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PERFORMANCE EVALUATION OF SUSTAINABLE GEOPOLYMER CONCRETE INCORPORATING COPPER SLAG

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ABSTRACT

This study evaluates the performance of concrete incorporating copper slag as a partial replacement for natural fine aggregate. Copper slag is an industrial by-product generated during the extraction and refining of copper and has significant potential for use as an alternative construction material. The experimental investigation was carried out by replacing natural sand with copper slag at different proportions of 0%, 10%, 20%, 30%, 40%, and 50%. The workability of the concrete mixtures was evaluated using the slump test. The results showed that the slump increased from 22 mm for the control concrete to 44 mm at 40% copper slag replacement, indicating improved workability. At 50% replacement, the slump slightly decreased to 40 mm. The improvement in workability is attributed mainly to the lower water absorption and relatively smooth, glassy surface of copper slag, which provides greater availability of free water within the concrete mix. The results indicate that copper slag can be effectively utilized as a partial replacement for natural sand, with 40% replacement showing the optimum slump value among the mixtures investigated. The utilization of copper slag can also contribute to sustainable concrete production by reducing the consumption of natural fine aggregates and promoting the beneficial reuse of industrial waste.

KEYWORDS: Copper slag; Sustainable concrete; Fine aggregate replacement; Workability; Slump test; Industrial by-product; Natural sand; Concrete mix.

INTRODUCTION

The construction industry is one of the major contributors to the consumption of natural resources and the generation of greenhouse gas emissions. Conventional Portland cement-based concrete requires significant quantities of raw materials and energy, while the production of cement is associated with substantial carbon dioxide emissions. At the same time, the rapid development of infrastructure has increased the demand for concrete and natural aggregates, resulting in the depletion of natural resources. These environmental concerns have encouraged researchers and engineers to develop sustainable and environmentally friendly alternatives to conventional concrete.

Geopolymer concrete (GPC) has emerged as a promising sustainable alternative to ordinary Portland cement concrete. Geopolymer concrete is produced by activating aluminosilicate-rich industrial by-products or supplementary cementitious materials using alkaline solutions. Materials such as fly ash, ground granulated blast furnace slag (GGBS), metakaolin and other industrial residues can be utilized as geopolymer precursors. The geopolymerization process forms a three-dimensional aluminosilicate binder network that can provide desirable mechanical and durability characteristics while reducing the dependence on Portland cement.

In addition to the environmental benefits associated with geopolymer concrete, the utilization of industrial waste materials as aggregates can further enhance its sustainability. Copper slag is a granular industrial by-product generated during the extraction and refining of copper. Large quantities of copper slag are produced worldwide, and improper disposal can create environmental and land-management problems. Copper slag possesses favourable physical and mechanical characteristics, including relatively high density, good hardness, angular particle shape and resistance to abrasion. These properties make copper slag a potential alternative to natural fine aggregate in concrete. The incorporation of copper slag into geopolymer concrete provides an opportunity to simultaneously address two major environmental challenges: the reduction of cement consumption and the beneficial utilization of industrial waste. Replacing a portion of natural fine aggregate with copper slag can reduce the demand for naturally occurring sand and provide a productive application for an industrial by-product. However, the performance of copper slag-based geopolymer concrete depends on several factors, including the percentage of copper slag replacement, type and proportion of geopolymer precursor materials, concentration of alkaline activators, curing conditions, water-to-binder ratio and mix proportions.

The mechanical and durability performance of sustainable geopolymer concrete should therefore be evaluated systematically to determine the optimum incorporation level of copper slag. Important properties such as workability, density, compressive strength, split tensile strength, flexural strength, water absorption and durability characteristics provide an overall assessment of its suitability for structural and infrastructure applications. Excessive replacement of natural aggregate with copper slag may also influence workability and other engineering properties because of differences in particle characteristics and density. Hence, an optimum replacement percentage is necessary to achieve a balance between sustainability and engineering performance.

The present study, entitled. The study contributes to the development of sustainable construction materials by promoting the conversion of industrial waste into useful construction resources. The successful utilization of copper slag in geopolymer concrete can reduce the consumption of natural sand, minimize waste-disposal requirements and reduce dependence on conventional cement-based materials. Therefore, copper slag-based geopolymer concrete has significant potential as an environmentally responsible material for future sustainable construction and ground or structural infrastructure applications.

METHODOLOGY

Improvements have been occurring in concrete technology for the past several years. Uses of supplementary materials for sustainability and revolutionary developments in superplastic sing admixtures have facilitated improvements in the mechanical and durability properties of concrete composites. Over the years, many research works have been done with main aim of achieving high mechanical performance with cementations matrix materials. As a result, a new class of highly resilient concretes, called Reactive Powder Concrete (RPC), with compressive strengths comparable to that of some steels has evolved; they are now labeled and classified as Ultra High Performance Concretes (UHPC). This study adopts an experimental methodology to evaluate the performance of sustainable geopolymer concrete (GPC) incorporating copper slag as a replacement for fine aggregate. Geopolymer concrete mixtures are prepared using aluminosilicate source materials such as fly ash and ground granulated blast furnace slag (GGBS), activated by an alkaline solution consisting of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Copper slag is introduced at different replacement levels of natural sand to determine its influence on concrete performance. The constituent materials are first characterized based on their physical and chemical properties, followed by mix proportioning according to the target strength requirements. Concrete specimens are cast, compacted, and cured under controlled conditions, either at ambient temperature or through heat curing depending on the experimental design.

Mix design

IRC 44: 2008 recommends, minimum M40 grade of concrete (flexural strength 4.5 MPa) for construction of normal concrete pavements. For rural roads minimum M30 grade of concrete (flexural strength 3.8 MPa) is recommended to be used.

Table 1 M40 grade of concrete for materials required 1m.^{3}

Cement	Sand	Aggregate	water
420 kg/m^3	768 kg/m^3	1111 kg/m^3	151 l/m^3

But our work we can used fly ash in place of cement and solution of (Noah + SMS)

Solution calculation

Total molecular weight of NaOH = 23+16+1 = **40gm (Na= 22.99 , O= 15.99, H=1)**

1000ml (1 lit Water) — 40gm (NaOH) — 1Molarity

For 1 Lit water

12.5 M required NaOH = 12.5*40 = 500gm

SMS take 50% total weight of NaOH

Table 2 M40 grade of concrete for materials required 1m^3 for our works.

Fly ash	Copper slag%	Fine Aggregate	Course Aggregate	water
420 kg/m^3	0	768 kg/m^3	1111 kg/m^3	151 l/m^3
420 kg/m^3	10	691.2 kg/m^3	1111 kg/m^3	151 l/m^3
420 kg/m^3	20	614.4 kg/m^3	1111 kg/m^3	151 l/m^3
420 kg/m^3	30	537.6 kg/m^3	1111 kg/m^3	151 l/m^3
420 kg/m^3	40	460.8 kg/m^3	1111 kg/m^3	151 l/m^3
420 kg/m^3	50	384 kg/m^3	1111 kg/m^3	151 l/m^3

RESULT AND DISCUSSION

This chapter discuss the experimental results which are presented. Each of the testing result data plotted in tables and bar charts corresponds to the mean value of test results of concrete specimens in a series. Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete works. Systematic testing of raw materials, fresh concrete and hardened concrete are inseparable part of any quality control programmed for concrete, which helps to achieve higher efficiency of material used and greater assurance of the performance of the concrete with regard to both strength and durability. The test methods should be simple, direct, and convenient to apply.

Slump test

With the addition copper slag, the slump loss with time is directly proportional to increase in the copper slag content due to the introduction of large surface area in the concrete mix by its addition. Although the slump decreases, Slump was maximum for the concrete mixture containing 40% copper slag in place of sand. Slump test values each proposition of copper slag shown in table 4.1

Table 3 Slump Test.

Copper slag %	Slump (in mm)
0	22
10	34
20	36
30	41
40	44
50	40

From the results, the slump value increased from 22 mm at 0% copper slag to 44 mm at 40% copper slag, followed by a slight decrease to 40 mm at 50% replacement. Copper slag generally possesses lower water absorption capacity and a smoother, glassy surface texture compared to natural fine aggregate (sand). Due to these characteristics, more free water remains available in the concrete mix, which improves the mobility of particles and enhances workability. At 10% replacement, the slump increased noticeably from 22 mm to 34 mm, showing that even a small amount of copper slag positively affects flow characteristics.

As the copper slag content increased to 20% and 30%, the slump values further improved to 36 mm and 41 mm, respectively. This gradual increase indicates better lubrication between aggregate particles and reduced internal friction, allowing the concrete to become more workable and easier to compact. The maximum slump of 44 mm at 40% copper slag replacement suggests that this proportion produced the optimum workability among all mixtures tested. At this level, the balance between particle packing and available free water appears most effective, leading to improved consistency. When the copper slag content reached 50%, the slump decreased slightly to 40 mm.

Figure 1 Slump test result graph.

CONCLUSION

The slump test results indicate that the incorporation of copper slag as a partial replacement for natural sand significantly influenced the workability of the concrete. The slump increased from 22 mm for the control mix (0% copper slag) to a maximum value of 44 mm at 40% copper slag replacement, indicating improved workability and consistency. This improvement can be attributed to the lower water absorption and smoother surface texture of copper slag, which increased the availability of free water in the concrete mix and reduced internal friction between aggregate particles.

However, at 50% copper slag replacement, the slump decreased slightly to 40 mm, suggesting that excessive copper slag content may adversely affect the flow characteristics of the mix. Therefore, based on the slump test results, 40% copper slag replacement can be considered the optimum proportion for achieving maximum workability. The results demonstrate that an appropriate proportion of copper slag can improve the fresh properties of concrete while contributing to the sustainable utilization of industrial waste materials.

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