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EVALUATION OF MODULUS OF ELASTICITY FOR ECO-FRIENDLY CONCRETE MADE WITH SEAWATER AND MARINE SAND

Tu T. Nguyen[a], Pham Thanh Tung[b,*], Kobir Hossain[c]

[a] *Faculty of Civil Engineering, Hanoi Architectural University, Km 10 Nguyen Trai street, Thanh Xuan district, Hanoi, Vietnam*
[b] *Faculty of Building and Industrial Construction, Hanoi University of Civil Engineering, 55 Giai Phong road, Hai Ba Trung district, Hanoi, Vietnam*
[c] *Civil Engineering at Dhaka University of Engineering & Technology, Gazipur, Bangladesh*

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Abstract

The ultimate aim of this study is to use experimental work for evaluating the modulus of elasticity (MOE) of Geopolymer concrete (GPC) using marine sand as fine aggregate and seawater for the mix. Four different groups of concrete mixtures, namely CP1a, CP1b, CP2a, CP2b were identified. While the CP1a mix was prepared using GPC with marine sand and seawater, the CP1b was made by adding sodium sulfate (Na_2SO_4) into the CP1a mix. The same procedure was applied for CP2a and CP2b mixtures; however, instead of using GPC, Portland Cement was used as the binder for the CP2 group (OPC). A total of 12 test samples were cast and tested to determine the development of MOE of GPC and OPC over time. The MOE of concrete was measured at 3, 7, 28, 60, and 120 days. Experimental results were then compared to the MOE obtained using the empirical equation from ACI 318 - 2008. It was found that the experimental MOE of both OPC and GPC specimens was higher than the estimated MOE values from ACI standards. The added sodium sulfate yielded a significant effect on the MOE of OPC but produced a minimal influence on the MOE of GPC.

Keywords: modulus of elasticity; geopolymer concrete; seawater; marine sand; Portland cement.

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1. Introduction

According to the World Meteorological Organization report [1], by 2025, more than half of the world's population would confront freshwater anxiety to some certain extent. Freshwater is not only crucial for the daily needs of human beings but also for the industrial production of various commodities such as in the production process of cement and concrete. For instance, about 1.5 billion tons of freshwater are required to produce 25 billion tons of concrete per year [2, 3]. To avoid the dependence on freshwater for concrete production, seawater is the best alternative candidate for the replacement of freshwater in producing concrete, especially for offshore projects where seawater is readily available.

Besides freshwater stress, the scarcity of river sand is obvious and the search for an alternate source of sand is unavoidable. Due to the overexploitation of river sand for the construction demand, the natural environment has encountered many severe concerns including instability of riverbank

*Corresponding author. *E-mail address:* tungpt@nuce.edu.vn (Tung, P. T.)

or lowering of water aquifers [4]. Many restrictions on river sand extraction over the world caused the price of river sand to increase significantly [5, 6]. One possible solution to provide a low-cost alternative to fine aggregate which has a less environmental impact in producing concrete is to replace the traditional fine aggregate with marine sand and seawater for the mix. However, the reinforced concrete using Portland cement is proven not suitable for using marine sand and saltwater [7–10]. Recent research, however, showed the high potential of using GPC with marine sand and seawater in the production of concrete [11–13].

Geopolymer concrete is an eco-friendly material that employs geopolymer as the main binder. Geopolymer is formed under a process, called polycondensation, at low temperature. The constituents of geopolymer include a mixture of aluminosilicate oxides and inorganic alkali polysilicates. The combination of the two components produces a polymeric Silicate-Oxygen-Alkaline (Si-O-Al) bond by the following chemical reaction process [14].

$$n(Si_2O_5, Al_2O_2) + 2nSiO_2 + 4nH_2O \xrightarrow{NaOH,KOH} n(OH)_3\text{–}Si\text{–}O\text{-}\underset{\underset{(OH)_2}{|}}{Al}\text{–}O\text{-}Si\text{-}(OH)_3$$

$$n(OH)_3\text{-}Si\text{-}O\text{-}\underset{\underset{(OH)_2}{|}}{Al}\text{-}O\text{-}Si\text{-}(OH)_3 \xrightarrow{NaOH,KOH} (Na,K)^{(+)}\text{ - }(\text{-}\underset{\underset{\underset{|}{O}}{|}}{\overset{|}{Si}}\text{-}O\text{-}\underset{\underset{\underset{|}{O}}{|}}{\overset{|}{Al}}\text{-}O\text{-}\underset{\underset{\underset{|}{O}}{|}}{\overset{|}{Si}}\text{-}O\text{-}) + 4nH_2O$$

Significant research effort related to the prediction of mechanical properties of GPC and OPC using data-driven-based methods [15–21]. For instance, Awoyera et al. [15] and Pham et al. [17] applied the Artificial Neural Networks (ANN) to predict the 28-day compressive strength of geopolymer self-compacting concrete and GPC, respectively. In another study, Nguyen et al. [18] employed ANN and an adaptive neuro-fuzzy inference system (ANFIS) to predict the compressive strength of self-compacting concrete. The effects of changing ingredient inputs to the variation of concrete compressive strength were observed in that study by performing the parameter sensitivity analysis.

Research has also been conducted to study the effect of marine sand and seawater on the quality of conventional reinforced concrete. Some researchers have stated that the hydration process in concrete was affected due to the presence of chemical ions in seawater [22–30], others concluded that the high-level presence of chloride in marine sand and seawater could lead to the corrosion of reinforcing steel in concrete [26, 27]. The influence of saltwater on setting time and strength enhancement was also reported in several studies [28, 29]. To make the use of saline sand and seawater in the production of concrete, different approaches have been presented in the literature. For example, instead of using the normal steel bar, non-corrosive (i.e., glass-FRP) reinforcement was recommended for use in concrete produced with marine sand and seawater [30]. Another potential solution to prevent the adverse effects of chloride in concrete is to replace the OPC with GPC [31].

With regard to the study of using marine sand for fine aggregate replacement, Yang et al. [32] used slag to replace Portland cement to produce alkali-activated slag concrete by replacing freshwater and river sand with marine sand and seawater. The effects of seawater, marine sand, and the combination on the compressive, tensile, and shrinkage properties and resistance to chloride permeability of concrete were investigated. It was found that the concrete strength of the four combinations is close to each other, however, the resistance to chloride ion permeability is significantly improved. In another study, Anbarasan and Soundarapandian [33] investigated the mechanical and microstructural properties of GPC. Different experimental tests with various percentages of marine sand and seawater replacement were conducted. It was concluded that the river sand can be well substituted by the sea sand in producing GPC.

Saranya et al. [34] investigated the compressive and flexure strength, split tension, water absorption, sorptivity of M40 grade GPC using marine sand, river sand, and crushed sand as fine aggregate. Portland cement was replaced with fly ash and ground granulated blast furnace slag, and a combination of hydroxide and silicates of sodium is used as reaction liquid. Three types of concrete specimens with the same proportion by volume using different types of sands were cast and tested. Results from the experimental investigation stated that "The performance of GPC with marine sand and crushed sand is comparable or marginally higher than that of GPC made of river sand in terms of mechanical and durable properties."

The application of marine sand and seawater in the GPC mix has been argued for years [31–34]. Regarding the compressive strength of GPC, researchers [31–33] have reported that marine sand and seawater produced no or little negative effects, while others reported positive effects [34]. Specifically, Shinde and Kadam [32] found comparable 28-day compressive strength of fly ash-based GPC using desalinate marine sand to that of concrete produced using river sand. In another study, Anbarasan and Soundarapandian [33] reported that the splitting tensile strength and flexural strength at 28 days of slag-based GPC using marine sand was found lower than that of GPC using river sand. On the contrary, the rise in the compressive strength of GPC using marine sand was reported in a study by Saranya et al. [34].

The purpose of this experimental study is to investigate the development of the MOE of GPC and OPC using marine sand and saltwater to replace the river sand and freshwater in the mixture. Additionally, the authors would like to explore the effects of marine sand and seawater on the MOE of GPC and OPC. To achieve the goals, four different mixtures were produced with the different major binder (i.e., Geopolymer and Portland cement) and dosage of sodium sulfate. The MOE of the test samples was evaluated at the ages of 3, 7, 28, 60, and 120 days to monitor the growth of MOE over time. Experimental results were then compared with the MOE obtained from the empirical equation in ACI 318 standards. Details are presented in the following sections.

2. Materials and methods

2.1. Material preparation

A combination of fly ash (FA) and blast furnace slag (BFS) with the chemical composition in terms of percentage by mass, listed in Table 1, was used in producing the GPC mixtures in this study. The solid alkaline substance which includes the combination of sodium silicates and sodium hydroxide was used as the activator for the GPC mix.

Table 1. Chemical composition of cementious materials

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

The coarse aggregate utilized in this study was the natural crushed rock with a maximum size of less than 40 mm. The fine aggregate was natural marine sand collected from the local beach having a particle size of less than 5 mm. Details of sieve analysis followed by TCVN 7572-2 [35] are presented in Table 2.

Table 2. Sieve analysis for coarse and fine aggregates

Type	Sieve size (mm)	Cumulative retained (%)
Coarse aggregate	40	0
	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

Seawater with the chemical compositions, as in Table 3, collected directly from the local ocean was used in this study. Ordinary Portland cement (PC40) was used for the conventional mix. The physical properties of the commercial PC40 are listed in Table 4.

Table 3. Chemical composition of seawater used for concrete mix

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

Table 4. Physical properties of Portland cement PC40

Physical properties	Unit	Value
Specific gravity		3.1
Specific surface (Blaine)	cm^2/g	2800
Initial setting time	min	45
Final setting time	min	420
Compression strength 3 days	N/mm^2	23.1
Compression strength 7 days	N/mm^2	46.2

2.2. *Mixture design*

Two GPC mixtures, namely CP1a and CP1b, with different levels of sodium sulfate (Na_2SO_4) were prepared. The first mix (i.e., CP1a) included coarse aggregates, marine sand, activator, FA, BFS, and seawater. The second mix (i.e., CP1b) had the same components as in the first mix, however, an amount of sodium sulfate of 2.4 percent by mass of cementitious materials was added to the mix.

Two mixtures using OPC, namely CP2a and CP2b, were also prepared. The component and the quantity of each element in the CP2a and CP2b mix were almost identical except for the level of sodium sulfate dosage (i.e., 2.4% Na_2SO_4 added to the CP2b mix). The detailed mixture proportion per cubic meter of GPC and OPC batch used in this study is presented in Table 5.

Table 5. Mixture proportions of GPC and OPC

Material	Quantity for 1 m^3 GPC (kg)		Quantity for 1 m^3 OPC (kg)	
	CP1a	CP1b	CP2a	CP2b
BFS	255	255	-	-
FA	85	85	-	-
Cement PC40	-	-	594.9	553
Marine sand	760	760	447	1065
Coarse aggregate	1050	1050	1037	212.1
Seawater	165	165	224.5	553
Activator	68	68	-	-
Cement/seawater ratio	-	-	2.65	2.22
Na_2SO_4	-	2.4%	-	2.4%

For each mixture, a set of three standard cylinder samples with the dimension of 150 × 300 mm ($D \times H$) was cast following the standard concreting procedure. Specimens were cast into the molds and kept in for 24 hours. The specimens were then de-molded and cured at the normal conditions until the testing date. The entire preparing mix, casting, and curing specimens complied with TCVN 3105:1993 [36].

2.3. *Test procedure*

This experimental study aimed at determining the MOE of OPC and GPC at the ages of 3, 7, 28, 60, and 120 days. Fig. 1 shows cylinder specimens ready for testing and a tested sample, respectively. To perform the MOE test, the specimen was placed into the compression testing machine. The testing procedure presented in ASTM C469 – 1994 [37] was used in this study. The testing load was increased at a constant speed of 35 ± 7 psi/s (0.24 ± 0.05 MPa/s) until the stress in the specimen reached approximately 40% of cylinder compressive strength. The load and relative strain of the tested specimen was recorded over time. An identical procedure was applied for all specimens in this study.

(a) Cylinder specimens

(b) Tested specimen

Figure 1. Specimens and test apparatus

2.4. Modulus of Elasticity

The MOE of GPC and OPC at different ages is presented in Fig. 2. It is worth noting that the MOE of GPC and OPC specimens was calculated from experimental results using Eq. (1) from ASTM C469 – 1994.

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.00005} \tag{1}$$

where E is the MOE of concrete, S_2 is the stress in the specimen at the point of 40% of the ultimate load, S_1 is the stress (psi) in the specimen at $\varepsilon_1 = 0.000050$, and ε_2 is the strain in the specimen at stress S_2.

Besides, the MOE was also estimated using the ACI 318-2008 [38] using Eq. (2)

$$E = 4730\sqrt{f_c'} \quad \left(\text{N/mm}^2\right) \tag{2}$$

where E is the MOE of concrete, f_c' is the compressive strength of concrete.

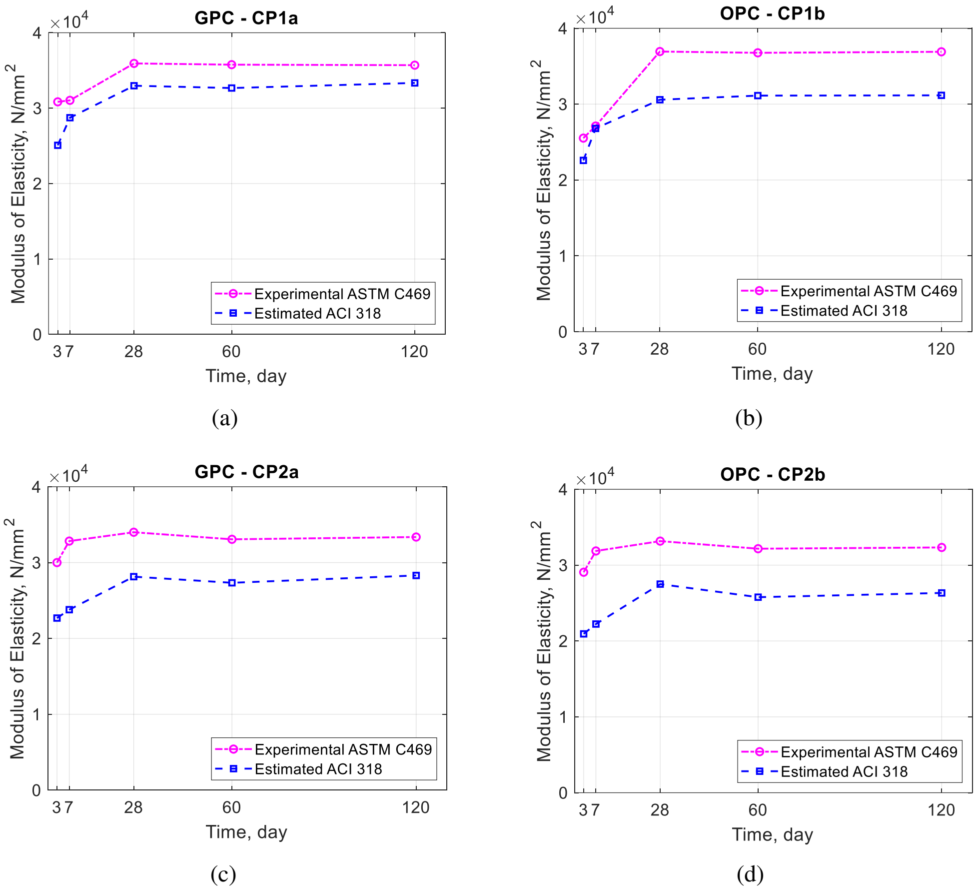

Figure 2. Experiment versus calculation results of different concrete mixtures

3. Results and discussion

3.1. Comparison between experimental results and calculation

Fig. 2 presents the MOE of the four concrete mixtures including experimental results and the calculated ones using the empirical equation obtained from ACI 318 – 2008 standards. It can be seen that, for all concrete mixtures, the experimental results were higher than the results obtained from the empirical equation. The difference of MOE values between experimental results and ACI 318 - 2008 for all concrete mixtures was found nearly constant after 28 days. Additionally, a difference of around 7% was found in GPC – CP1a mix (Fig. 2(a)) compared to approximately 16% for the rest of the mixtures.

3.2. Effects of added sodium sulfate

The influence of added sodium sulfate on the growth of MOE for GPC and OPC mixtures is presented in Fig. 3. It is shown that for both GPC and OPC, the mixtures with added sodium sulfate experienced a decrease in MOE. The GPC mixture (i.e., CP1a) had the highest MOE in the four experimental mixtures. On the contrary, the OPC mix with added sodium sulfate (i.e., CP2b) experienced the lowest value of MOE. With the same added sodium sulfate amount (i.e., 2.4%), the MOE of the GPC mix was found higher than that of the OPC mixture.

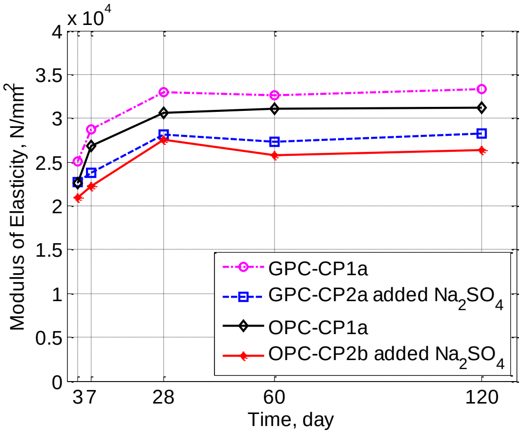

Figure 3. Effects of added sodium sulfate on MOE

It is worth noting that sodium sulfate produced significant effects on the development of MOE of both GPC and OPC concrete. As expected, the MOE of concrete specimens with added sodium sulfate was slightly lower than that of without sodium sulfate added ones, with a reduced rate of 3.1% for the GPC group, and 3.4% for the OPC group. The reduction in MOE is probably due to the forming of ettringite ($3\,CaO \cdot Al_2O_3 \cdot 3\,CaSO_4 \cdot 32\,H_2O$) in the concrete structure. The amount of calcium sulfoaluminate or ettringite in specimens with added sodium sulfate is much greater than in specimens without adding sodium sulfate, which leads to the reduction in the MOE.

4. Conclusions

The experimental work to determine the MOE of GPC and OPC using marine sand and seawater was presented in this study. Four mixtures with different types of cementitious material and the level of added sodium sulfate were investigated. MOE of all mixtures was measured at 3, 7, 28, 60, and 120 days, respectively. The MOE experimental results were compared with the calculated values obtained from the empirical equation in the ACI 318 standards. It was shown that the experimental MOE in all investigated mixtures was found to be higher than that obtained using the empirical equation. The original GPC mix had the highest MOE values among all mixtures.

With regard to the effect of added sodium sulfate on the MOE of concrete, the MOE of the two types of concrete decreased when the amount of sodium sulfate increased. Additionally, the MOE of the GPC mix was found higher than that of the OPC mix with the same added sodium sulfate amount. Regarding the influence of marine sand and saltwater on MOE, it was observed that the MOE of the GPC mix met the required value at 28 and 120 days as in this study. In contrast, for the OPC mixture, the MOE was developed significantly within 28 days and the rate of MOE development declined after that. The MOE values at 28 and 120 days were found not to meet the designed requirement.

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