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Behavior of Concrete with Silica Fume and Copper Slag as Partial Replacement of Cement- An Experimental Investigation.

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ABSTRACT—

In the realm of concrete formulation, several critical factors come into play, including workability, strength, durability, cost-effectiveness, and environmental sustainability. Incorporating copper slag as a partial replacement for cement offers a promising approach to both reduce pollution and conserve resources due to its lower cement content. Additionally, a combination of silica fume and copper slag is used to enhance concrete structures. This study focused on optimizing key variables in concrete mix design, such as cement factor, water-to- binder ratio (w/b), copper slag, and silica fume. Experimental research adhering to established standards was conducted to achieve optimal adjustments in these aspects. The study's findings revealed that a mix design combining copper slag and silica fume with appropriate cement factor and w/b ratio values results in concrete that is stronger, more durable, and easier to work with. In the optimized mix design, silica fume and copper slag replaced 10% and 20% of the cement, respectively. This blend offers a practical, robust, cost-effective, and long-lasting solution. The study involved creating beam specimens using M30 grade concrete, with replacements of 10%, 20%, and 30% of both silica fume and copper slag. These beams were tested at the age of 28 days to determine flexural strength and compressive strength using destructive testing equipment..

Keywords— concrete, workability, strength, durability, cost-effectiveness, copper slag.

I. Introduction

Concrete is an immensely popular construction material that finds widespread use across various types of structures. It is created by mixing coarse and fine aggregates, water, cement, and additives in specific proportions. Concrete serves a vast array of construction needs, from basic road and channel linings to intricate architectural structures and dams. With innovations like reinforcement, changes in structural design, and the use of pre-stressing and post-tensioning techniques, concrete has become the fundamental material in construction.

Concrete's popularity stems from its structural robustness and strength. It's utilized in diverse structures due to its capacity to provide the required stability and functionality. The process of determining the appropriate constituents of concrete and their relative proportions to achieve the desired qualities of strength, durability, and functionality while maintaining cost-effectiveness is known as concrete mix design. The compressive strength of hardened concrete is often considered a benchmark for its various properties, influenced by numerous factors.

Ordinary Portland Cement (OPC) is a key ingredient in concrete production and remains irreplaceable in the construction industry. However, concrete production generates significant carbon dioxide emissions, contributing to the greenhouse effect and global warming. This has spurred the search for alternative materials or partial replacements for OPC. Materials like fly ash, ground granulated blast furnace slag, rice husk powder, high-reactive metakaolin, and silica fume are among the pozzolanic materials that can be used as partial replacements for cement. Adding silica fume to concrete brings advantages such as increased strength, durability, and reduced cement production.

Concrete is essentially a composite material where coarse and fine aggregates serve as filler, while cement acts as the binding agent. This composite consists of ingredients like sand, rocks, crushed rocks, or other aggregates held together by a solid paste of hydraulic cement and water. When the components are properly proportioned, they create a pliable mass that can be molded into specific sizes and shapes. As the cement hydrates over time, the concrete hardens into a strong and durable material, making it versatile for various construction purposes.

As construction advancements have expanded, so has the application of concrete. It is a fundamental material used in the construction of various buildings and non-building structures. However, it's crucial to address the environmental impact of concrete production. A significant amount of waste materials, approximately 10-12 million tons, is generated and disposed of. To mitigate this, efforts are being made to replace fine aggregates (cement) with alternative materials like silica fume and copper slag.

When making these substitutions, various properties need to be considered to ensure that the replacements maintain the desired levels of productivity, economy, quality, and environmental sustainability. This can involve replacing cement and aggregates with other cementitious materials or partially substituting aggregates with waste materials.

Recent developments in the field of concrete construction focus on reducing the use of cement. For instance, replacing fine aggregates (sand) with waste materials like wooden powder can decrease carbon dioxide emissions. Utilizing industrial waste materials in concrete production can lead to better-quality concrete. Substituting fine aggregates with waste materials can be beneficial for both construction and the environment, resulting in improvements in properties such as workability, durability, and resistance to various forces.

II. Literature review

Vaičiukynienėa et al. (2012) explored the utilization of thermally activated technogenic silica gel additive in concrete-based materials. They found that adding up to 10% of this additive to the total cement content increased the strength of hardened cement paste. Roy (2012) investigated the effect of replacing cement with silica fume on the strength parameters of concrete, observing that a 10% replacement led to increased compressive, split tensile, and flexural strengths.

Raveendran and Kumar (2015) examined the impact of mineral admixtures, including silica fume, on water permeability and compressive strength of M20 grade concrete. They discovered that silica fume improved concrete strength at specific replacement percentages, despite slightly reduced compressive strengths at higher replacement ratios.

Patnaik et al. (2015) assessed the strength and durability characteristics of concrete with partial copper slag substitution for sand. They found that concrete strength improved with up to 40% copper slag substitution, although it exhibited lower resistance to acid attack and better resistance against sulfate attack.

Raza et al. (2015) studied the effect of replacing coarse aggregates with iron slag at varying proportions. Their investigation of M40 grade concrete demonstrated enhanced compressive and flexural strengths with different percentages of iron slag aggregate.

Chauhan and Bondre (2015) delved into the partial replacement of sand with copper slag in concrete. Their experiments indicated that incorporating copper slag in concrete led to improved compressive properties, especially when the copper slag fine aggregate ratio reached certain proportions.Based on the aforementioned results and discussions, the following conclusions can be drawn:The mix proportion of 1:1.5:3 (cement: aggregate: sand+quarry dust) yielded the optimal strength in this study.The compressive strength of concrete increases gradually with the increasing proportion of Copper slag, as long as the Copper slag proportion does not exceed 50%The compressive strength of cured concrete increases with the duration of curing, with the strength values at 28 days surpassing those at 7 days.The measured compressive strength values are consistently higher than the minimum required compressive strength of 7 N/mm2 for normal concrete. This indicates that Copper slag is a suitable replacement for sand in the concrete mixture for the construction industry.

In a study by **Devi and Rao (2015)**, the impact of fly ash and copper slag on concrete properties was analyzed. The research investigated the effects of replacing cement with fly ash at various percentages (0%, 10%, 20%, and 30% by weight of cement) and replacing sand with copper slag at different percentages (20%, 30%, and 40% by weight of sand) for an M20 mix. Experimental investigations were conducted to assess concrete properties such as compressive strength at curing ages of 7, 14, 28, 56, and 90 days, as well as compressive strength of cylinders, split tensile strength, modulus of elasticity, and ultrasonic pulse velocity of concrete at 28 days of curing. Concrete mixtures were formulated, tested, and compared with conventional concrete.Fly ash increases water demand for consistency and workability.Incorporating fly ash into cement accelerates initial setting time but reduces final setting time.Overall, all mixtures achieve strengths greater than the target strength compared to control concrete, regardless of curing duration.All mixtures gain strength regardless of curing duration.

The compressive strength of cylindrical specimens is slightly lower than that of cubic specimens.

The blend containing 20% fly ash and 30% copper slag is considered the optimum mix in terms of compressive strength, stiffness, and modulus of elasticity. Partial replacement of cement with fly ash and sand with copper slag not only enhances concrete strength but also reduces production costs and addresses environmental pollution issues.

Subramaniam et al. (2015) investigated the utilization of wood ash as a partial replacement for cement in sand-cement blocks. They found that a blend with 15% wood ash replacement material exhibited higher compressive strength. Additionally, the specimens with 15% wood ash replacement showed the lowest water absorption. Slower heat release was observed in the specimens with 15% and 20% wood ash replacement after 21 days of curing. They concluded that adding 15% wood ash to concrete blocks met standard requirements.

Kumar et al. (2015) studied the effect of cow manure ash (CDA) on the strength of mortar and concrete. They observed that the consistency limits increased up to an optimal content of CDA and decreased with further increase in CDA percentage. The compressive strength increased when 5% of CDA replaced cement and decreased with higher cow manure ash content. They concluded that 5% of cement could be replaced with CDA in mortar and 5% of cow manure ash could be used as a partial replacement for cement in concrete.

Saxena and Simalti (2015) focused on the replacement of foundry sand with copper slag in concrete. They discussed how copper slag, as a substitute for sand, could reduce construction costs. They reviewed various studies on the replacement of copper waste in foundry sand and its impact on concrete strength.

Rohini and Arularasi (2016) examined the influence of fly ash and copper slag as partial replacements for cement and fine aggregate in concrete. They found that replacing 40% of cement and fine aggregate with fly ash and copper slag resulted in higher compressive strength compared to standard concrete.

Miyan and Krishnamurthy (2017) investigated the effects of replacing fine aggregate with copper slag in M30 grade concrete. They determined the compressive and split tensile strengths of concrete samples with different levels of copper slag replacement.

Reddy and Ramadasu (2017) researched the effect of silica fume on the compressive strength of cement- silica fume mortars. They concluded that incorporating silica fume improved the compressive strength of the mortar mixes.

Qureshi et al. (2018) examined the impact of cement replacement with silica fume on the compressive strength of glass fiber reinforced concrete. They found that incorporating glass fibers and silica fume increased the compressive strength of the concrete.

III. METHODOLOGY

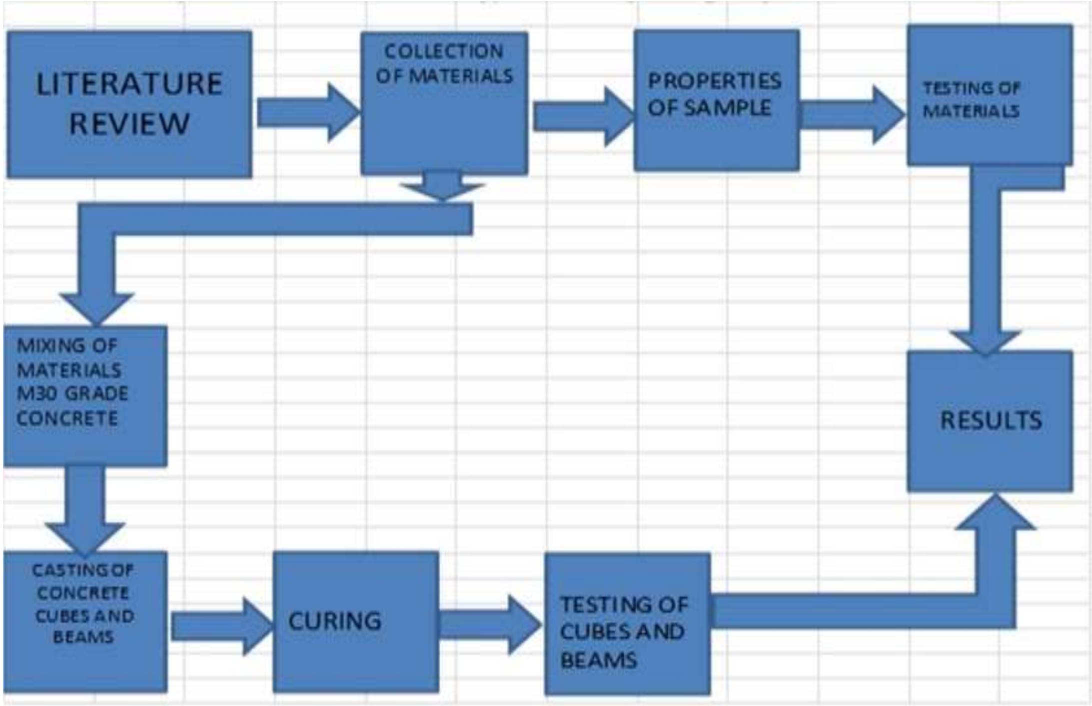

Figure 1.: Methodology showing the progress of work

IV. Consistency of Concrete Mix:

This test's objective is to ascertain the proportion of water needed to prepare cement pastes for subsequent testing. Table 1. displays the typical consistency of pastes that contain copper slag and silica fume.

Table 1. : Normal Consistency of Cement with Different Properties of Different Material

S .No	Material	Percentage of Replacement			
		0%	**10%**	**20%**	**30%**
1	**Silica fume**	30	32.5	34	35
2	**Copper slag**	30	32	33.5	34

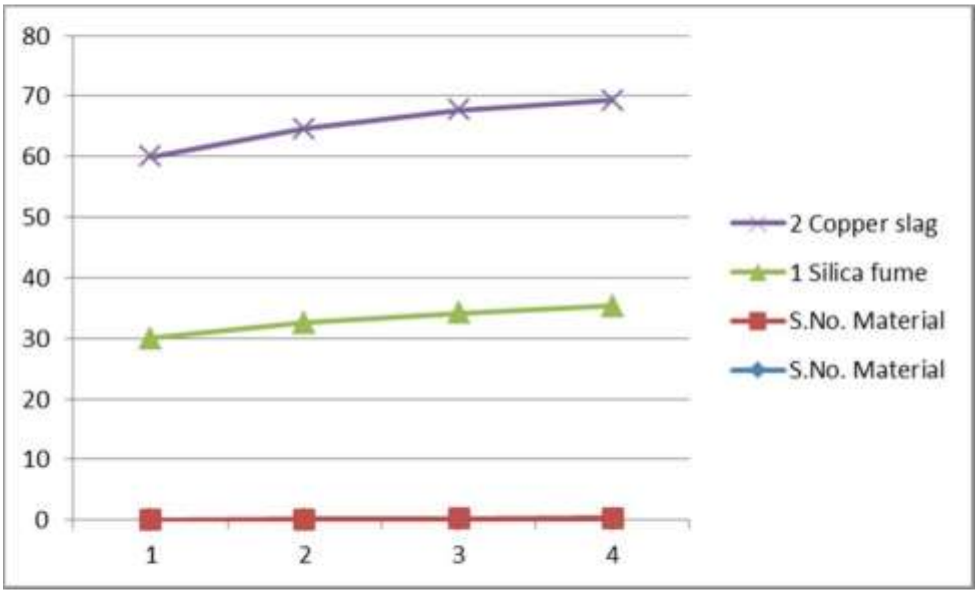

Figure 2: Normal Consistency of Cement

The consistency values of all the pastes containing copper slag and silica fume were normal and either higher or equal to those of the control paste. With just little deviations, the typical consistency held true for replacements up to 10% and 20%. On the other hand, a marginal rise in normal consistency was noted at a 30% replacement level, with a maximum of 35%.

Flexural strength of cylinder concrete contain silica fume

The results of the UTM test for flexural strength are provided in table and graph form for M30 grade concrete beams with a nominal concrete mix.

Table 2: Concrete beams of grade M30 UTM results

S. No.	M30,Normal concrete beam	Strength after 28 days curing **(N/mm2)**
1	Beam 1	5.37
2	Beam 2	5.6
3	Beam 3	5.13
4	Average	5.36

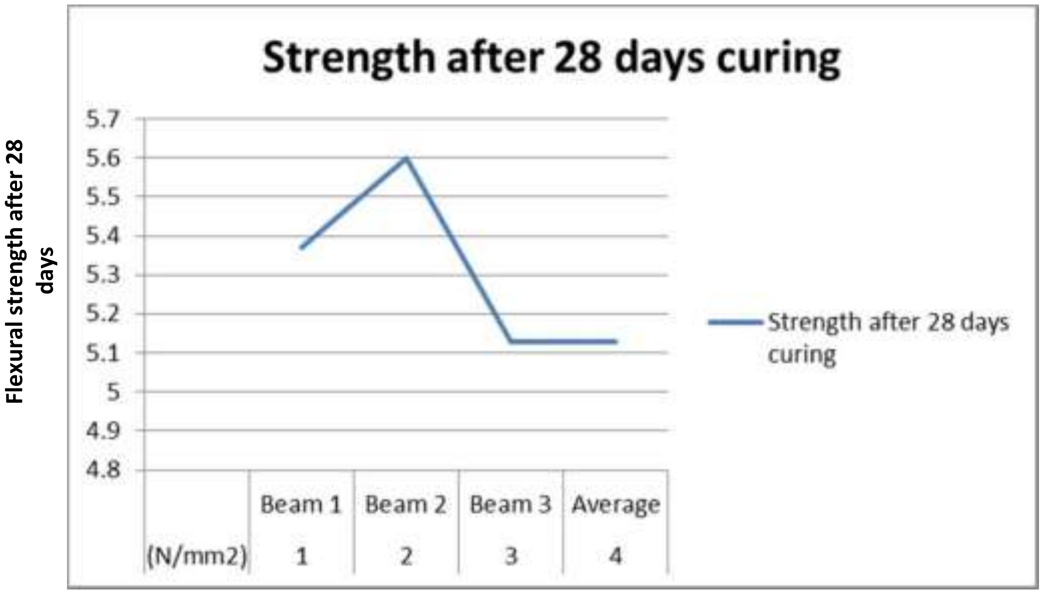

Figure 3: Flexural Strength with nominal mix

In this particular test, a total of 3 beams with dimensions of 700mm x 100mm x 100mm were cast using M30 grade concrete. The replacements involved using 10% silica fume in place of cement.

V. Conclusion

Based on the above study following conclusions can be made:

- At 0%, 10%, 20%, and 30% replacements, the typical consistency of cement including copper slag is 30%, 33%, 34.5%, and 35%, respectively. Conversely, cement that has silica fume replaced at0%,10%,20%, and 30% often has a consistency of30%,33.5%,35%, and 36%, respectively.
- At 28 days, the flexural strength of M30 grade concrete is 5.10 N/mm², 5.40 N/mm², 5.33 N/mm², and 5.03 N/mm², respectively, when copper slag replaces 0%, 10%, 20%, and 30% of the cement. The highest flexural strength may be achieved with a 10% replacement of copper slag, since the flexural strength normally improves with 10% replacement and drops with 20% and 30% replacements.

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