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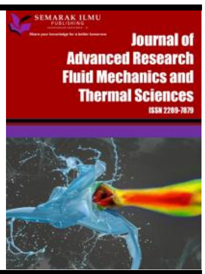

Optimal Curing Temperature for Determination of Compressive Strength of Geopolymer Concrete via Artificial Neural Network (ANN)

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ABSTRACT

Geopolymer concrete offers a promising alternative to traditional Portland cement concrete, exhibiting comparable mechanical and durability performance while reducing environmental impacts. However, achieving desirable properties in geopolymer concretes through heat curing remains challenging. This study proposes the use of an unsupervised Artificial Neural Network (ANN): Self-Organizing Map (SOM) to determine the optimal curing temperature of geopolymer concrete based on experimental datasets. The novelty of this study lies in utilizing SOM for clustering and pattern recognition to establish the relationship between curing temperatures and compressive strength, providing a novel data-driven methodology for enhancing material performance. Data on compressive strength at different curing temperatures were collected and used to train and validate SOM models. Fly ash based geopolymer concretes of size 100mm^3 cubes were prepared in two sets of activators; sodium hydroxide (NaOH) and a combination of sodium silicate (Na2SiO¬3) with NaOH. These samples underwent curing under three conditions: ambient, 60° and 80° for 28 days. Clustering analysis generated by the SOM model provides valuable insights into the relationship between curing conditions, activator dosages, and compressive strength. Consequently, a cluster of mix proportion was developed, enabling the selection of specific curing conditions that result in targeted compressive strength. The results show that curing temperatures of 80°C offers optimal compressive strength ranging from 27MPa to 34MPa. This method introduces a novel "cluster mix proportion" for selecting curing parameters and demonstrates the potential of machine learning in advancing sustainable construction materials. The approach provides a distinct advantage by reducing reliance on trial-and-error methods, saving time and resources, and establishing a foundation for further exploration of data-driven techniques in cement and concrete research.

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1. Introduction

Construction industry is a major contributor to greenhouse gas emissions, which play a significant role in climate warnings. Ordinary Portland Cement (OPC), commonly used in construction, is responsible for substantial CO_2 emissions with a 7% contribution [1,2]. To address this issue, eco-friendly alternatives such as fly ash, ground granulated blast furnace slag (GGBS), and metakaolin are being explored as substitutes for cement. These alternative materials not only reduce the carbon footprint of construction but also offer promising properties for sustainable development [3]. Geopolymer binders, which are used as alternatives to cement, are produced by reacting with aluminosilicate materials, such as fly ash, metakaolin, and GGBS. Among these, fly-ash based geopolymers exhibit high strength properties [4,5]. The alkaline solutions commonly employed in geopolymer production are sodium hydroxide (NaOH), sodium silicate (Na_2SiO_3) and potassium hydroxide (KOH). The geopolymerization process involves several chemical transformations—dissolution, ion exchange, gel formation, and polymerization—resulting in materials with desirable strength and durability properties as described by Singh and Singh [6]; the first stage involves the dissolution of aluminosilicate atoms from a solid precursor in an alkaline environment. The second stage is the rearrangement and exchange of dissolved ions between the aluminosilicate source and the activator solution [7]. In the third stage, the rearrangement and exchanging of ions results in the formation of two types of gel: calcium aluminate silicate hydrate from high calcium precursor and sodium aluminate silicate hydrate from low calcium precursor. Finally, in the fourth stage, the monomer gels combine to form polymers through polycondensation, solidifying, and hardening process to develop strength. In addition, higher proportions of alumina (Al) and silica (Si) present in alkali activated materials generally result in higher compressive strength [8-10].

Mechanical properties of geopolymer concrete are greatly influenced by its mix design, and there are certain factors that hinder the widespread use and acceptance of geopolymers. These factors include the variability in properties of the alkali-activated material and high- temperature curing conditions, which have been identified in studies by Hassan *et al.,* [11] and Siciliano *et al.,* [12]. Curing regime and temperature also significantly influence the strength development of geopolymer concrete [13]. Generally, higher curing temperatures improve compressive strength, but excessive temperature can lead to strength degradation due to moisture loss [14,15]. Curing involves the formation of sodium alumina silicate hydrate (N-A-S-H) gel, which contributes to the material’s strength. Thus, precise control of the curing temperature is needed to achieve the optimal strength, which can vary depending on the specific conditions and combination of the geopolymer concrete mix design [16].

Artificial intelligence (AI) techniques have been widely implemented in civil engineering applications from prediction of mechanical properties to monitoring of infrastructures [17,18]. AI has shown excellent capability in tackling complex engineering problems. Recently, many researchers have developed interest in utilizing ANN to predict the compressive strength of geopolymer concrete, which proves that it is very popular in the civil engineering field for predicting the mechanical properties of concrete [19-21]. AI-driven approaches in concrete research could also enable the optimization of mix designs, potentially reducing material waste and energy consumption in the production process. Furthermore, these techniques may facilitate the development of novel concrete formulations with enhanced durability and performance characteristics, thereby addressing the growing need for sustainable construction materials in the face of global environmental challenges. The integration of AI into concrete technology could also lead to more precise quality control measures, allowing for real-time monitoring and adjustments during construction, ultimately resulting in safer and more reliable structures [22].