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Compressive strength of geopolymer concrete composites: a systematic comprehensive review, analysis and modeling

Hemn Unis Ahmed[a,b], Ahmed S. Mohammed[a], Shaker M. A. Qaidi[c], Rabar H. Faraj[d], Nadhim Hamah Sor[e] and Azad A. Mohammed[a]

[a]Department of Civil Engineering, College of Engineering, University of Sulaimani, Sulaimani, Iraq; [b]Department of Civil Engineering, Komar University of Science and Technology, Sulaimani, Iraq; [c]Department of Civil Engineering, College of Engineering, University of Duhok, Duhok, Iraq; [d]Department of Civil Engineering, University of Halabja, Halabja, Iraq; [e]Department of Civil Engineering, University of Garmian, Kalar, Iraq

ABSTRACT

The desire to make the concrete industry more environmentally friendly has existed for a long time. Geopolymer concrete, which uses industrial or agricultural by-product ashes as the primary source of binder materials instead of Portland cement, has emerged as a viable building material due to the environmental concerns associated with cement production. One of the most important mechanical parameters for all types of concrete composites, including geopolymer concrete, is compressive strength. This parameter is influenced by a variety of factors, including the alkaline solution to binder ratio, the type and amount of binder, the chemical composition of the binder materials, the amount of aggregate present, the type and amount of alkaline solutions, the ratio of alkaline liquid to binder materials, the curing regime, and the age of the specimens. In this context, a detailed systematic assessment was conducted to demonstrate the effect of these various parameters on the compressive strength of fly ash-based geopolymer concrete (FA-GPC). In addition, multi-scale models such as artificial neural networks, M5P-tree, linear regression, and multi-logistic regression models were developed to predict the compressive strength of FA-GPC composites. Results show that the curing temperature (between 60 °C to 90 °C), sodium silicate to sodium hydroxide ratio (between 1.5 to 2.5), and the alkaline solution to the binder ratio (between 0.35 to 0.5) are those parameters that govern the compressive strength of the FA-GPC. Furthermore, based on the statistical assessment tools, the ANN model has better performance for predicting the compressive strength of FA-GPC than the other developed models as it has the highest value of the coefficient of determination (0.96), lower values of the root mean squared error (3.33), mean absolute error (2.58), objective function value (2.91), and scatter index (0.109).

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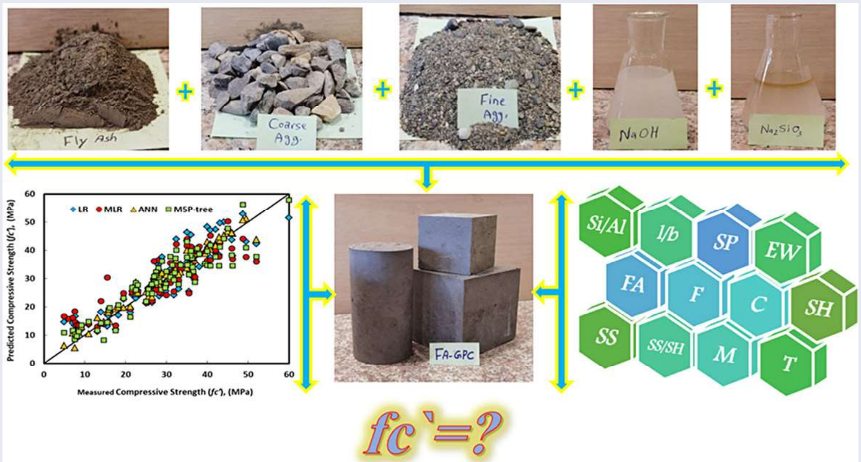
CONTACT Hemn Unis Ahmed hemn.ahmed@univsul.edu.iq; hemnunis@yahoo.com Department of Civil Engineering, College of Engineering, University of Sulaimani, Sulaimani, Iraq.

GRAPHICAL ABSTRACT



1. Introduction

A better understanding of the carbon footprint associated with the use of cement in construction has resulted in extensive research into alternative binder systems, such as geopolymers and alkali-activated binders, over the last two decades (Duxson et al., 2007). These alternative binders are frequently industrial byproducts rich in aluminosilicates that exhibit cement-like binding properties in the presence of aqueous alkali-metal solutions, promoting the use of materials in a more sustainable manner. The amorphous aluminosilicate species dissolves and condenses rapidly in an alkaline environment, forming large networks of polymeric gels (Nawaz et al., 2020). Geopolymers are a novel type of binder used in cement and concrete composites. They are formed when aluminosilicate material reacts with alkaline solutions (Davidovits, 1991). Instead of metakaolin as the primary binding material in concrete, slag and fly ash have emerged as popular source materials for geopolymers due to their high silica and alumina contents and abundance in landfill sites (Olivia & Nikraz, 2012). Fly ash is a heterogeneous material with a variable chemical composition that can have an impact on the final geopolymer product. Because high calcium poses the risk of fast setting, low calcium fly ash is preferred. The composition of the raw materials, the concentrations of alkaline solutions used, and the curing method are the main parameters influencing the fly ash geopolymer mixtures (Olivia & Nikraz, 2012). Alkali activators are mixtures of potassium silicate and potassium hydroxide, or sodium silicate and sodium hydroxide; however, the most commonly used alkaline activator is a combination of sodium silicate and sodium hydroxide (Sharif, 2021). The geopolymer concrete comprises aluminosilicate source binder materials, fine and coarse aggregates, alkaline solutions, and water in various proportions. Combined with the polymerization process, these ingredients produce solid concrete that is nearly identical to conventional concrete (Ahmed et al., 2022). Geopolymer is fundamentally different from traditional concrete, which uses hydraulic cement as a binder. As a binding medium, an alkali-activated mineral admixture holds an inert aggregate together to form a compact mass (Mohammed et al., 2021). Geopolymers are materials that are primarily composed of amorphous sodium aluminium silicate hydrate. They are mostly solids formed by the reaction of an alumino-silicate powder and an alkali sol. Furthermore, the geopolymer network is made up of AlO_4 and SiO_4 tetrahedra linked by oxygen atoms; the negative charge is balanced by positively charged ions (e.g., Ca^{2+}, Na+, K^+, and Li^+) present in the cavity framework (Qaidi et al., 2022).

The hardening of geopolymer materials is accomplished by breaking and recombining the Si-O and Al-O bonds in the presence of an alkaline activator. The reaction process consists primarily of the four steps as follows. (i) Dissolution: The alkali activator breaks the Si-O and Al-O bonds in the aluminosilicate materials, releasing the Si-O and Al-O tetrahedral monomers. (ii) Diffusion: The dissolved tetrahedral monomers Si-O and Al-O diffuse into the reaction system. According to the principle of chemical equilibrium, the concentrations of silicon and aluminium on the particle surface decrease due to