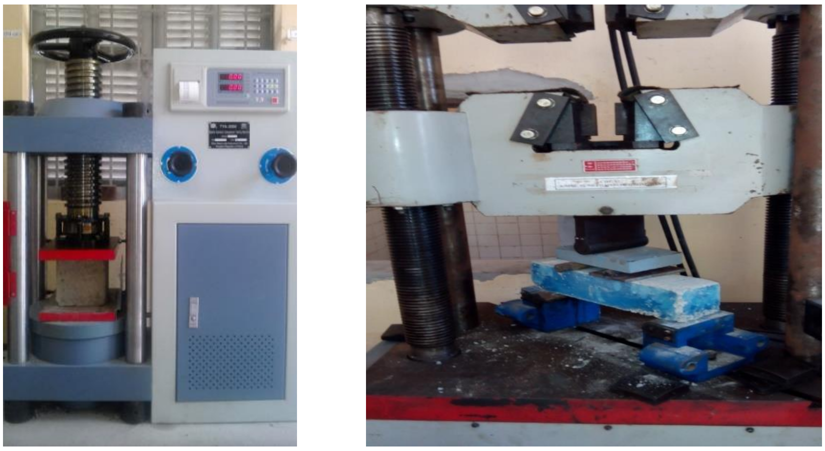
The quality of the mixture during the preparation stage was controlled using a slump test. Figure 3 shows the test result using an Abrams cone. For each mixture, a set of 15 standard cubes with the dimension of 150×150×150 mm, and six rectangular specimens with a dimension of 100×100×400 mm (width × thickness × length) were fabricated. The specimens were cured at room temperature until the testing date. The curing condition of GPC specimens was identical to normal OPC samples. The cube specimens were used to determine the compression strength, and rectangular samples were utilized for determining the tensile strength of concrete.

(a) Inverted flow cone test (b) Concrete sample

Figure 3. Slump flow test and test sample

2.3. Test Apparatus and Procedure

The main purpose of this study was to determine the compression strength of OPC and GPC at the ages of 3, 7, 28, 60, and 120 days, and the tensile strength at 7 and 28 days. Figure 4 shows the compression testing machine used to determine the compression and tensile strength of specimens in this study. The compression tests conformed to the requirements of TCVN-3105 [26] and TCVN-3118 [27] and were conducted in the lab using the TYA2000 Unit test machine. The maximum compression capacity of the testing equipment is 2000 kN. The compression tests were implemented with the constant loading speed of 6 ± 0.4 $daN/cm^2/s$ until the test specimen failed.



(a) Compression testing machine (b) Tensile testing machine

Figure 4. Test apparatus for specimens

For the tensile test, a XIYI bending machine was used with a maximum capacity of 1000 kN. The tensile strength of the concrete sample was determined through the bending test. The test was performed at a constant speed of 6 ± 0.4 daN/cm^2/s until the test sample was completely broken. It is worth noting that the failure load should be approximately estimated inside the working range of the machine. In this study, the failure load was less than 80% of the maximum capacity of the tensile testing machine. For each test, the maximum force was recorded and documented.

3. Results and Discussion

This section provides the results of testing to determine the compression and tensile strength of GPC and OPC using sea sand and seawater in the mix. In addition, the comparison of compression and tensile strength between the two types of concrete was also presented and discussed. Finally, the development curves of both compression strength and tensile strength for GPC and OPC are presented. Detailed is presented in the subsequence.

3.1. Compressive Strength

The compression strength of OPC and GPC specimens at different ages is presented in Table 8. To determine the compression strength of concrete at a certain age, a group of three samples was tested. The force at the point where the tested specimen failed was recorded. The compression strength was calculated by the average strength of three samples and was determined by Equation 2.

$$R_i = \frac{1}{n}\sum_{i=1}^{n}\frac{F_i}{A_i} \tag{2}$$

where R_i is the compression strength of the i^{th} test sample, F_i is the failure load of the i^{th} sample, and A_i is the area of the i^{th} specimen.

Table 8. The compression strength of GPC and OPC specimen

Age (day)	GPC				OPC			
	Force (N)	*R* (MPa)	Average *R* (MPa)	Std. (MPa)	Force (N)	*R* (MPa)	Average *R* (MPa)	Std. (MPa)
3	856	38.0	33.7	3.04	621	27.6	27.6	0.45
	704	31.3			633	28.1		
	716	31.8			608	27.0		
7	996	44.3	44.3	0.12	681	30.3	30.3	1.63
	993	44.1			639	28.4		
	1000	44.4			728	32.4		
28	1407	62.5	58.3	5.04	1008	44.8	43.5	0.96
	1152	51.2			959	42.6		
	1378	61.2			968	43.0		
60	1393	61.9	57.2	3.32	964	42.8	40.1	2.06
	1224	54.4			850	37.8		
	1246	55.4			893	39.7		
120	1341	59.6	59.6	0.61	965	42.8	42.9	0.04
	1356	60.3			962	42.9		
	1323	58.8			966	42.9		

3.2. Tensile Strength

Table 9 lists the tensile strength of GPC and OPC test samples at 7 and 28 days. The tensile strength of the test sample was obtained through the bending test using Equation 3.

$$R_{t_i} = \gamma.\frac{F_i.l}{a_i.b_i^2} \tag{3}$$

where R_{ti} is the tensile strength of the i^{th} test sample, l is the clear span between two supports; F_i is the failure load of the i^{th} sample, a_i is the width of the i^{th} test sample, b_i is the thickness of the i^{th} test sample. The coefficient $\gamma = 1.05$ was applied for the rectangular test sample.

Table 9. Tensile strength of GPC and OPC specimen

Age (day)	GPC				OPC			
	Force (N)	R_t (MPa)	Average R_t (MPa)	Std. (MPa)	Force (N)	R_t (MPa)	Average R_t (MPa)	Std. (MPa)
	12	3.80			15	4.7		
7	14	4.40	3.90	0.37	13	4.1	4.40	0.24
	11	3.50			14	4.4		
	18	5.70			17	5.4		
28	15	4.70	5.40	0.47	17	5.4	5.30	0.19
	18	5.70			16	5.0		

3.3. Comparison of Compression and Tensile Strength

In order to evaluate the development of compression strength of GPC and OPC using sea sand and seawater, the compression strength was compared to the standard compression of the typical M500 type (as reference) using ordinary portland cement. The compression strength of the M500 type was specified in TCVN 8218-2009 [28]. To do that, the compressive strength at t days old was normalized to the strength at the age of 28 days using the following Equation 4:

$$R_{28} = \frac{R_t}{k} \tag{4}$$

where R_{28} is the compression strength at 28 days, R_t is the compression strength at *t* days; *k* is the coefficient obtained from Table 10.

Table 10. The conversation coefficient k

Age (day)	3	7	14	21	28	60	90	180
k	0.50	0.70	0.83	0.92	1.00	1.10	1.15	1.2

Figure 5 illustrates the comparison of the development of compression strength of GPC and OPC using sea sand and ocean water. The strength of the two types of mentioned concrete was compared to the strength of the standard M500 specified in the current standard [28]. As can be observed, the compression strength of GPC using sea sand and seawater was higher than that of the standard M500. In contrast, the compression strength of OPC using sea sand and seawater was lower than that of the reference. Regarding the compression strength of the two candidates both using sea sand and seawater in the mix, the GPC compression strength was found higher than that of OPC.

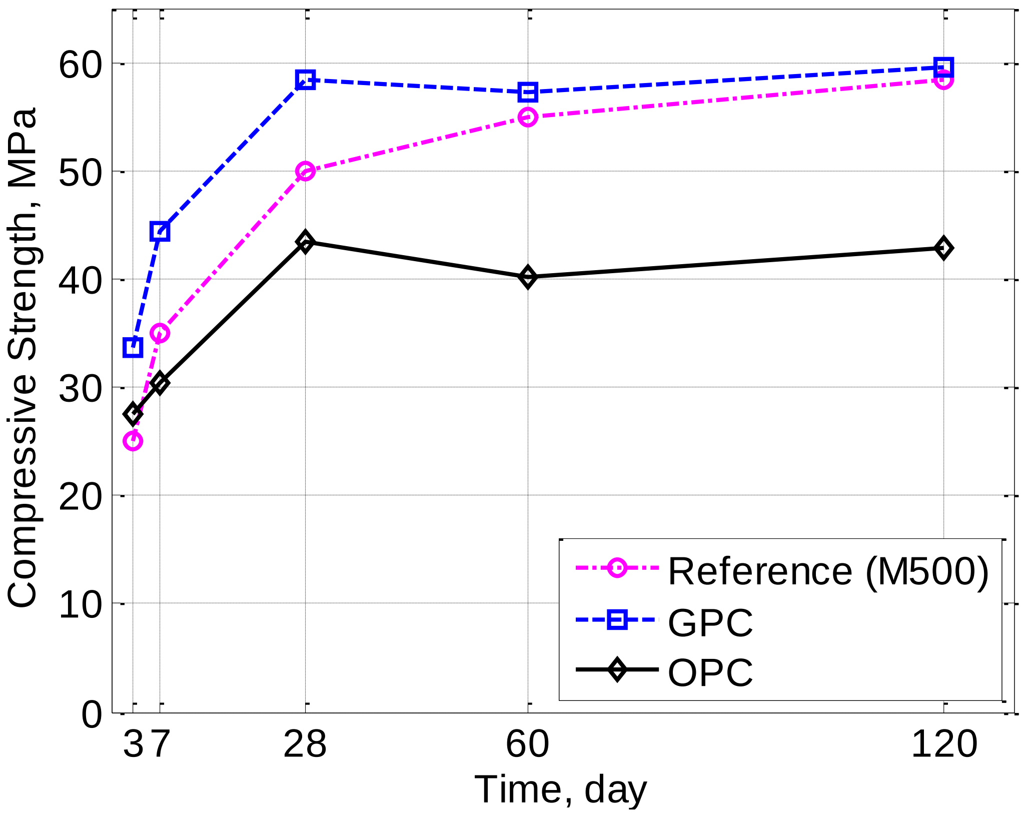


Figure 5. The compression strength of different concrete

It is interesting to note that the compressive strength of both GPC and OPC using sea sand and seawater at 60 days was lower than that of concrete strength at 28 days old. The possible reason for this phenomenon is due to the forming process of calcium sulfoaluminate or ettringite ($3CaO•Al_2O_3•3CaSO_4•32H_2O$) in the concrete structure. The amount of calcium sulfoaluminate or ettringite in the OPC specimen is much greater than in GPC due to the greater CaO in the binder of OPC than that of GPC. It is explained that the OPC specimen had a higher level of compressive strength reduction than GPC. The recovery of the compressive strength at 120 days old could be the result of the deceleration of the ettringite formation process.

Relating to the tensile strength, Table 9 presents the tensile strength of the two types of concrete using sea sand and seawater in the mix. As can be seen, the OPC tends to quickly develop tensile strength in the first week after casting compared to the GPC. However, the trend was reduced the week after. At the age of 28 days, the tensile strength of OPC is just under that of GPC, at 5.3 MPa and 5.4 MPa, respectively. It is worth noting that with the limited number of data points, the tensile results in this study might be varied in some cases. For that reason, it is recommended that more tensile strength tests should be performed for both types of concrete mentioned to obtain a more reliable dataset.

As mentioned above, the effects of sea sand and seawater on GPC compression strength remain unclear recently, however, most researchers [14-16, 29] have agreed that the compressive strength at early age of GPC concrete using sea sand and seawater is higher than that of conventional concrete. This study has confirmed that statement as the experimental results are presented in Figure 5. As can be seen, the compressive strength of GPC concrete using sea sand and seawater on day 3 and day 7 was 33.7 MPa and 44.3 MPa, respectively, compared to about 25 MPa and 35 MPa for conventional concrete (as reference, M500), in that order. Concerning the compressive strength of GPC concrete after 28 days, the experimental results in this study showed a minimal difference in compressive strength between GPC and conventional concrete after 120 days. This finding was also in line with the previous study by Yang et al. (2019) [16].

Regarding the production of OPC using sea sand, seawater, and Portland cement to make OPC, the experimental results from this study showed a significant decrease in the compression strength of OPC in comparison with that of GPC and conventional concrete (M500 reference type). As clearly indicated in Figure 5, the compression strength of OPC at 28 days was about 30% lower than that of the reference. In other words, the application of OPC using sea sand and seawater is not feasible with Portland cement. The outcomes were in line with the previous studies [4, 5]. With regard to the feasibility of using sea sand and seawater for GPC concrete, experimental results revealed a slightly higher compression strength of GPC compared to that of the reference. Thus, it is feasible to use those materials to produce GPC. An identical agreement was also found in the previous study conducted by Saranya et al. (2020) [14].

4. Conclusions

The experimental tests for determining the compression and tensile strength of GPC and OPC using sea sand and seawater were presented in this paper. A comprehensive number of specimens were fabricated and tested. It was shown that, by using sea sand and seawater in the mix, the compression strength of GPC was found to be higher than that of the standard M500 type. In contrast, the compression strength of OPC was lower compared to that of the reference.

With regard to the compression strength development, the GPC compression strength developed rapidly within 28 days compared to that of OPC, and the trend remained stable until 120 days after casting. Relating the tensile strength, OPC tends to quickly develop the tensile strength in the first week after casting compared to that of GPC. At 28 days old, GPC tensile strength was found to be slightly higher than that of OPC.

It is noted that the limitation of samples and the lack of tests for other mechanical properties are the major drawbacks of this study. Thus, it is recommended that a wide range of tests for different mixtures and concrete properties should be investigated in the future to gain a better knowledge of GPC using sea sand and seawater. However, within the context of this study, through a comparison of the experimental results to the previously published documents, some important conclusions could be drawn as below:

- The compression strength of GPC employing sea sand and seawater is slightly higher compared to that of conventional concrete;
- The use of sea sand and seawater is not recommended for OPC since the compression strength is far lower than the strength of conventional concrete;
- With the same amount of sea sand and seawater, the compression strength of the GPC at 28 days was found to be 30% higher than that of the GPC;
- Replacing river sand and freshwater with sea sand and seawater to produce GPC is feasible in terms of compression strength.

5. Declarations

5.1. Author Contributions

Conceptualization, T.T.N. and T.P.T.; methodology, T.P.T.; software, T.T.N.; investigation, T.T.N.; resources, T.T.N. and T.P.; data curation, T.P.T. and T.T.N.; writing—original draft preparation, T.T.N.; writing-review and editing, T.P.T., and T.N.T.; supervision, T.P.T.; project administration, T.N.T. and T.P.T. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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