International Journal of GEOMATE, March, 2025 Vol.28, Issue 127, pp.71-78
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2025.127.g13269
Geotechnique, Construction Materials and Environment

# STRESS-STRAIN RELATIONSHIP OF GEOPOLYMER CONCRETE UNDER COMPRESSIVE LOADING

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**ABSTRACT:** This research aimed to comprehensively investigate the stress-strain relationship of geopolymer concrete (GPC) under compressive loading. Geopolymer concrete was prepared by fly ash from Mae Moh Power Plant, Thailand and activated through sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$) solutions. The NaOH concentration was fixed at ten molar, and the solution-to-fly ash ratio was set to 0.6. Four different ratios of $Na_2SiO_3$/NaOH (0.50, 0.75, 0.85 and 1.00) were employed to prepare GPC specimens. The specimens were designed as short columns with cross-sectional dimensions of 200 mm x 200 mm and a height of 500 mm. The specimens were divided into two sets and subjected to different curing regimes. One set was cured at 65°C for 48 hours and then tested at seven days of age, while the other set was cured at ambient temperature and tested after reaching the age of 28 days. The compressive strength of the specimens was evaluated using the ASTM C39 standard for testing cylindrical samples. The results revealed that the compressive strength was found to be positively correlated with the ratio of sodium silicate to sodium hydroxide, curing temperature, and curing time. Furthermore, the stress-strain relationship of the GPC specimens was modeled using the stress-strain equations of concrete, and appropriate formulas were derived from the data obtained. These equations can be implemented to accurately predict the stress-strain behavior of GPC in structural applications for construction, facilitating its broader adoption as a durable and sustainable alternative to conventional concrete.

*Keywords: Geopolymer concrete, Stress-strain model, Fly ash, Compressive strength, NaOH*

## 1. INTRODUCTION

Concrete is among the most extensively utilized building materials worldwide due to its adaptability, durability, and dependability. Traditionally, Portland cement is the principal binder in concrete and aggregates such as sand, gravel, and water to create a robust, enduring material essential for contemporary infrastructure. The extensive utilization of Portland cement has a considerable environmental effect. Resource-intensive production generates significant $CO_2$ emissions, accounting for around 8% of global carbon dioxide emissions. Each ton of Portland cement produced results in around 0.95 tons of $CO_2$ emissions, mainly attributed to the calcination process and the energy demands of manufacturing [1]. This environmental issue has prompted academics to explore more sustainable alternatives to conventional Portland cement-based concrete.

Geopolymer concrete (GPC) is a viable alternative to traditional cement, utilizing industrial by-products such as fly ash and slag as binders. These pozzolanic materials, abundant in silica ($SiO_2$) and alumina ($Al_2O_3$), react with alkaline solutions commonly sodium hydroxide (NaOH) and sodium silicate ($Na_2SiO_3$) to produce a robust, enduring binder. GPC presents several benefits compared to Portland cement concrete, such as reduced greenhouse gas emissions, enhanced chemical resistance, and superior thermal stability [3, 4]. Fly ash, an industrial by-product of coal combustion in power plants is among the raw materials most often utilized to produce geopolymer binders. Its application lowers environmental waste and offers a viable substitute for cementitious materials in buildings [5]. Many research studies have investigated the mechanical characteristics of geopolymer concrete, particularly its compressive strength, which is a critical measure of its load-bearing capability. The mechanical performance of GPC is greatly influenced by factors like the kind of precursor material, concentration of alkaline activator, curing temperature, and duration [6, 7]. Research has shown that increasing the ratio of sodium silicate to sodium hydroxide in the alkaline activator improves the compressive strength of GPC [8, 9]. Moreover, increased curing temperatures have been demonstrated to accelerate the polymerization process, resulting in accelerated strength development, essential for early-age strength in structural applications [10]. Although more sustainable and economical, curing at ambient temperatures may lead to slower strength development, but it can still yield geopolymer concrete with acceptable mechanical characteristics over time [11].

The structural performance of GPC under various loading conditions, particularly the material stress-strain relationship under compressive loading, is crucial for assessing its suitability as a substitute for traditional concrete. The stress-strain relationship of concrete is essential in structural engineering, as it elucidates the material's behavior under stress, ranging from the elastic phase, where stress and strain are proportional, to the plastic phase, where irreversible deformation occurs and eventual failure ensues [12]. Comprehending this connection allows engineers to anticipate the mechanical behavior of concrete in various structural applications and to design structures with enhanced performance and safety.

The present research investigates the stress-strain relationship of geopolymer concrete utilizing fly ash from the Mae Moh Power Plant in Northern Thailand. The fly ash was activated using a ten-molar sodium hydroxide solution together with several ratios of sodium silicate to sodium hydroxide (0.50, 0.75, 0.85, and 1.00). The geopolymer concrete's compressive strength and stress-strain characteristics were examined, utilizing specimens configured as short columns with a cross-section of 200 mm x 200 mm and a height of 500 mm. The compressive strength was assessed following ASTM C39 criteria, widely acknowledged for evaluating cylindrical concrete specimens [12].

The research examines the impact of curing regimes on the mechanical characteristics of geopolymer concrete. One group of specimens was cured at 65°C for 48 hours and tested at seven days of age, while another group was cured at ambient temperature and assessed after 28 days. Prior studies indicate that curing at increasing temperatures improves the early-age strength of geopolymer concrete, as the heat accelerates the geopolymerization reaction, resulting in denser microstructures and increased strength [13]. Conversely, ambient curing, albeit slower, maybe more energy-efficient and environmentally sustainable, rendering it a feasible choice for sustainable construction methodologies [14].

The present study attempted to simulate the stress-strain connection of geopolymer concrete and assess compressive strength by utilizing published stress-strain equations for conventional concrete. The equations were modified to align with the data acquired from testing geopolymer concrete specimens, establishing a framework for forecasting the mechanical behavior of GPC under compressive loads. Precise modeling of the stress-strain relationship by applying stress-strain equations of concrete from previous research using the least-squares regression method is crucial for designing and studying reinforced concrete buildings, as it allows more dependable predictions of material performance under actual conditions.

## 2. RESEARCH SIGNIFICANCE

This research offers practical insights into the stress-strain behavior and mechanical performance of geopolymer concrete (GPC), emphasizing its potential for real-world structural applications. By identifying the optimal mix design and curing conditions, the study provides engineers with precise guidelines for utilizing GPC as a high-performance and sustainable alternative to traditional Portland cement concrete. The outcomes enable improved design and modeling of GPC in infrastructure projects, promoting reduced $CO_2$ emissions and environmental sustainability. This work supports the construction industry in adopting greener practices while ensuring durable and reliable building materials for future developments.

## 3. MIXED DESIGN AND CURING PROCESSES

The research study employed fly ash from the Mae Moh Power Plant, Mae Moh district, Lampang province, Thailand, to prepare GPC. Alkaline activators were part of the mix, specifically sodium silicate ($Na_2SiO_3$) and sodium hydroxide (NaOH). The concentration of the sodium hydroxide solution was maintained at ten molars. The solution to fly ash ratio was kept constant at 0.6. The paste volume, constituted by the solution and fly ash, accounted for 36% of the total volume, whereas the aggregate volume contributed to the remaining 64% of the total volume. Concerning the sodium silicate to sodium hydroxide ratio, previous studies indicate an ideal range between 0.67 – 1.00 for the preparation of geopolymer concrete [15]. Thus, the ratios of 0.50, 0.75, 0.85 and 1.00 were investigated in this study. Table 1 presents the specific mix proportions for the geopolymer concrete.

Table 1. Mixture Proportions of GPC

| Mixture ratio | Mix designation | | | |
|---|---|---|---|---|
| (kg/m$^3$) | G0.50 | G0.75 | G0.85 | G1.00 |
| FA | 400 | 400 | 400 | 400 |
| $Na_2SiO_3$/NaOH | 0.5 | 0.75 | 0.85 | 1.00 |
| $Na_2SiO_3$ | 80 | 103 | 110 | 120 |
| NaOH | 160 | 137 | 130 | 120 |
| Fine Agg. | 583 | 583 | 583 | 583 |
| Coarse Agg. | 1100 | 1100 | 1100 | 1100 |

The production of geopolymer concrete using a concrete mixer requires meticulous control owing to the rapid setting time of the material, which directly impacts its ultimate compressive strength. The duration of mixing was maintained at 15 minutes following the methodology outlined by Chindaprasirt

[15]. In the first step, the concrete mixer and all associated mixing equipment underwent a comprehensive cleaning process to remove any remaining materials effectively. Subsequently, the components were meticulously prepared: fly ash, sodium hydroxide, sodium silicate, coarse aggregate, and fine aggregate. The mixing process was started, and the fly ash was subsequently incorporated into the mixture. The introduction of sodium hydroxide followed this, and the blending procedure was continued for five minutes. The coarse and fine aggregates were subsequently added and mixed for an additional duration of five minutes. Subsequently, sodium silicate was introduced into the amalgamation, and the blending process was prolonged for an additional duration of five minutes. Finally, the geopolymer concrete was carefully poured to prepare short column specimens, which were subsequently subjected to compression testing to evaluate the stress-strain correlation. The specimens had cross-sectional dimensions of 200 mm x 200 mm and a height of 500 mm. Implementing this comprehensive procedure ensured the attainment of a uniform mixture of geopolymer concrete while also considering the impact of the rapid setting time on the resultant compressive strength.

Previous research has demonstrated that applying heat to induce the polymerization reaction can enhance the geopolymer compressive strength during its initial stages [16]. This attribute holds significant importance in the context of geopolymer concrete. Nevertheless, curing geopolymer concrete at elevated temperatures may introduce challenges that could hinder its practical implementation. Consequently, the present study utilized two distinct curing methods for preparing geopolymer concrete column specimens. The first method implied putting the specimens at a temperature of 65 degrees Celsius in an oven for 48 hours. Subsequently, the specimens were subjected to ambient room temperature conditions within a controlled environment until they reached the desired age of 7 days for the compressive strength test. For the second method, the specimens were cured at ambient temperatures for 28 days. During ambient curing, the temperature was measured three times daily to determine the mean curing temperature encountered by the geopolymer concrete over 28 days. Eight specimens were prepared for each mix proportion: three were cured in the oven, while the remaining five were cured at ambient temperatures.

## 4. PREPARING AND TESTING SETUP OF EXPERIMENTS

The setup of test specimens was an essential procedure to ensure accurate and reliable information collection throughout the following testing process. The specimens, permitted to attain the specified age under varying curing conditions, underwent surface refinement to eradicate imperfections and to provide smooth, uniform surfaces for more consistent test results. Surface refinement is essential for ensuring that the load applied during the compression test is uniformly distributed throughout the specimen's surface, minimizing the risk of localized stress concentrations that may result in premature failure or erroneous measurements. After surface preparation, strain gauges were attached to the surface of each specimen. These strain gauges, with a gauge length of 120 mm, were meticulously chosen to precisely measure the strain response of the specimens subjected to compressive pressure. The strain gauges were positioned at the mid-height of the specimens to measure the longitudinal strain, which is essential for assessing the stress-strain relationship. The meticulous positioning of the strain gauges guaranteed that any deformations in the specimen during the loading could be precisely quantified.

During the testing procedure, the specimens were positioned in a universal testing machine (UTM) with a maximum load capacity of 300 kN, as seen in Fig. 1. The UTM offers a regulated setting where specimens may endure compressive stresses according to conditions. The testing apparatus additionally incorporated Linear Variable Differential Transformers (LVDTs) to quantify the displacements of the specimens precisely. The LVDTs were essential in measuring the subtle deformations that occurred while applying the compressive force. These devices transduce mechanical displacement into an electrical signal, enabling the deformation assessment and the consequent strain calculation.

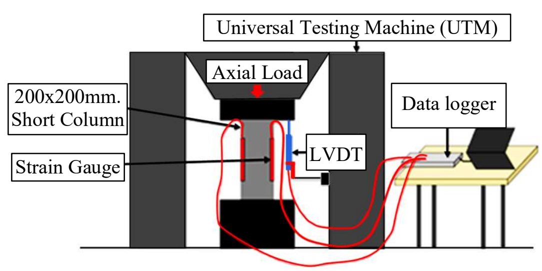


Fig.1 Experimental Testing Setup

The compression test was performed in accordance with the ASTM C39 standard [12], which delineates procedures for assessing the compressive strength of cylindrical concrete specimens. The test utilized a force-controlled approach, maintaining a constant loading rate of 200 N/sec. The consistent loading rate is crucial to ensure the specimens experience a homogeneous stress application, reducing sudden variations that may lead to erroneous measurements or accidental specimen failure. The ASTM C39 standard [12] prescribes this testing approach to provide uniformity and reliability in measuring the compressive strength of concrete.

A data logger was employed to record and retain all pertinent data during the testing procedure. The data logger persistently documented essential characteristics like load, displacement, and strain, guaranteeing the capture of all data points throughout the test. Implementing a data logger enabled real-time data acquisition and subsequent investigation of the stress-strain relationship in geopolymer concrete. After that, the collected data will be processed and evaluated to ascertain essential mechanical parameters, including the final compressive strength and the modulus of elasticity. This testing process included strain gauges, LVDTs, and a data logger with the universal testing machine to record the geopolymer concrete sample's stress-strain behavior accurately. Accurately quantifying the applied force and the resultant deformations was vital for cultivating a thorough comprehension of the material's mechanical properties under compressive loading, which is imperative for its utilization in structural engineering.

## 5. EXPERIMENTAL RESULTS

The results of the flow and compressive strength assessments for the geopolymer concrete (GPC) columns, each measuring 200 mm x 200 mm in cross-section and 500 mm in height, are displayed in Table 2. The testing yielded insights into the mechanical properties and workability of GPC at different mix ratios and curing circumstances. Table 2 illustrates the impact of the sodium silicate to sodium hydroxide ratio and the curing temperature on flow, maximum compressive strength, and elastic modulus.

### 5.1 Flow Test Results

The flow test is a critical measure of the concrete mix's workability, influencing its placement and compaction efficiency. The flow test findings indicate that the ratio of sodium silicate to sodium hydroxide ($Na_2SiO_3/NaOH$) considerably influences the flow values of the GPC. The mix's workability diminished as the sodium silicate concentration rose compared to sodium hydroxide. The inverse correlation between the $Na_2SiO_3/NaOH$ ratio and flow values corroborated prior research, hence reinforcing the influence of the alkaline solution ratio on concrete workability. When the ratio was 0.50, the measured flow value was 50.3 cm, signifying enhanced workability. As the ratio rose to 1.00, the flow value diminished to 42.8 cm, indicating a more rigid mixture. The reduction in flow is owing to the elevated sodium silicate concentration, which generally results in a denser, less fluid paste because of the heightened viscosity of the solution.

### 5.2 Compressive Strength Results

The compressive strength results indicated significant patterns in the influence of curing conditions and mix ratios on the mechanical properties of the GPC specimens. A comparative study was conducted between specimens cured at 65°C for seven days in an oven and those cured at ambient temperature for over 28 days. The specimens treated at ambient temperature consistently demonstrated superior compressive strength across all mix ratios, with enhancements ranging from 10% to 20% compared to those cured in an oven. The improved performance can be attributed to the extended curing time under ambient circumstances, which likely facilitated a more thorough and persistent polymerization process, leading to a denser and stronger microstructure. Conversely, whereas heat curing expedited the initial strength acquisition, the abbreviated curing duration may have constrained the complete maturation of the geopolymer matrix.

### 5.3 Impact of Sodium Silicate to Sodium Hydroxide Ratio on Compressive Strength

A significant discovery of the study is the fluctuation in compressive strength contingent upon the $Na_2SiO_3/NaOH$ ratio. Of the evaluated ratios, 0.85 exhibited the greatest compressive strength. The compressive strength of the GPC specimens treated in the oven at 65°C was recorded at 516.34 ksc for this ratio. The ambient-cured specimens demonstrated an even greater strength at this ratio, with a maximum compressive strength of 631.61 ksc, highlighting the significant advantages of prolonged ambient curing.

In the other mix ratios, although the compressive strengths were somewhat inferior to those of the 0.85 ratio, they exhibited a comparable trend, with ambient-cured specimens consistently surpassing oven-cured specimens. At a $Na_2SiO_3/NaOH$ ratio of 1.00, the compressive strength of oven-cured GPC was recorded at 492.16 ksc, whereas the strength of ambient-cured GPC was 551.76 ksc. This indicates a strength similar to the 0.85 ratio but with a minor decrease, implying that augmenting the sodium silicate concentration beyond a specific limit may not provide further strength advantages.

## 6. STRESS-STRAIN RELATIONSHIP

The relationship between stress and strain is essential for comprehending the mechanical properties of geopolymer concrete (GPC) subjected to compressive forces. This study examined the stress-strain characteristics of short-column GPC test specimens with varying mix ratios of sodium silicate to sodium hydroxide. Figs. 2-5 illustrates the stress-strain curves derived from these experiments, emphasizing specimens cured at ambient temperature.

Ambient curing conditions were selected for investigation due to prior research demonstrating that these circumstances facilitate a more thorough and prolonged polymerization process, directly affecting the mechanical performance of GPC.

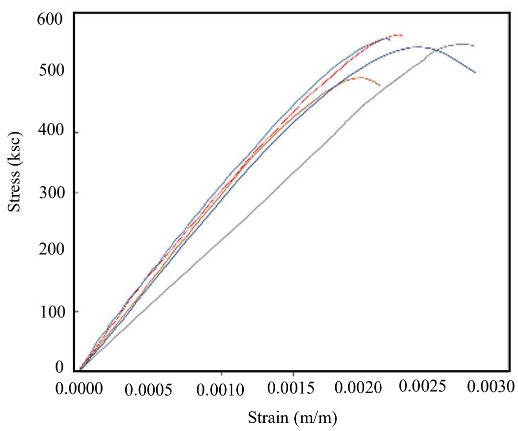


Fig. 2 The relationships between stress and strain for GPC with $Na_2SiO_3/NaOH$ ratio of 0.50.

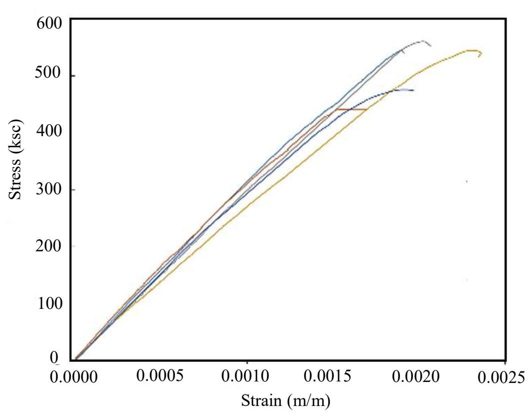


Fig. 3 The relationships between stress and strain for GPC with $Na_2SiO_3/NaOH$ ratio of 0.75.

The strain at the highest stress for all sodium silicate to sodium hydroxide mix ratios was determined to be about between 0.0022 and 0.0023. These values offer crucial insights into the ductility and deformation properties of GPC under compressive stresses, which are vital for forecasting the performance of this material in structural applications. The stress-strain data acquired in this investigation were further examined to formulate a model capable of precisely predicting the stress-strain relationship for GPC, akin to the models suggested for ordinary concrete in earlier research.

Numerous prior research has suggested various models for the stress-strain relationship of concrete under compressive force. This study aimed to modify these models to align with the characteristics of GPC, considering its unique composition and mechanical properties. The assessment procedure entailed juxtaposing the stress-strain relationship of GPC with the models previously articulated by Mohamad et al. [17], Kent and Park [18], Cui et al. [19], and Da et al. [20]. Table 3 summarizes the various formulations of the stress-strain equations provided by these researchers.

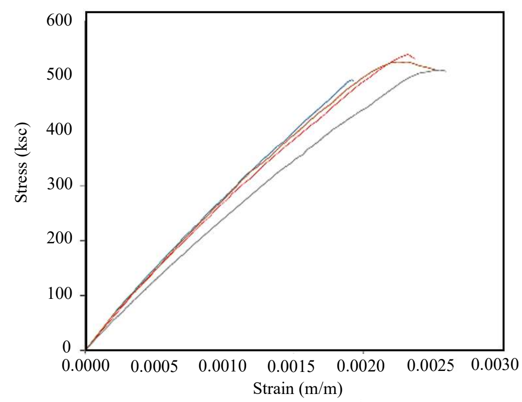


Fig. 4 The relationships between stress and strain for GPC with $Na_2SiO_3/NaOH$ ratio of 0.85

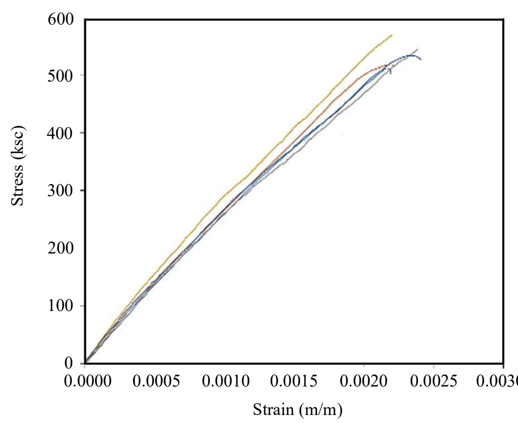


Fig. 5 The relationships between stress and strain for GPC with $Na_2SiO_3/NaOH$ ratio of 1.00.

### 6.1 Data Normalization and Analytical Procedure

Before evaluating the data to ascertain the optimal stress-strain relationship, preparing the raw data to guarantee uniformity and reduce redundancy was essential. This entailed standardizing both stress and strain levels. The stress levels were normalized by dividing the recorded stress by the highest stress attained by each specimen. Similarly, strain data were standardized by dividing the measured strain by the strain at the point of greatest stress. The normalizing procedure facilitated the stress-strain curves across various mix ratios and specimens, irrespective of differences in their absolute values. The investigation concentrated solely on the climbing segment of the stress-strain curve, representing the elastic and first plastic deformation phases before attaining ultimate compressive strength. This curve portion is crucial for structural engineering applications since it indicates the material's response to service loads.

Based on the experimental results, a least-squares regression approach was employed to obtain the optimal stress-strain equation for GPC. The least-squares method is a recognized statistical technique used to minimize the aggregate of the squared discrepancies between the observed data points and the model's projected values. This strategy was selected as it guarantees that the resultant model achieves the optimal fit to the experimental data, hence minimizing error and variance.

The parameters derived from the least-squares regression analysis, referred to as constants 'a', 'b' and 'c' are presented in Table 3. The parameters were included in the relevant equations established by Mohamad et al. [17], Kent and Park [18], Cui et al. [19], and Da et al. [20], enabling a direct comparison of the model's efficacy in fitting the GPC data.

### 6.2 Evaluation of Models

Analysis of the least-squares regression findings revealed that the various models exhibited differing degrees of accuracy in forecasting the stress-strain relationship for GPC. Three principal metrics were employed to assess the appropriateness of each model: the coefficient of determination ($R^2$), the sample variance, and the error. The coefficient of determination ($R^2$) quantifies the extent to which the model accounts for the variability in the observed data. An elevated $R^2$ value signifies a superior alignment between the model and the data. The investigation demonstrated that the models put out by Mohamad et al. [17], Kent and Park [18], and Cui et al. [19] all had an equal $R^2$ value of 0.9942, signifying a robust correlation between the anticipated and observed stress-strain values for GPC. Conversely, the model presented by Da et al. [20] had a somewhat lower $R^2$ value of 0.9783, indicating a considerably less explanatory capacity relative to the other models.

Sample variance quantifies the dispersion of observed data points relative to the projected values. A reduced sample variance signifies that the model predictions are tightly grouped around the observed data, which is advantageous for an accurate stress-strain model. The model presented by Cui et al. [19]
Table 2. Experimental Results and Data Analysis
demonstrated the minimal sample variance of 8.3107, signifying a close alignment with the data. Mohamad et al. [17] and Kent and Park [18] reported sample variances of 8.4024 and 8.4191, respectively. Da et al. [20] exhibited a notably elevated sample variance of 31.1995, signifying a considerably broader dispersion of the data relative to the projected values.

The error metric directly quantifies the model's accuracy, with decreased error values signifying a more accurate fit to the data. The model given by Cui et al. [19] demonstrated a minimal error of 0.0228, indicating it yielded the most precise predictions for the stress-strain behavior of GPC. The models developed by Mohamad et al. [17] and Kent and Park [18] had analogous error levels of 0.0229, signifying equivalent performance efficacy. Conversely, Da et al. [20] exhibited the most significant error value of 0.0441, reaffirming its comparatively diminished appropriateness for predicting the stress-strain relationship of GPC.

### 6.3 Selection of Model and Conclusive Equation

Following an exhaustive evaluation of various models, the study determined that the model proposed by Cui et al. [19] was the most suitable for accurately predicting the stress-strain relationship of GPC. This conclusion was drawn based on the model’s superior performance across all key evaluation metrics, including the coefficient of determination ($R^2$), sample variance, and error. This signified a close and reliable alignment between the predicted and observed data points. These results indicate that this model is not only statistically robust but also provides a practical tool for forecasting the mechanical behavior of GPC under compressive forces.

The ultimate stress-strain equation for GPC, formulated by integrating the constants acquired by least-squares regression into the model suggested by Cui et al. [19], is delineated in Eq. (1). This equation is advised for forecasting the stress-strain behavior of GPC, especially for specimens with sodium silicate to sodium hydroxide ratios between 0.50 and 1.00. The final equation, shown in Eq. (1), is not only a theoretical tool but also a practical instrument for engineers and researchers striving to optimize the use of geopolymer concrete in modern infrastructure. This work underscores the potential of GPC to serve as a durable, high-performance, and environmentally sustainable building material.

$$\frac{f}{f_O} = \frac{1.2810\left(\dfrac{\varepsilon}{\varepsilon_O}\right) - 1.2068\left(\dfrac{\varepsilon}{\varepsilon_O}\right)^2}{1 - 0.719\left(\dfrac{\varepsilon}{\varepsilon_O}\right) - 0.2068\left(\dfrac{\varepsilon}{\varepsilon_O}\right)^2} \quad (1)$$

| Mixed design | Flow test (cm) | Curing (Day) | Curing temp. (ºC) | Maximum stress (ksc) | Stain at Max. stress (m/m) | Elastic modulus (ksc) x $10^5$ |
|---|---|---|---|---|---|---|
| G0.50 | 50.3 | 2 | 65 | 474.87 | - | - |
| | | 54 | 35.2 | 530.74 | 0.0022 | 2.81 |
| G0.75 | 50.0 | 2 | 65 | 483.86 | - | - |
| | | 50 | 35 | 535.41 | 0.0022 | 3.01 |
| G0.85 | 45.2 | 2 | 65 | 516.34 | - | - |
| | | 44 | 30.6 | 631.61 | 0.0023 | 2.71 |
| G1.00 | 42.8 | 2 | 65 | 492.16 | - | - |
| | | 58 | 30.8 | 551.76 | 0.0023 | 2.70 |

Table 3. The evaluation of parameters based on the relationships of previous researches

| Previous work | Equation | Parameters | Coefficient of determination | Sample variance | error |
|---|---|---|---|---|---|
| [17] | $\frac{f}{f_o}=a\left(\frac{\varepsilon}{\varepsilon_o}\right)+b\left(\frac{\varepsilon}{\varepsilon_o}\right)^2+c\left(\frac{\varepsilon}{\varepsilon_o}\right)^3$ | a = 1.2640<br>b = -0.1998<br>c = -0.0437 | 0.9942 | 8.4024 | 0.0229 |
| [18] | $\frac{f}{f_o}=\frac{2a\varepsilon}{\varepsilon_o}-b\left(\frac{2\varepsilon}{\varepsilon_o}\right)^2$ | a = 0.6400<br>b = 0.0640 | 0.9942 | 8.4191 | 0.0229 |
| [19] | $\frac{f}{f_o}=\frac{a\left(\frac{\varepsilon}{\varepsilon_o}\right)+(b-1)\left(\frac{\varepsilon}{\varepsilon_o}\right)^2}{1+(a-2)\left(\frac{\varepsilon}{\varepsilon_o}\right)+b\left(\frac{\varepsilon}{\varepsilon_o}\right)^2}$ | a = 1.2810<br>b = -0.2068 | 0.9942 | 8.3107 | 0.0228 |
| [20] | $\frac{f}{f_o}=a\left(\frac{\varepsilon}{\varepsilon_o}\right)+(3-2a)\left(\frac{\varepsilon}{\varepsilon_o}\right)^2+(a-2)\left(\frac{\varepsilon}{\varepsilon_o}\right)^3$ | a = 0.7964 | 0.9783 | 31.1995 | 0.0441 |

## 7. CONCLUSIONS

This research study examined the stress-strain relationship of geopolymer concrete (GPC) produced using fly ash sourced from Thailand's Mae Moh Power Plant. The GPC was initiated using a sodium hydroxide solution, and four specific ratios of sodium silicate to sodium hydroxide were analyzed to assess their impact on the mechanical qualities of the concrete. The compressive strength of short-column specimens was evaluated in accordance with the ASTM C39 standard. From the experimental data and analysis, the subsequent conclusions may be derived:

1. A strong correlation was established between the sodium silicate to sodium hydroxide ratio and the workability and compressive strength of the GPC. It was observed that an increase in the ratio of sodium silicate to sodium hydroxide resulted in a decrease in flow values. The reduction in flow signifies that elevated sodium silicate levels led to enhanced viscosity, thereby diminishing the mixture's workability. This indicates that mix ratios must be meticulously tuned based on the required workability and performance of the GPC in actual applications.

2. The curing conditions significantly influenced the compressive strength of the GPC samples. Specimens treated at ambient temperature exhibited a compressive strength enhancement of roughly 10% to 20% relative to those cured in an oven at 65°C. The observed rise across all solution mix proportions indicates that extended curing at ambient temperatures results in a more thorough polymerization process. This improved polymerization probably aids in forming a denser and more resilient microstructure. The GPC with a sodium silicate to sodium hydroxide ratio of 0.85 had the greatest compressive strength among the evaluated mix ratios. This outcome indicates that this ratio may signify the ideal combination for attaining enhanced mechanical characteristics in GPC, especially when cured at ambient temperatures.

3. The stress-strain study demonstrated a uniform strain at the highest stress point across all tested ratios, which varied between 0.0022 and 0.0023. This consistency underscores the consistent performance of GPC under compressive pressures, further validating its promise as a robust and trustworthy building material. A comprehensive comparison of the stress-strain models from prior studies revealed that the model established by Cui et al. (2013) yielded the most accurate match for the experimental data derived from the GPC samples analyzed in this work. This model provides a dependable framework for forecasting the stress-strain behavior of GPC, crucial for its application in structural design and analysis.

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