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Analysis of using Rice Husk Ash and Copper Slag in Geopolymer Concrete: A Comprehensive Review

Lomas Bhargav[1] **and Raushan Kumar**[2]
Research Scholar, Department of Civil Engineering[1]
Assistant Professor, Department of Civil Engineering[2]
Eklavya University, Damoh M.P, India

Abstract*: This Paper is looking for copper slag substitutes for traditional components used in concrete manufacture. This work attempts to evaluate their effects on mechanical qualities, microstructural features, durability, sustainability, and financial viability. Along with indicators of durability including acid resistance and chloride penetration, extensive testing was conducted to evaluate how well the many concrete mixes made with varying copper slag concentrations performed. The findings indicate that adding up to 40% more copper slag to fine aggregate will increase the material's early-age strength and resistance to acid deposition and chloride intrusion. Still, too much slag and RHA content increases the material's porosity, therefore compromising its strength and durability.*

Keywords: Copper slag, rice husk ash, concrete, sustainable construction, mechanical properties, durability, economic analysis.

I. INTRODUCTION

Geopolymer formulations reduce energy consumption and carbon dioxide emissions by about 80% when compared to standard concrete compositions. Interestingly, they use an abundance of industrial leftovers as raw materials instead of gathering and processing limestone and other natural resources. Given these qualities, geopolymer concrete has enormous potential as an affordable and environmentally friendly way to satisfy the demands of the construction sector on behalf of a growing global population

Joseph Davidovits became the most significant figure in the advancement of geopolymer technology during the 1970s. According to Davidovits' theory, binders may be produced when polysialates are activated in an alkaline environment and form networks that resemble chains. The older inorganic cements that were in use at the time served as the basis for this concept. Thus, the composition of these mineral polymers was referred to as "geopolymers".

The principal aim at the outset of the development process was to convert waste from manufacturers and mines into fireand acid-resistant ceramic materials. In order to use geopolymers researchers started looking into the feasibility of synthesising geopolymers from aluminosilicate source materials in the 1990s. As a result, the precast concrete and building materials industries saw the creation of new uses.

II. GEOPOLYMER SYNTHESIS

The aluminosilicate precursors described above providing the sources of Si and Al can react with alkaline solutions to produce geopolymer binders. While the specific aluminosilicates differ in structure and composition, they all share several essential traits that enable the geopolymerization reaction: (1) the presence of reactive Si-O/Al-O bonds, (2) availability of Al3+ and Si4+ sites, and (3) largely amorphous or vitreous phase.

The chemical reaction proceeds as follows. The aluminosilicate reacts with a highly alkaline hydroxide, silicate, carbonate or sulfate activator solution. As more Al and Si species accumulate from ongoing dissolution, the supersaturation point is reached causing the dissolved ions to rapidly condense according to the general formula:

$Mn\{-(SiO2)z\text{-}AlO2\}n \,.\, wH2O$

where Mn+ denotes the charge balancing alkali cation (Na+, K+), n is the degree of polymerization, z is 1, 2, or 3, and w denotes the water contained within the gel structure. This condensed gel phase surrounds and binds the undissolved or partially dissolved aluminosilicate particles into the hardened geopolymer matrix.

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The physical and mechanical properties of the resulting geopolymer depend on multiple factors:
(1) Chemical composition Overall Si:Al ratio, type of alkali cation (Na vs K), alkali content.
(2) Aluminosilicate reactivity Amorphicity/crystallinity, particle size distribution, specific surface area.
(3) Activator solution Type (combination of sodium/potassium hydroxide, silicate, carbonate, sulfate solution), concentration, Ms modulus.
(4) Curing conditions Temperature, humidity, time under heat.
By tuning these parameters, the molecular structure and morphology of the geopolymer binder can be controlled to achieve desired qualities such as mechanical strength, setting time, porosity, durability, etc. tailored toward specific usages.

III. EFFECTS ON FRESH CONCRETE PROPERTIES

a) Workability: Metakaolin's large surface area raises the water content of the concrete mixture. If ignored, this could make mix designs less feasible. Workability may be improved by superplasticizers.
b) Setting time: Metakaolin expedites the setting of concrete, particularly at higher replacement levels. This works well for concrete in cold weather, but in warmer weather, it might need to be modified.
c) Bleeding and segregation: The wide surface area and small particle size of metakaolin help hold water in fresh concrete, preventing bleeding and segregation.

Modifications to Hardened Concrete Properties:

a) Compressive strength: Especially in the early stages, metakaolin improves the compressive strength of concrete. Its pores are more refined and thick because of its high pozzolanic reactivity and filler action.
b) Durability: Concrete containing metakaolin generally exhibits improved durability characteristics, including:
Reduced permeability
Enhanced resistance to chloride ion penetration
Improved sulfate resistance
Mitigation of alkali-silica reaction (ASR)
c) Shrinkage: Metakaolin can help reduce drying shrinkage in concrete, leading to improved dimensional stability and reduced cracking potential.
d) Color: The use of metakaolin can result in a whiter or lighter-colored concrete, which may be desirable for architectural applications.

Sustainability Aspects:

Metakaolin offers several sustainability benefits when used as a partial cement replacement:
a) Reduced CO2 emissions: The production of metakaolin generates significantly less CO2 compared to Portland cement production, as it requires lower calcination temperatures and does not involve carbonate decomposition.
b) Energy efficiency: The energy required to produce metakaolin is generally lower than that needed for cement production.
c) Resource conservation: Metakaolin production utilizes naturally occurring kaolin clay, which is abundant in many parts of the world.
4. The common sources of aluminosilicate and the key characteristics that make them suitable as precursors for geopolymer concrete are enumerated in the following table.

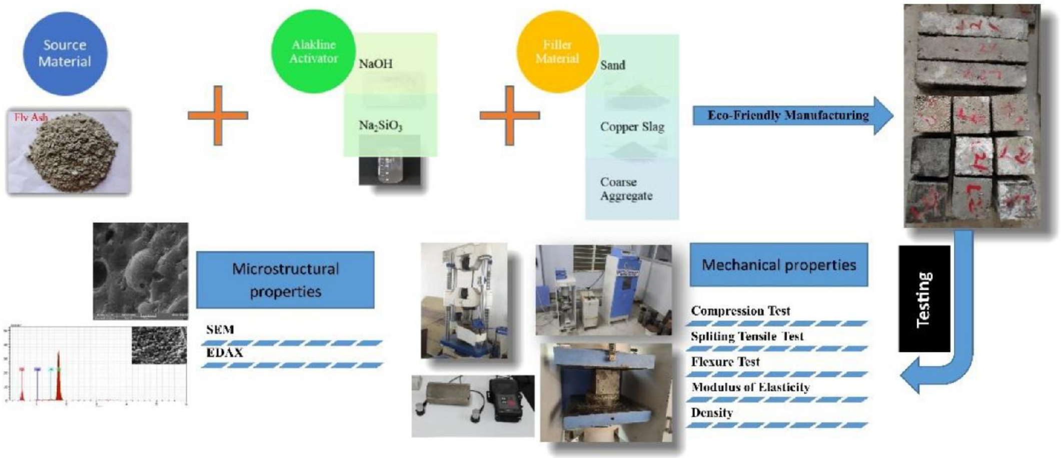
Table 1.1 Properties of common alumino-silicate source materials

Source Material	Si/Al ratio	Reactivity	Availability
Metakaolin	1-2	High	Limited quantities
Fly ash	1.5-4	Medium/low	Abundant by-product

Blast furnace slag	0.8-1.5	Slow	Plentiful industry waste
Rice husk ash	0.15–5	Fast/medium	Agricultural waste product

Alkaline Inducers An aqueous phase with dissolved alumino-silicate species and cation donor elements is produced by alkaline activators. Si and Al atoms from the source particles dissolve in the high pH solution to generate precursor ions. After that, the species proceed through reorganisation and condensation to form the solid geopolymer gel phase.

The most often used alkaline solutions combine. Typical activator combinations and concentrations are shown in Table 2. Mixture design is heavily influenced by the selection and proportions of these alkaline compounds, which control the formation of the microstructure, dissolution kinetics, and geopolymerization reaction processes.



V. RICE HUSK ASH

Rice husk ash (RHA) is the ash produced from burning rice husk as a fuel for processing paddy rice to obtain rice grains. About 20 kg RHA is produced from burning 100 kg rice husk. This RHA poses safe disposal challenges owing to its high silica content. However, the high reactivity and amorphous silica content offers unique benefits for application as a supplementary cementitious material.

Production and Characteristics

RHA characteristics vary depending on burn temperature, duration as well as efficiency of combustion. Typically, RHA is greyish white consisting of non-crystalline silicon dioxide with high specific surface area and high silica content of over 80%. It also contains some impurities like unburnt carbon. The reactivity of RHA can be improved by grinding as it enhances particle size, porosity and surface area. Mitigation of high carbon content and cellular structure of RHA are current improvement areas throughsieving, oxidation or acid leaching methods.

Potential Applications

The pozzolanic property of RHA is useful for blending with cement and concrete as a partial replacement for conventional Portland cement. As a result, this simultaneously reduces the environmental effects associated with cement manufacture and enhances the qualities of strength and durability. RHA can display pozzolanic interaction with portlandite. RHA dosages are typically limited to 20–30% replacement, which is one of the highest strengths that may be achieved. Furthermore, the application of RHA helps to address problems related to waste management and pollution of the environment produced by rice husk ash.

Using industrial by-products like copper slag and rice husk ash as building materials can help to expedite the conversion of wastes into resources that are advantageous to the circular economy. By using these materials as replacements or supplementary materials, issues like the buildup of solid waste, formation of pollutants during production processes can be resolved. To guarantee that their large-scale application in the building industry, which accounts for the yearly need for billions of tonnes of materials, is successful, a number of challenges must be overcome. These challenges include end-users' inadequate understanding, incomplete technical standards, and diversity in quality.

The relevance of this scientific work is explained as follows:

The biggest problem it resolves is the substantial carbon emissions generated by the cement industry and the over-reliance of concrete on conventional Portland cement. Reusing waste materials from other sectors in place of some of the cement in concrete is a creative step towards creating carbon-neutral concrete.

This research makes it simpler to dispose of waste by-products in a safe way by incorporating them into geopolymer concrete, even if two of them are environmentally problematic. This reduces the costs associated with landfilling copper slag and rice husk ash and offsets the rising cost of cement. The economy benefits from this.

In this study, a technological first, the combined effects of blended rice husk ash and copper slag in geopolymer systems are being studied for the first time. The utilisation of fifty percent copper slag and twenty percent rice husk ash has the potential to set a benchmark for the maximum constraints of inclusion of these waste materials in the construction of sustainable concrete.

The examination of geopolymer concrete's workability, mechanical characteristics, and durability performance provides groundbreaking insights into how industrial and agricultural waste items impact the material's fresh and hardened features. The scientific investigation of these traits yielded this knowledge.

The data gathered forms the foundation for the development of structural geopolymer concrete including rice husk ash and copper slag. By exploiting readily available local waste streams, this concrete aims to promote sustainable construction on a worldwide scale.

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