EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT AND FINE AGGREGATE WITH METAKAOLIN AND COPPER SLAG WITH SELF-CURING AGENT

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Abstract - *Due to its high compressive strength and workability, concrete is the most widely used building material. For good hydration and to reach the desired strength, plain concrete requires a comfortable environment with moisture for a minimum of 28 days. Self-curing concrete is one of the unique concretes used to defend insufficient curing brought on by human error, such as a lack of water in dry areas, difficulty in accessing structures, or areas where the presence of fluorides in the water will negatively affect the properties of concrete. Evaluation of the use of water-soluble polyethylene glycol (PEG-400) as a self-curing agent is the investigation's main goal. Metakaolin was substituted for cement in varying amounts of 10, 15, and 20%, copper slag for 40%, 50%, and 60%, and PEG-400 for 1% when making self-curing concrete of the M30 grade. In this study, self-curing concrete's compressive strength and split tensile strength are assessed and contrasted with specimens made of conventional concrete.*

Key Words: self-curing concrete, Metakaolin, Copper Slag, PEG-400.

1.INTRODUCTION

Concrete is a widely used building material due to its strength, durability, and versatility. However, it also has significant environmental impacts, such as high carbon emissions during production and the depletion of natural resources. To address these concerns, researchers have been exploring the use of additives to improve concrete performance and sustainability. This paper aims to discuss the benefits of using additives, specifically metakaolin and copper slag, and self-curing agents in concrete.

Metakaolin is a pozzolanic material that is produced by calcining kaolin clay at high temperatures. When added to concrete, metakaolin improves the microstructure by filling in the gaps between cement particles, resulting in denser and more durable concrete. It also enhances workability, making it easier to place and shape the concrete. The addition of metakaolin reduces the water demand of concrete, leading to a lower water-to-cement ratio, which improves strength and durability. Furthermore, metakaolin has a high reactivity with calcium hydroxide, a byproduct of cement hydration, resulting in the formation of additional cementitious compounds that contribute to the strength and durability of concrete.

Copper slag is a byproduct of copper extraction and refining processes. It is a granular material that can be used as a partial replacement for fine aggregates in concrete. The addition of copper slag improves the strength and durability of concrete due to its pozzolanic properties. It reacts with calcium hydroxide to form additional cementitious compounds, resulting in denser and more durable concrete. Copper slag also enhances the resistance of concrete to chemical attack and reduces the permeability, making it more resistant to water penetration and chloride ingress. Additionally, the use of copper slag as a replacement for fine aggregates reduces the demand for natural resources and helps in the management of industrial waste.

Curing is a crucial process in concrete production that involves maintaining adequate moisture levels to ensure proper hydration and strength development. Traditionally, external water curing techniques, such as ponding or spraying, are used to prevent moisture loss. However, these methods are time-consuming, labor-intensive, and can lead to water wastage. Self-curing agents offer an alternative solution by providing internal moisture to the concrete, eliminating the need for external water curing. These agents are added to the concrete mix and release water during the hydration process.

2 MATERIALS AND METHODOLOGY

2.1 MATERIALS

The resources specified under are used in conjunction with this essay.

1. Cement

Fine-dust binding ingredient that is blended in to water along with additional aggregates to formulate concrete. The experiment made use of cement from OPC class 43 as illustrated in Fig.1. Through a specific gravity of 3.12, cement.

Fig.1 Cement

2. Fine Aggregate

A crucial component in constructing industry is sand or fine aggregate. This comprises a granulated mixture generated up of minuscule fragments from quarries, broken stone, and other natural sources as illustrated in Fig.2. Sand has a 2.56 specific gravity.

Fig.2 Sand

3. Coarse Aggregate

Coarse aggregate, notably for concrete, as a vital part of building supplies. Gravel, crushed stone, and quarries are among the instances for raw materials which generate coarse aggregate as illustrated in Fig.3. The inclusion of coarse aggregate considerably increases the load, stability, and longevity of concrete compositions. 2.67 specific gravity of coarse aggregate.

Fig.3 Coarse Aggregate

4. PEG-400

PEG-400 is a self-curing agent. The condensation polymers known as polyethylene glycol, or PEG, is generated by the bonding of ethylene oxide with water. The usual quantity of repeating oxyethylene groups is marked by the generic formula H(OCH2CH2) OH. The properties are recorded in the Table-1.

Table-1 Physical properties of PEG-400

Molecular Weight	400
Appearance	Clear Fluid
Odor	Mild
pH	6
Specific Gravity	1.2

Fig.4 PEG-400

5. Water

Liquid is a vital part of the procedure of hydrating that lends concrete its load and durability, therefore being a component that is required in both the production and curing of concrete. Calcium silicate hydrates (C-S-H), which reinforce and prolong the life of the concrete, occurs when cement grains and water are mixed together.

6. Metakaolin

By calcining kaolin clay at high temperatures, metakaolin is generated, an additional cementitious part. It is popular for its pozzolanic attributes, which render them a valuable addition to generate cement and concrete. The physical and chemical properties of metakaolin are stated in the following Table-2.

Table-2 Physical and chemical properties of metakaolin

1	Appearance	White
2	Fineness	1.5µm
3	Specific Gravity	2.46
4	Fe_2O_3	4
5	SiO_2	19.43%

6	Al_2O_3	5.64%
7	CaO	61.60%
8	MgO	2.41%
9	Na_2O	0.11%
10	SO_3	2.94%
11	K_2O	0.78%
12	LOI	1.85%

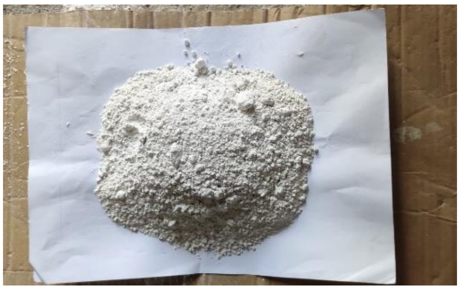

Fig.6 Metakaolin

7. Copper Slag

While copper ore is melted and refined, a byproduct called copper slag is generated that is shown in Fig.7. For its unique properties, this granular material is widely used in an array of applications. The table of properties are stated in the below Table-3.

Table-3 Physical properties of copper slag

1	Appearance	Blackish gray, Glassy
2	Grain Shape	Granular
3	pH	6.5
4	Moisture Content	Less than 0.1%
5	Bulk Density	1.99 g/cm^3
6	Specific Gravity	3.47
8	CU	0.6-0.9%
9	FE (Total)	40-44
10	S	0.8-1.2%
11	SIO_2	33-35%
12	Free Silica	< 0.5%
13	Al_2O_3	4.0-6.0%
14	CaO	0.8-1.5%
15	MgO	1.0-2.0%
16	Ni	0.01-0.03%
17	Pb	0.01-0.04%
18	Zn	0.2-0.3%
19	Bi	0.01-0.02%
20	Co	0.04-0.13%
21	FeO	50-55%
22	Magnetite	1.5-5.0%

Fig.7 Copper Slag

2.2 METHODOLOGY

1. Design of Concrete Mix

Utilize a mix design to establish the ratios of each ingredient according to the desired qualities of the concrete. By utilizing IS-10262 (2019). Compute the water-to-cement ratio and the ratios of each component. The ratio of each component is stated in Table-4 according the mix design carried out.

2. Mix Proportioning:

Compute the sum of copper slag that will prevail over the sand with the quantity of metakaolin that will swap the cement. For metakaolin and copper slag, this replacement refers typically range from 10% to 20% and 40% to 60%, respectively, depending on the aimed performance goals. The mix ratios are stated in Table-5.

The entire cementitious content (cement + metakaolin) and whole fine aggregate content (sand + copper slag) should be altered to retain the desired characteristics.

Table-5 Mix Ratio

Sl. No.	% Replacement of MT and CS	Mix Ratio
1	MT-10 , CS- 50%	1: 1.237: 1.837
2	MT-15%,CS- 50%	1: 1.305: 1.938
3	MT-20%,CS- 50%	1: 1.381: 2.05
4	MT-10%,CS- 40%	1: 1.237: 1.837

5	MT-10%,CS- 50%	1: 1.237: 1.837
6	MT-10%, CS- 60	1: 1.237: 1.837

3. Batching and Mixing:

Following the specified proportions and ensuring thorough mixing, batch and integrate the amended concrete ingredients in a concrete mixer.

Cement, metakaolin, copper slag, aggregates (coarse and fine), and water are merged to generate the concrete mix.

To guarantee adequate workability and uniform dispersion of the parts, carefully mix every component as illustrated in Fig.8.

Fig.8 Concrete being mixed in a concrete mixer.

4. Water-Cementitious Ratio

Adjust the liquid-cementitious proportion to attain the vital standardization while retaining the appropriate load in light of the existence of metakaolin and probable changes in liquid demand.

5. Batching and Mixing:

Following the specified proportions and ensuring thorough mixing, batch and integrate the amended concrete ingredients in a concrete mixer.

6. Self Curing Agent Addition:

Mixture now contains the self-curing agent. Self-curing agents belong to compounds that emit moisture over time to aid in curing and eliminate the desire for additional curing steps.

7. Placing and Compacting the freshly prepared concrete:

To evacuate voids and achieve adequate consolidation, lay and compact the amended concrete mix over the formwork or moulds as illustrated in Fig.9.

Fig.9 Placing and compacting the freshly concrete in moulds

8. Curing:

By allowing a regulated release of moisture from the concrete, the self-curing ingredient will speed up the curing process. This supports the preservation of the ideal conditions for cement hydration and loadening. The concrete specimens were under air curing as it is self-curing concrete as illustrated in Fig. 10.

Fig.10 Air Curing

9. Testing Process:

Experiments for the amended concrete should be run, including ones for workability and compressive load as illustrated in Fig.11. To evaluate the success of the adjustments, compare the outcomes to those typical concrete.

Fig.11 Compression test on concrete blocks

Concrete with increased load, workability, and sustainability may be generated via a self-curing agent, copper slag in place of sand, and replacing a portion of cement with metakaolin.

3. RESULTS AND DISCUSSIONS

3.1 EXPERIMENTAL PROCESS

For performing compressive load examination, concrete cubes are typically utilized. From the same batch of concrete being used for construction, standard cube specimens (typically 150 mm x 150 mm x 150 mm) are cast. To ascertain the concrete's compressive load, these cubes are permitted to cure under carefully monitored conditions. With respect to materials for compressive load, 44 cubes total were cast by altering the amounts of copper slag and metakaolin.

The split tensile examination is a unique technique for determining the tensile load of concrete. In this test, a standard cylindrical exhibit is spread out horizontally, and its surface is pressed radially until a vertical crack emerges along the specimen's diameter. 44 cylinders in all are cast to test their split tensile force.

3.2 EXPERIMENTAL CONDUCTED

1. Slump Examine:

The slump inspection, which evaluates the evenness and workability of newly poured concrete, is a straightforward and prevalent process. It examines the extent that concrete "slump" or settling happens when an experiment is shaped into a conical shape as illustrated in Fig. 12 and allowed to sag beneath its own weight. Important information on the water content, workability, and probable segregation of the concrete mixture credible gleaned from outcomes of the slump examination. The slump values are tabulated in Table-6 and the slump chart is illustrated in Fig. 13. Altitude of the slump cone is 300 mm, foot diameter is 200 mm, and upper diameter is 100 mm.

Fig.12 Slump Test

Table-6 Slump Values

Sl. No.	Percentage Replacement of MT and CS	Slump (mm)
1	Normal Concrete	100
2	Normal with PEG-400	115
3	MT-10%, CS- 50%	120
4	MT-15%, CS- 50%	110
5	MT-20%, CS- 50%	105
6	MT-10%, CS- 40%	125
7	MT-10%, CS- 50%	120
8	MT-10%, CS- 60%	130

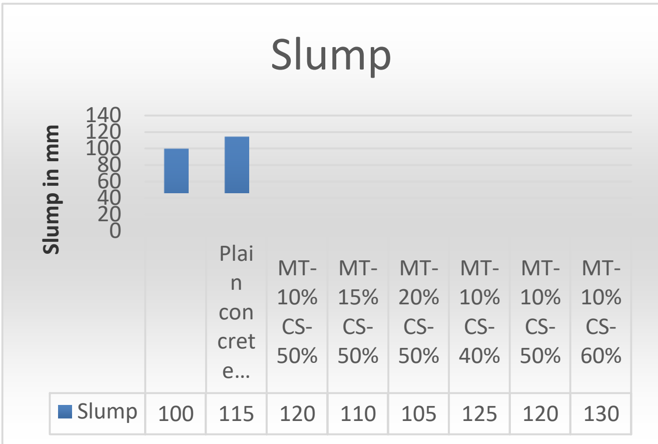

Fig. 13 Slump Chart

2. Compressive Load

The pozzolanic matter metakaolin may boost the attributes of concrete when employed conversely to cement. Its minute particles interact with calcium hydroxide to generate withal cementitious' compounds that are harder and have an extended lifespan. Copper slag is a leftover from the process of extracting and refining copper. When utilized as an alternative for fine aggregate, it improves the workability and capacity of concrete. The angular and rough surface of copper slag granules may benefit interlocking inside the mixture. PEG 400 is a typical water-soluble polymer additive used to alter the structure of concrete. By functioning as a plasticizer and minimizing demand for water, it boosts workability. PEG 400 may boost the cohesion of the concrete mix while minimizing the risk of segregation and bleeding.

The concrete cube's compressive force is provided by,

Cube strength = $\frac{\text{Average load}}{\text{Area of cross section}}$ N/mm^2

The outcomes are compiled in Table-7.

Fig.14 Compression Examine Machine

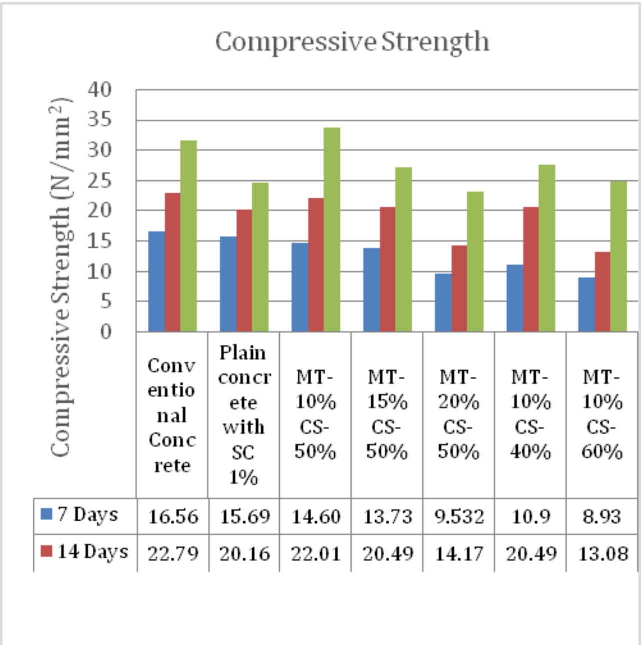

Fig.15 Compression Examine Results

3. Split Tensile Load:

Tensile force, there is significant effects on the size and rate of cracking in structures, constitutes one among the most fundamental and vital features of concrete. Additionally, concrete is exceedingly weak beneath tension owing to its brittle nature. Hence. It won't be anticipated that it will withstand the direct assault. Concrete thus fractures when tensile stresses exceed the material's tensile load. It is required to ascertain the breaking load of concrete's to establish the load at which the concrete members can break. By applying a tensile force perpendicular to a cylindrical specimen's longitudinal direction, the split tensile load test, employed in concrete research, assesses the tensile load of concrete. This test determines the material's resilience to cracking.

The formulae:

Split Tensile Load = $\frac{2P}{\pi DL}$ N/mm^2

Fig. 16 Split Tensile Examine Machine

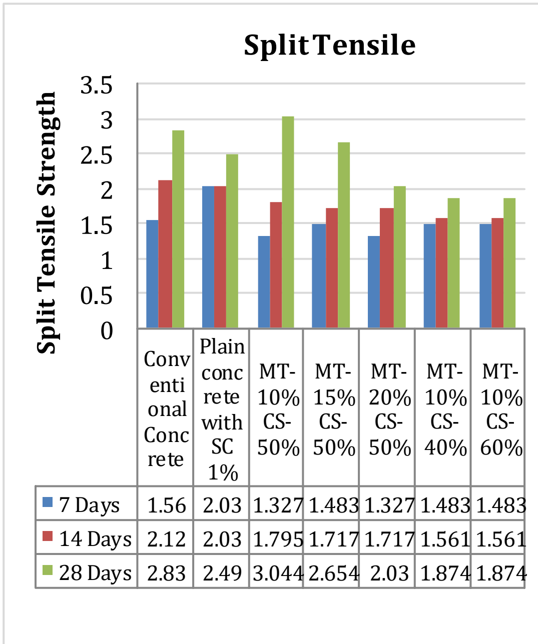

Fig.17 Split Tensile Examine Results

CONCLUSION

The current investigation ensures the conclusions:

- The compressive and split tensile force of concrete having copper slag and metakaolin partially replaced are higher than of normal concrete.
- With fixed copper slag quantity (50%) and PEG-400 as 1%, workability diminishes as metakaolin content rises.

- In comparison to PEG-400 plain concrete, the compressive and split tensile values are raised.
- Metakaolin can be altered up to 10% and Copper Slag up to 50% to achieve hardness.
- The exertion of copper slag and metakaolin can lessen the demand for cement and sand.
- Concrete is often employed for constructions like war refugees, nuclear complexes, chimneys, etc. where extreme heat and impact must be resisted owing to its high density of copper slag as fine aggregate.
- The findings support the notion that self-curing treatments are an alternative to standard curing processes.

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