EVALUATION OF FACTORS AFFECTING THE COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE USING SEA SAND AND SEAWATER

Le Thang VUONG, Hoai Chinh TRUONG*, Trong Hieu TRAN

The University of Danang - University of Science and Technology, Vietnam

*Corresponding author: thchinh@dut.udn.vn

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Abstract - This study comprehensively analyzes the impact of temperature and curing time on the compressive strength of geopolymer concrete made with locally sourced sea sand and seawater. The research aims to utilize abundant regional materials while reducing the environmental footprint associated with traditional construction practices. By conducting systematic experiments at elevated temperatures of 90°C and 120°C over varying durations, the study evaluates the critical factors influencing the mechanical performance of geopolymer concrete. The results reveal that optimizing curing temperature and time significantly enhances the compressive strength and durability of the material. This breakthrough presents promising opportunities for its broader application in eco-friendly and sustainable construction, particularly in coastal and marine environments.

Key words - Sea sand; seawater; geopolymer concrete; temperature; curing time; compressive strength.

1. Introduction

Geopolymer concrete has gained considerable attention from scientists and engineers worldwide due to its potential for significantly reducing CO_2 emissions when compared to traditional Portland cement-based concrete [1-6]. International research efforts have largely focused on the development and optimization of geopolymer concrete formulations, utilizing abundant materials such as fly ash, blast furnace slag, and natural sands. Among the most influential factors in enhancing the compressive strength and mechanical properties of geopolymer concrete are curing temperature and duration [7-11].

High curing temperatures have been shown to improve the bonding between the components of the geopolymer matrix, leading to increased compressive strength [8, 11]. Curing time is also critical, with durations of 3 to 28 days commonly used to track strength development in geopolymer concrete [7, 9, 10]. Additionally, multiple studies have demonstrated the feasibility of using locally sourced sand and seawater to produce geopolymer concrete, creating a sustainable construction material well-suited for marine environments [12-14]. For instance, Adam's research confirmed that maximum compressive strength was achieved at a curing temperature of 120°C and a curing time of 20 hours for the specific materials used in geopolymer concrete production [15].

In Vietnam, research on geopolymer concrete is still relatively new, but significant progress has been made in recent years. Domestic studies have mainly focused on the application of fly ash and ground granulated blast-furnace slag, two common industrial by-products, in the production of geopolymer concrete [16-19]. Several universities and research institutes, such as Hanoi University of Civil Engineering and the Institute of Construction Science and Technology, have conducted experiments on the factors influencing the strength and durability of geopolymer concrete. However, research on the use of sand and seawater in geopolymer concrete production remains limited.

Local studies have emphasized the importance of utilizing available resources to reduce costs and environmental impact. However, the potential of using seawater and sand from coastal areas, such as Ha Tien in Kien Giang Province, has not been widely explored (Figure 1). These coastal regions offer significant opportunities for the development of geopolymer concrete adapted to local environmental and climatic conditions, which could reduce reliance on traditional materials like river sand, a resource that is becoming increasingly scarce.

Figure 1. *Mui Nai Beach in Ha Tien City, Kien Giang Province*

This study aims to evaluate the impact of curing temperature and duration on the compressive strength of geopolymer concrete made from sea sand and seawater sourced from Mui Nai Beach, Ha Tien City, Kien Giang Province. The abundant resources in this area make it an ideal location for experimental research. Additionally, the study includes a comparative analysis with control samples made using freshwater and regular sand to provide more objective results. The selected curing temperatures were 90°C and 120°C, with curing durations of 3, 7, 14, and 28 days, to not only assess the mechanical properties of the material but also determine optimal curing conditions that could enhance the performance and quality of geopolymer concrete for practical construction applications.

2. Methodology

2.1. Research Content

2.1.1. Material Preparation

Marine sand and seawater were collected from Mui Nai

Beach, Ha Tien City, Kien Giang Province. The sand was sieved to remove impurities and debris, while the seawater was chemically analyzed to ensure the absence of contaminants that could negatively impact the geopolymerization process. The particle composition of both sea sand and river sand is presented in Figure 2. The fineness modulus of the sea sand is 2.537, while that of the river sand is 2.32. Both the particle composition and fineness modulus of the sea and river sands comply with the aggregate standards for concrete production as specified by Vietnamese Standard TCVN 7570:2006 [20].

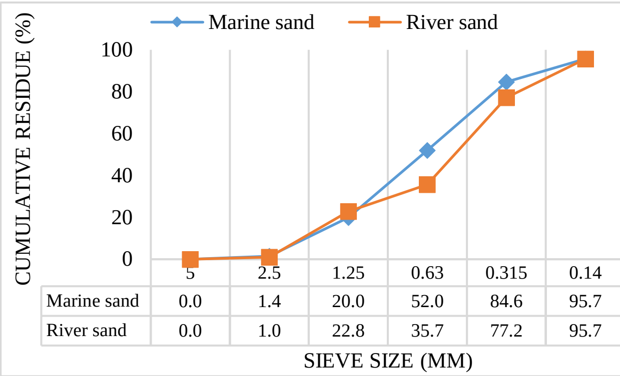


Figure 2. *Particle composition of sea sand and river sand*

2.1.2. Binder

Fly ash was mixed with an alkaline solution of NaOH and Na_2SiO_3 to form the geopolymer mixture (Figure 3, 4). The activating solution, a combination of NaOH and Na_2SiO_3, initiates the geopolymerization process in the concrete, with a Na_2SiO_3 to NaOH mass ratio of 2.5.

Figure 3. *Fly ash from Duyen Hai 1-2 Thermal Power Plant in Tra Vinh Province*

Figure 4. *Anhydrous NaOH solution*

2.1.3. Casting and Heating of Concrete Samples

After the geopolymer mixture is thoroughly mixed, it is poured into molds with dimensions of 150x150x150 mm. The samples are initially cured at room temperature for a short period to stabilize before undergoing the designated temperature and curing duration experiments.

2.1.4. Compressive Strength Testing

After the designated curing periods, the concrete samples are placed in a hydraulic compression machine to test their compressive strength. Each sample set consists of 3 specimens, and the result is the average value of the set.

2.1.5. Data Analysis and Results Evaluation

The compressive strength results of the geopolymer concrete samples using seawater will be compared with control samples made from regular sand and freshwater. Additionally, statistical analysis will be conducted to determine the extent of the influence of temperature and curing time on the compressive strength of the samples. The procedure is illustrated in Figure 5.

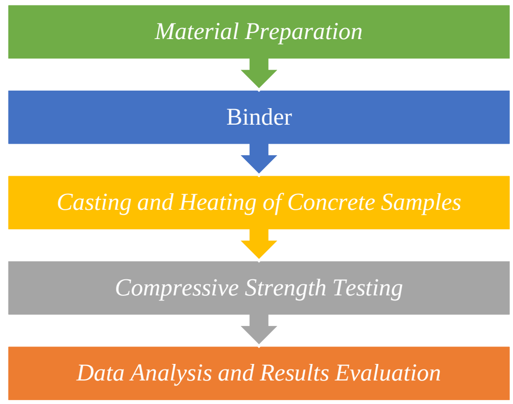


Figure 5. *Research routing*

2.2. Geopolymer Concrete Mixtures

The geopolymer concrete mix design was based on Rangan's guidelines [21]. The study conducted concrete production with two cases where the binder accounted for 25% and 35% of the total concrete mix. In each case, the proportion of fly ash was varied at 10%, 15%, and 20% of the binder weight, respectively.

2.3. Curing Samples Under Various Temperature Conditions

The concrete samples were divided into two groups and cured at temperatures of 90°C and 120°C for a drying period of 20 hours. After the initial heat curing, the samples were further cured and subjected to compression testing at 3, 7, 14, and 28 days to evaluate their compressive strength at each interval.

Figure 6. *Concrete drying machine*

The heat curing process was conducted in the laboratory of the University of Science and Technology, University of Danang (Figures 6 and 7).

Figure 7. *Heat curing process for concrete samples*

2.4. Compressive Strength Testing

The compressive strength of the concrete samples was measured using a SYE-2000A hydraulic compression machine, capable of applying a maximum load of 200 tons. The characteristic compressive strength was then determined using Equation (1).

$$f_c = \frac{P}{A} \tag{1}$$

Where P is the destructive compressive force, and A is the cross-sectional area of the specimen.

Each sample set consists of three specimens, and the final compressive strength value is taken as the average of these three specimens (Table 1 and Table 2).

Table 1. *Compressive Strength of Concrete Cured at 90°C*

Mixture	Binder Ratio (%)	Fly ash (%)	Time (days)	Compressive strength of Concrete (Mpa)	
				Sand and freshwater	Marine sand and Seawater
CP1-1	25%	10%	3 days	9.1	9.508
CP1-2	25%	10%	7 days	17.7	18.517
CP1-3	25%	10%	14 days	22.7	23.730
CP2-1	25%	15%	3 days	9.7	9.842
CP2-2	25%	15%	7 days	20.6	20.981
CP2-3	25%	15%	14 days	26.0	26.459
CP3-1	25%	20%	3 days	12.1	12.723
CP3-2	25%	20%	7 days	23.4	24.491
CP3-3	25%	20%	14 days	26.2	27.461
CP4-1	35%	10%	3 days	9.7	10.742
CP4-2	35%	10%	7 days	21.8	24.084
CP4-3	35%	10%	14 days	23.2	25.668
CP5-1	35%	15%	3 days	11.8	13.641
CP5-2	35%	15%	7 days	21.0	24.409
CP5-3	35%	15%	14 days	23.6	27.401
CP6-1	35%	20%	3 days	12.1	12.319
CP6-2	35%	20%	7 days	22.4	27.925
CP6-3	35%	20%	14 days	25.9	32.307

Table 2. *Compressive Strength of Concrete Cured at 120°C*

Mixture	Binder Ratio (%)	Fly ash (%)	Time (days)	Compressive strength of Concrete (Mpa)	
				Sand and freshwater	Marine sand and Seawater
CP1-1	25%	10%	3 days	15.1	11.007
CP1-2	25%	10%	7 days	29.4	21.432
CP1-3	25%	10%	14 days	37.7	27.466
CP1-4	25%	10%	28 days	39.8	28.963
CP2-1	25%	15%	3 days	15.3	11.362
CP2-2	25%	15%	7 days	32.7	24.230
CP2-3	25%	15%	14 days	41.2	30.555
CP2-4	25%	15%	28 days	43.4	32.163
CP3-1	25%	20%	3 days	18.1	14.353
CP3-2	25%	20%	7 days	34.8	27.628
CP3-3	25%	20%	14 days	39.0	30.979
CP3-4	25%	20%	28 days	45.2	35.881
CP4-1	35%	10%	3 days	14.5	12.637
CP4-2	35%	10%	7 days	32.5	28.328
CP4-3	35%	10%	14 days	34.7	30.193
CP4-4	35%	10%	28 days	42.8	37.274
CP5-1	35%	15%	3 days	16.8	15.987
CP5-2	35%	15%	7 days	30.0	28.611
CP5-3	35%	15%	14 days	33.6	32.117
CP5-4	35%	15%	28 days	44.1	42.074
CP6-1	35%	20%	3 days	15.1	14.106
CP6-2	35%	20%	7 days	34.2	31.975
CP6-3	35%	20%	14 days	39.6	36.991
CP6-4	35%	20%	28 days	50.3	47.022

3. Results and Discussion

3.1. Effect of Time on the Compressive Strength of Geopolymer Concrete

3.1.1. Concrete using Sand and Freshwater

The figures illustrate the effect of time on the compressive strength of concrete made with sand and freshwater at two different binder ratios (25% in Figure 8 and 35% in Figure 9). As anticipated, the compressive strength steadily increases over time across all fly ash ratios, a characteristic behavior of geopolymer concrete as the curing process progresses. In both figures, concrete with a 20% fly ash content consistently achieves the highest compressive strength, followed by the 15% and 10% fly ash ratios.

In Figure 8, where the binder ratio is 25%, the compressive strength of the 20% fly ash mix reaches 30.3 MPa at 28 days, while the 10% fly ash mix reaches 23.9 MPa. In Figure 9, with a 35% binder ratio, the concrete shows even greater strength, with the 20% fly ash mix achieving 32.9 MPa and the 10% fly ash mix reaching 28.6 MPa at 28 days.

This increase in compressive strength over time is attributed to the ongoing geopolymerization process, which enhances the material's strength. The higher binder content in Figure 9 (35%) leads to better performance, as the increased binder contributes to a stronger and more cohesive matrix. Similarly, the higher fly ash content further promotes the geopolymerization process, resulting in superior strength, particularly over extended curing periods. This explains why the 20% fly ash mix consistently outperforms mixes with lower fly ash content in both figures.

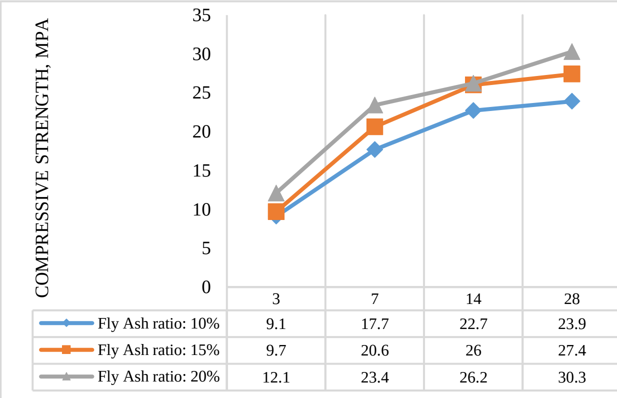


Figure 8. *Effect of Time on the Compressive Strength of Concrete (Binder Ratio 25%)*

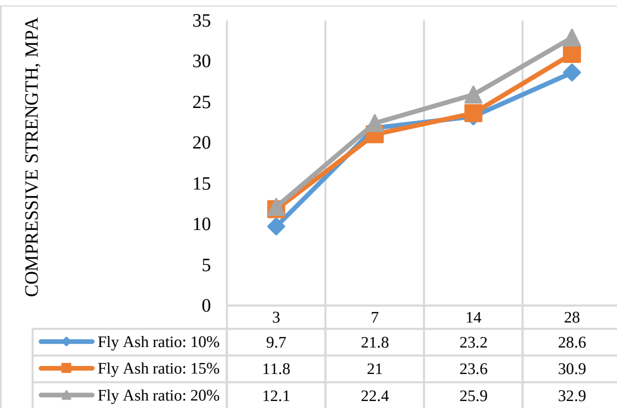


Figure 9. *Effect of Time on the Compressive Strength of Concrete (Binder Ratio 35%)*

3.1.2. For Concrete using Marine sand and Seawater

The analysis of the compressive strength development of geopolymer concrete made with marine sand and seawater demonstrates a clear trend of increasing strength over time, similar to the behavior observed in conventional concrete. At both binder ratios, 25% and 35%, the geopolymer concrete shows continuous strength gains as the curing process progresses.

In the case of geopolymer concrete with a 25% binder ratio (Figure 10), the mix with 20% fly ash content reaches a compressive strength of 31.807 MPa at 28 days, while the 10% fly ash mix achieves 25.022 MPa. This trend is further amplified when the binder ratio is increased to 35% (Figure 11), where the 20% fly ash mix reaches a compressive strength of 41.067 MPa, and the 10% fly ash mix reaches 31.689 MPa at 28 days.

Comparing this to conventional geopolymer concrete (using freshwater and sand), the results indicate that the use of marine sand and seawater does not hinder the strength development process. In fact, the concrete made with marine materials shows similar, if not slightly enhanced, performance over time. The presence of salts in seawater may act as a catalyst, accelerating hydration and geopolymerization reactions, particularly in mixes with higher fly ash content. This is most evident in the concrete with a 35% binder ratio, which consistently outperforms its counterpart with a lower binder ratio. The denser matrix formed by the higher binder content improves the overall cohesion and strength of the geopolymer structure.

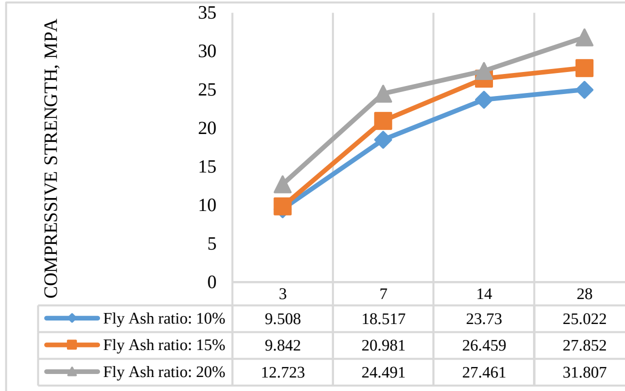


Figure 10. *Effect of Time on the Compressive Strength of Concrete Using Marine Sand and Seawater (Binder Ratio 25%)*

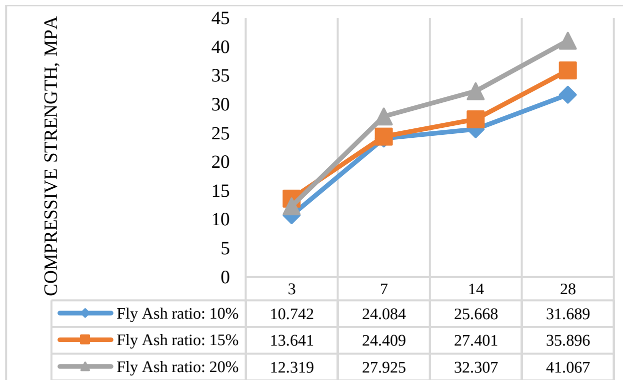


Figure 11. *Effect of Time on the Compressive Strength of Concrete Using Marine Sand and Seawater (Binder Ratio 35%)*

3.2. The effect of Curing temperature on the Compressive strength of Geopolymer concrete

The graphs depict the impact of temperature on the compressive strength of both standard concrete and concrete made with marine sand and seawater (Figure 12, 13). In both cases, the binder ratio is 35%, and the fly ash ratio is 20%. The key observation from the graphs is that concrete heated at 120°C exhibits a consistently higher compressive strength at all curing ages (3, 7, 14, and 28 days) compared to concrete heated at 90°C.

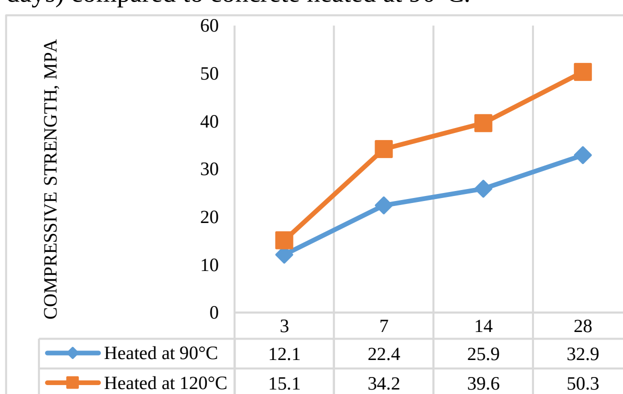
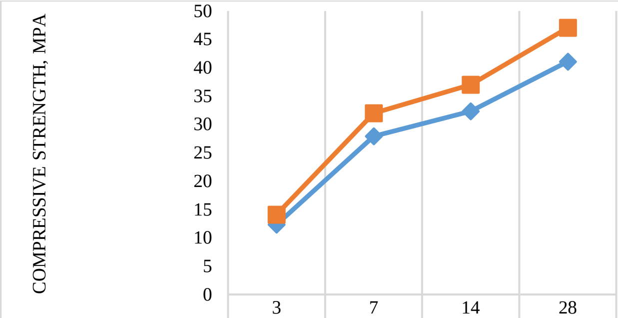


Figure 12. *The effect of curing temperature on the compressive strength of regular concrete*



	3	7	14	28
Heated at 90°C	12.319	27.925	32.307	41.067
Heated at 120°C	14.106	31.975	36.991	47.022

Figure 13. *The effect of curing temperature on the compressive strength of concrete using marine sand and seawater*

For regular concrete, the compressive strength for samples cured at 120°C increases more rapidly, reaching 50.3 MPa at 28 days, whereas the concrete heated at 90°C reaches only 32.9 MPa. Similarly, for marine sand and seawater concrete, the strength at 120°C reaches 47.022 MPa, compared to 41.067 MPa at 90°C after 28 days. The higher temperature accelerates the hydration reaction, leading to faster early-age strength gain.

The effect of marine sand and seawater also slightly enhances the strength at higher temperatures. The presence of chloride ions in seawater may act as a catalyst, improving the hydration process at elevated temperatures.

4. Conclusion

The findings of this study indicate that both curing time and temperature significantly influence the compressive strength of geopolymer concrete. Over time, the strength of the concrete progressively increases, and higher curing temperatures, particularly at 120°C, substantially accelerate early-age strength development. This suggests that temperature management is a critical factor in optimizing the mechanical properties of geopolymer concrete. Notably, the use of seawater does not negatively affect the strength development process and may even contribute positively due to the presence of salts that enhance the geopolymerization reaction.

Future research should focus on expanding the range of curing temperatures to determine the optimal temperature for producing geopolymer concrete, further optimizing its performance for sustainable construction in marine environments.

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