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An Analytical Research on Synergistic Effects of Copper Slag and Rice Husk Ash in Geopolymer Concrete

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Abstract: *This study investigated the possibility of fly ash (FA) and rice husk ash (RHA) as supplemental cementitious materials for partially substituting cement in the manufacturing of concrete, with the aim of lowering the CO_2 associated with the cement industry. The purpose of the study was to examine the combined impact on the fresh, hardened, non-destructive, and microscopic properties of concrete of a cement-based mixture including RHA and FA in varying amounts. Together with the experimental work, this study effectively used three different types of algorithms ANN (Analytical Neural Network), XGB (Extreme Gradient Boosting), and GBM (Gradient Boosting Model) to apply machine learning to forecast the compressive strength of RHA-FA concrete. Environmental conservation is currently a goal that everyone aspires to accomplish. Sustainable development compliant alternative material advancements have been affected by the building sector. In this article, 20% fly ash and 80% blast furnace slag were combined to create reinforced concrete. Because they offer the lowest porosity in the cementitious matrix, these concentrations were selected. The activator was rice husk ash. Fibres from Guadua angustifolia were utilised to assess the concrete's mechanical performance. X-ray fluorescence was utilised to ascertain the raw materials composition, AFM was used to ascertain the fibres' microstructure, and SEM was employed to ascertain the surface properties of guadua fibres and concrete mixtures.*

Keywords: Synergistic Effects, Copper Slag, Rice Husk Ash, Geopolymer Concrete, CO_2, XGB

I. INTRODUCTION

Since it has both mechanical and physical qualities, concrete is the most commonly utilised material in building. Although it lacks tensile strength, it has outstanding compressive strength. In constructions that are subjected to tensile and bending forces, reinforced concrete is typically utilised in conjunction with steel rods. By enhancing the system's behaviour under tensile loads, these reinforcements lessen the likelihood that the structures will fail when subjected to wind, temperature cycles, and traffic. But there is no longer a connection between steel and concrete when steel is subjected to corrosive environments. Because bond failure reduces the steel's cross-sectional area, it compromises the integrity of the structure. It has been suggested that natural and synthetic polymeric fibres be added to concrete to increase its resilience. The biggest ecological issue facing Portland-style High CO2 emissions are associated with concrete. To address this, it has been suggested to develop ecological buildings with minimal energy usage that are resilient and long-lasting. Thus, research on the synthesis of geopolymers from industrial by-products, including steel, thermoelectric, and rice production, has been conducted during the past 20 years. Fly ash (FA), ground granulated blast furnace slag (GGBFS), and silica fume (SF) are the most widely used substitutes for cement. One byproduct of coal-fired power plants is fly ash. Low-calcium fly ash (ASTM C618 Class F, CaO < 10%) and high-calcium fly ash (ASTM C618 Class C, CaO > 10%) are the two general classifications of fly ash. The low-calcium FA is thought to be a typical pozzolan, composed mostly of iron oxide, silicon oxide, and aluminium oxide. Because of its pozzolanic characteristics and the necessity for potlandite, which is created during clinker hydration, for its particles to react, this kind of FA requires calcium hydroxide (Ca(OH)2). By adding fly ash, concrete becomes more durable, stronger, and requires less heat to hydrate. by long-term filler and pozzolanic effects. Granulated blast furnace slag that has been ground is a byproduct of the iron-making sector. CaO (30–35%), SiO2 (28–38%), Al2O3 (8–24%), and Mg (1–18%) make up the majority of GGBFS. Slag possesses hydraulic qualities. As a result, it would begin to respond as soon as it set. The presence of slag lowers the heat of hydration and causes the microstructure of concrete and mortars to be substantially refined. Consequently, the addition of FA and GGBFS decreases concrete's permeability and increases its resistance to harsh conditions. To achieve the necessary levels of strength and durability, blended concretes with different combinations of additions and replacement ingredients are being developed in binary, ternary, and quaternary forms. An intriguing substitute is offered by using blast furnace slag and fly ash. In recent decades, some researchers have experimented with combining these two byproducts with Portland cement. According to Shenchun Xu et al, a decrease in compressive strength of roughly 14% at 28 days was implied by raising GGBFS (from 30% to 50%) while maintaining a 10% FA content. At the same age, a 10% increase in FA quantity (to 20%) and a 30% GGBFS content similarly resulted in a 12% decrease in compressive strength. The sample that had 10% fly ash and 30% slag had the highest compressive strength it even outperformed the reference cement's. The ternary concrete's long-lasting qualities, which include fly ash and Slag from blast furnaces was also assessed by submerging them in a 2% H_2SO_4 solution for a year. With little weight loss and a slower rate of compressive strength degradation, the ternary concrete consisting of 25% FA and 15% GGBFS performed better in terms of resistance to sulphate attack. Using two distinct kinds of cement, Fernandez et al. investigated the effects of these two by-products on the mechanical and physical characteristics of ternary binders. Portland cement with a high alkali and high C_3A content exhibited a considerable reduction in the first heat of hydration and a delay in the setting time. On the other hand, they were marginally behind schedule in the Portland cement with less alkali and C_3A.

II. RELEVANCE OF RESEARCH

This research is noteworthy from two perspectives. The expense comes in second, and the environment comes first. Cement is essential to the creation of mortar and concrete from an environmental standpoint. The production of cement releases large amounts of CO_2, which has significantly increased pollution. In order to create sustainable cement mortar, concrete, and bricks, researchers used industrial and agricultural wastes like fly ash (FA) and rice husk ash (RHA) to partially or completely replace OPC in the building industry. In poor countries, rice paddy hulls are often a crop residue from a financial standpoint. It can be gathered from rural areas and burned using a regulated combustion process. Fly ash is also utilised as a low-cost energy source plus a substitute for Portland cement. Numerous studies have examined the qualities of using rice husk and fly ash to produce concrete and examined the effects on properties, strength, and other aspects. On the other hand, this study will offer more thorough details on the synergistic effects of fly ash and rice husk ash with reference to fresh characteristics, microstructure, strength analysis, and non-destructive tests. Furthermore, this is a novel way to forecast the compressive strength of RHA-FA concrete: creating an effective machine learning model. As a result, this research will also help in the creation of an effective predictive model that uses SHAP and PDP studies to determine the ideal range of mixtures for the contributions of each parameter.

III. GEOPOLYMERIZATION PROCESS AND COMPONENTS OF GEOPOLYMERS

The methods used in the geopolymerization process and the end products have a significant impact on the mechanical properties of geopolymers. The three steps of the geopolymerization process are (1) dissolution, (2) orientation, and (3) polycondensation, in that order, according to John et al. Alkaline activation is an essential step in the dissolving process. The production of an alkaline solution with Si–O–Al–O bonds is the result of the reaction between the silicates and alumina that were initially present in the raw materials known as precursors (such as fly ash, blast furnace slag, etc.) and an alkali component mixture (such as NaOH, Na_2SiO_3, etc.). A schematic depiction of the metakaolin particles interacting with the alkali activator was presented by Zhou et al. The function of Na^+ is to balance the negative charge brought about by the alumina and silica monomers present. The sides of the metakaolin particles dissolve first, as seen in Figure 1. After that, a process known as solvation causes Na^+ and OH^- ions to target the particles' centre.

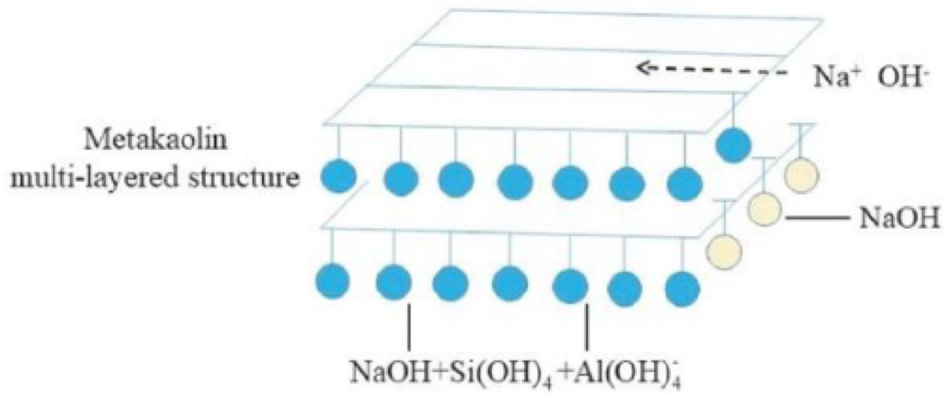

Figure 1- Schematic diagram of metakaolin particles subjected to chemical action

In order to hasten the dissolution of Si4+ and Al3+ from precursor and generate sodium alumina-silicate hydrate (N-A-S-H) and calcium alumina-silicate hydrate (C-A-S-H) gels, Zailani et al. stressed that the alkaline activator should have a high concentration. Fly ash is an example of a precursor, and equation shows how the silicates and aluminates in it react with the NaOH solution.

$$(SiO, Al\ O \text{ from fly ash}) + 2NaOH + 5H_2O \rightarrow Si(OH) + 2Al(OH)_4^- + 2Na^+.$$

$$Na^+ + Ca^{2+} + Si(OH)_4^- + 2Al(OH)_4^- \rightarrow (Na, Ca)Al_2Si_4O_{10}(OH)_2 \text{ (beidellite)}$$

$$OFeOH \cdot H_2O + Si(OH)_4 \rightarrow Fe(OH)_3 \cdot SiO_2 \text{ (fayalite)} + 2H_2O$$

SiO_4 and AlO_4 coupled together with cations like Na^+ and K^+ strewn throughout to counteract the polymer's negative charge are also known to be present in geopolymers. During

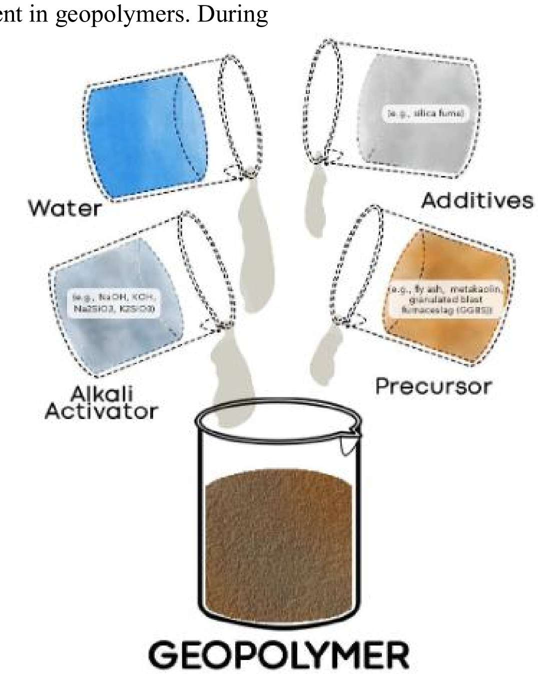

Figure 2- Components of geopolymers

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geopolymerization, other products are also produced. Ferrosialate gel can form in the precursor when Fe_2O_3 is present, and this gel can reinforce the final material. Fayalite (Fe_2SiO_4) and beidellite ($(Na,Ca)\ Al_2Si_4O_{10}(OH)_2$), which are created by dissolving other precursor components and employing an adequate concentration of alkali activator, are additional results of geopolymerization. The reactions leading to the creation of beidellite and fayalite are depicted in equations.

IV. RESEARCH METHODOLOGY

(i) Tensile Strength and Flexural Testing- Following ASTM-C-496 guidelines, specimens measuring 15 x 30 cm in cylinders had their tensile strength measured at 28 and 90 days using the tensile splitting method. The load was delivered at a speed of 1290 N/s using a hydraulic press that was automated and managed until failure. Furthermore, prismatic specimens with dimensions of 150 x 150 x 600 mm were bent 90 days after the ASTM-C-78 process. A 100 kN maximum capacity servo-controlled load frame was used to apply the load. The specimen's middle third or central third span was unaffected by the two continuous point loads applied at a load rate of 130 N/s.

(ii) Techniques- The sizes and ratios of fine and coarse particles used in concrete mixes were established by the ASTM C33 standard. Fourier Transform Infrared Spectroscopy (FTIR) was used to characterise the fibres of Guadua angustifolia and the concrete mixtures. An FTIR spectrometer (IS20, Thermo Fisher Scientific Co.) was connected to a heat analyser. For FTIR spectrometry, the data capture frequency was 5 s, with a range of 400 cm^{-1}–4000 cm^{-1}, and a spectral resolution of 1 cm^{-1}. Using a PANalytical XPert PRO MRD device, X-ray diffraction (XRD) was used to determine the crystalline character. This apparatus consists of a proportional X-ray counter, a goniometer with standard geometry resolution (θ–2θ), a copper tube (k = 1.54060 Å), and a minimum step size of 0.002.

(iii) Alkali Activation of the Mixtures- Different concentrations of blast furnace slag weight and class F fly ash were used to create concrete mixes. Rice husk ash/sodium silicate and sodium hydroxide were used to activate the combinations. The research of Criado et al. served as the basis for assigning this mix of activators. The liquid/solid (L/S) ratios of the concretes were computed using the activators and raw materials' chemical compositions as well as the mixing ratios. The combinations were made up of 80% steel slag and 20% fly ash, and they were further activated by mixing 15% rice husk ash/sodium silicate with 85% NaOH 14M. The Guadua angustifolia fibres were manually added to the aggregates in a proportion of 3% to the mixture's overall weight.

V. CONCLUSION

This study looked at how different ratios of RHA and FA in cement-based mixtures affected the mechanical, microscopic, and fresh properties of concrete. In addition, three machine learning models were used to determine how accurate the data from the experiment and predictions were. Six concrete mixtures varying in RHA and FA content from 5% to 25% were assessed. The following results were obtained using the ML models and empirically discovered rheological, mechanical, and microscopic features.

Both RHA and FA showed higher silica contents in the XRF examination, suggesting that they might be utilised as a partial replacement for cement. In the long run, SiO_2 gave concrete more strength even if CaO was relatively low in RHA.

larger RHA concentrations, as opposed to larger FA contents, tended to decrease slump flow and other fresh qualities of the RHA-FA concrete. This was explained by the larger surface area of the RHA particles.

Although both compressive and tensile strength findings declined as RHA replacement increased and FA replacement decreased, the hardened properties of RHA-FA concrete with an overall 30% cement substitution demonstrated higher performance. When comparing the 10RHA-20FA mix to all other mixes with their prior mix, it showed the least percentage drop in compressive strength.

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