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Experimental investigation on Partial Replacement of cement with Fly-Ash and Wollastonite in Concrete

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Abstract - *This research examines the impact of partially substituting cement with fly ash and wollastonite on concrete's characteristics. Fly ash, a byproduct of burning coal, and wollastonite, a naturally found mineral, are evaluated for their ability to enhance the sustainability and efficiency of concrete. The experimental procedure consisted of substituting cement with different proportions (20% and 25%) of fly ash and wollastonite (10% and 15%) across various concrete mixtures. The concrete's workability, compressive strength, flexural strength, and durability were assessed at various curing ages (7, 14, and 28 days). Findings indicated that incorporating fly ash and wollastonite enhanced the workability and mechanical properties of concrete at optimal replacement ratios. Compressive strength tests showed a notable enhancement in strength when fly ash was combined with wollastonite, with the ideal replacement of 20% fly ash and 15% wollastonite demonstrating the best performance. Additionally, durability assessments showed improved resistance to sodium sulfate damage and reduced water absorption, rendering the composite material appropriate for sustainable building methods. This study underscores the possibility of utilizing fly ash and wollastonite as substitute materials in cement-based composites, aiding in the decrease of cement usage and the improvement of concrete performance.*

Key Words: Fresh Concrete Test, Hardened Concrete Test, Workability, Split Tensile Strength, Durability Test (Na_2SO_4).

1. INTRODUCTION

Concrete stands out as a remarkable and essential material in the landscape of human development. It is recognized as the most commonly used engineered substance in the construction sector and is expected to maintain this status for years to come. This is attributed to concrete's remarkable characteristics, including its impressive strength, long-lasting nature, low maintenance requirements, and versatility in various structural uses. However, in recent times, the concrete industry has encountered significant challenges, primarily due to cement, which is an essential ingredient. According to the International Energy Agency, cement manufacturing is responsible for approximately 7% of global carbon dioxide emissions. It is projected that worldwide cement production will reach around 5 billion tons by 2020, leading to a predicted 100% increase in CO2 emissions from Portland cement production compared to current levels by that year. Utilizing the best mineral additives in optimal amounts combined with Ordinary Portland Cement can enhance several aspects of concrete, such as reducing heat generation during hydration, increasing impermeability to water, minimizing alkali-silica reactions, improving workability, and providing resistance against attacks from sulfate soils and seawater, among others. Currently, India ranks as the second-largest cement producer in the world. Despite this substantial production, we are grappling with serious environmental challenges. The cement sector is a significant contributor to carbon dioxide emissions. To address these environmental concerns, alternative solutions must be sought. Numerous studies indicate that incorporating mineral additives into concrete can result in stronger, more resilient concrete that better withstands environmental factors that lead to its deterioration.

1.1 FLY-ASH

- Fly ash is a substance generated from the burning of finely ground coal in power generation facilities. It appears as a fine, dusty material that rises with exhaust gases and is then collected by electrostatic precipitators or fabric filters prior to its release into the air. The main components of fly ash include silica, alumina, and iron oxides, and its characteristics can differ based on the coal type used and the method of combustion.

- In construction, fly ash is widely utilized, especially in making concrete. When combined with water and cement, fly ash improves the quality of concrete by enhancing its workability, decreasing heat generation, and boosting durability. It also supports sustainability efforts by lessening the demand for new materials and minimizing the carbon emissions associated with concrete manufacturing.

1.2 WOLLASTONITE

- Wollastonite is a naturally occurring mineral known for its distinct properties. Enhanced through advanced processing techniques, it has emerged as one of the most adaptable functional fillers available in the market. Wollastonite enhances the performance of a variety of products, including plastics, paints, coatings, construction materials, friction components, ceramics, and metallurgical uses, among others.

- This mineral, scientifically identified as calcium inosilicate (CaSiO3), may contain trace amounts of iron, magnesium, and manganese that partially replace calcium. Typically, it appears white. Wollastonite forms when impure limestone or dolomite is exposed to significant heat and pressure, which can occur in environments with silica-rich fluids such as skarns or when in contact with metamorphic rocks. The mineral is named after the English chemist and mineralogist William Hyde Wollaston (1766–1828).

- Wollastonite's valuable properties include its high brightness and whiteness, low absorption of moisture and oil, and minimal explosive potential. It is primarily utilized in ceramics, friction products like brakes and clutches, metal production, as a filler in paints, and in plastics.

- This white mineral is chemically inert, and its fibers are more cost-effective compared to carbon or steel micro-fibers. Wollastonite micro-fibers (WMFs) are extremely fine, with an aspect ratio between 3:1 to 20:1; they measure around 0. 4 to 0. 6 mm in length and have a diameter ranging from 25 to 150 micrometers. The mineral consists of two main components, CaO and SiO2, where in pure CaSiO3, each component contributes almost equally to the mineral's weight percentage.

- In 2010, India produced 120,000 tons of wollastonite, representing 22% of the global total. This mineral is widely found in Rajasthan, particularly in the Pali, Sirohi, and Udaipur districts, and is also located in Tamil Nadu, Uttarakhand, and Andhra Pradesh. It is used for minimizing shrinkage cracks in ceramic tiles and enhancing the tensile strength of plastics.

1.3 NA_2SO_4

It's crucial to understand the background before conducting a durability test on sodium sulfate (Na_2SO_4). Unlike metal or plastic, sodium sulfate is not usually evaluated for mechanical durability. However, due to its aggressive crystallization tendency during cycles of wetting and drying, sodium sulfate is frequently employed in durability testing of other materials, particularly in construction materials like concrete or stone.

2. Material And Methodology

2.1 Fine Aggregate (IS 2386 Part-1)

Table.1 Properties of Fine Aggregate

Properties	Sand
Sieve analysis	Zone II
Fineness modulus	2.871
Specific Gravity	2.64
Water Absorption	1.77
Bulk Density	1.62 (Loose) 1.76 (Compacted)

2.2 Coarse Aggregate (IS 383-1987)

Table.2 Properties of Fine Aggregate

Properties	20mm	10mm
Specific Gravity	2.88	2.99
Water Absorption	1.46%	0.29%
Aggregate Impact Value	9.21%	9.33%
Aggregate Crushing Value	11.75%	9.98%
Flakiness Index	10.89%	25.26%
Elongation Index	6.84%	7.66%
Bulk Density	1.657 (Loose) 1.75 (Compacted)	1.53 (Loose) 1.68 (Compacted)

2.3 Wollastonite

Table.3 Properties of Wollastonite

Properties	Value
PH Value	9.9
Specific Gravity	2.67
Bulk Density	1211.8 Kg/m^3
Colour	White

2.4 Mix Design (IS 10262-2019)

- For M45 Grade of Concrete Mix

Table.4 Mix Proportion (per cubic meter)

Water	Cement	FA	CA	Total
153.26	383.13	808.18	1197.71	2542.31
0.40	1.00	2.11	3.12	6.64

➢ For M50 Grade of Concrete Mix

Table.5 Mix Proportion (per cubic meter)

Water	Cement	FA	CA	Total
153.26	437.90	766.92	1179.36	2537.44
0.35	1.00	1.75	2.69	5.79

➢ For M55 Grade of Concrete Mix

Table.6 Mix Proportion (per cubic meter)

Water	Cement	FA	CA	Total
153.26	414.22	784.62	1188.84	2540.94
0.37	1.00	1.89	2.87	6.13

3. RESULTS

3.1 Workability

➢ The workability of freshly mixed concrete was assessed using a slump test. The slump value was determined by calculating the difference in height between the top of the mold and the highest point reached by the settled concrete.

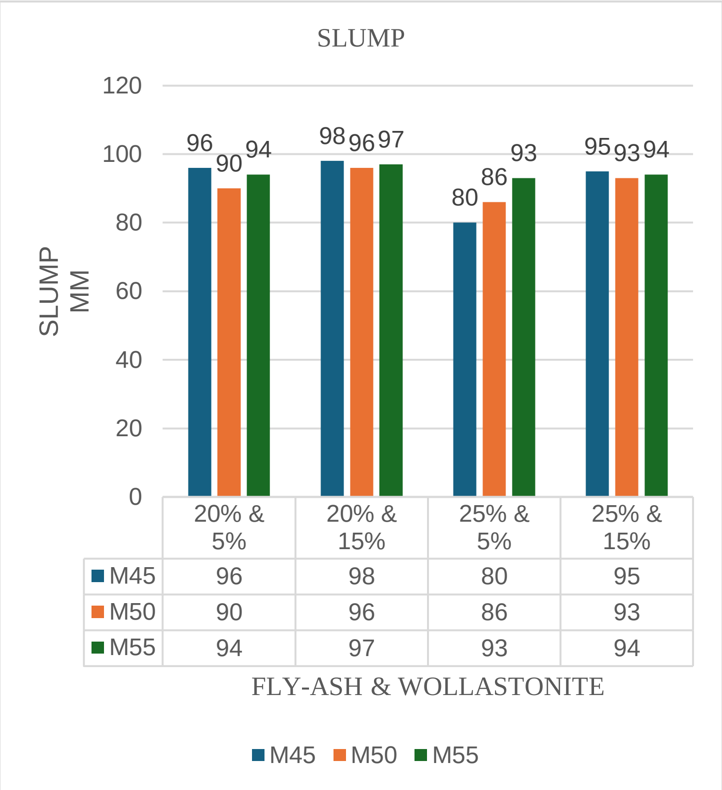

Chart -1: Slump Value Comparison

3.2 Compressive Test Results

➢ Cube samples measuring 150 mm x 150 mm x 150 mm underwent a compression test utilizing a compression testing apparatus. The load was incrementally increased on the samples until the concrete failed. The compressive strength was determined using the following formula.

$$\sigma = P/A$$

Where, P = failure load

A = cross sectional area of cube in mm

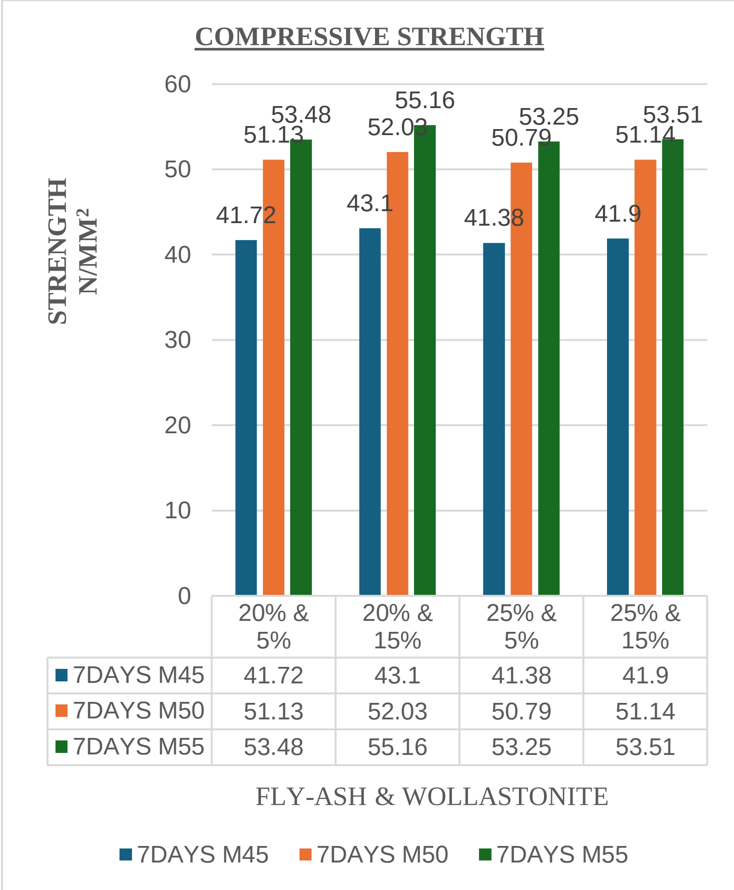

Chart -2: Compressive Test Result for 7-days

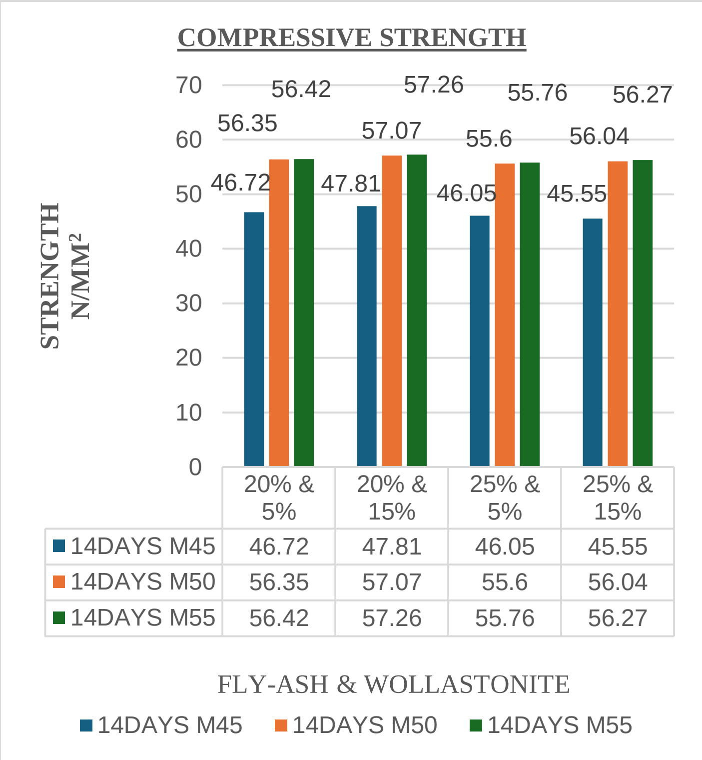

Chart -3: Compressive Test Result for 14-days

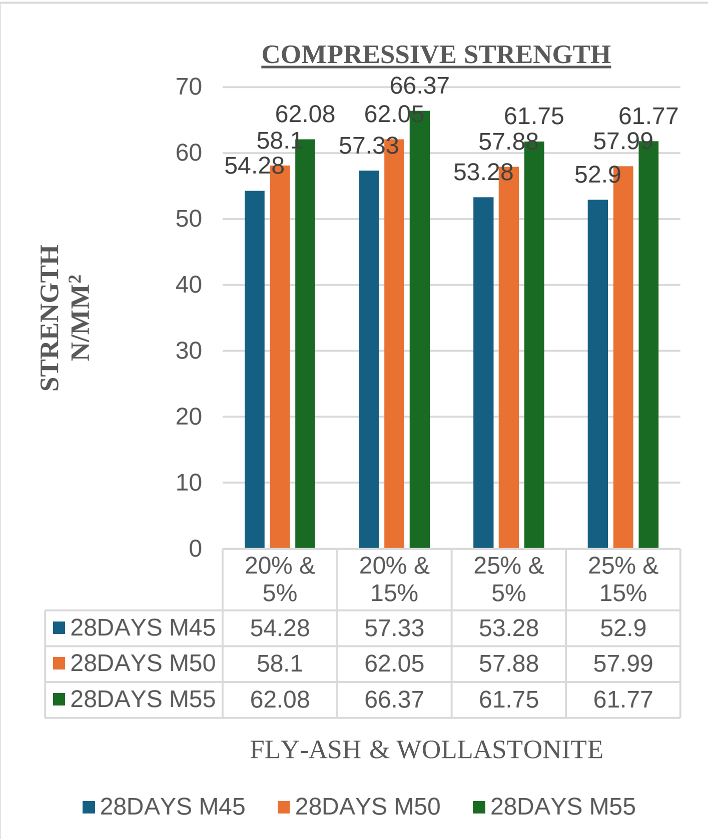

Chart -4: Compressive Test Result for 28-days

3.3 Split Tensile Test Results

- To determine the split tensile strength of concrete, cylindrical specimens measuring 150 mm in diameter and 300 mm in height were cast and tested at 28 days of age.

- The results obtained were compared with the concrete's compressive strength at the same age. During the testing procedure, the compression load will be applied along the two opposite axial lines.

Tsp = 2P/ 3.14 DL

Where, P = Applied Load
D =Diameter of the Specimen

L = Length of the Specimen

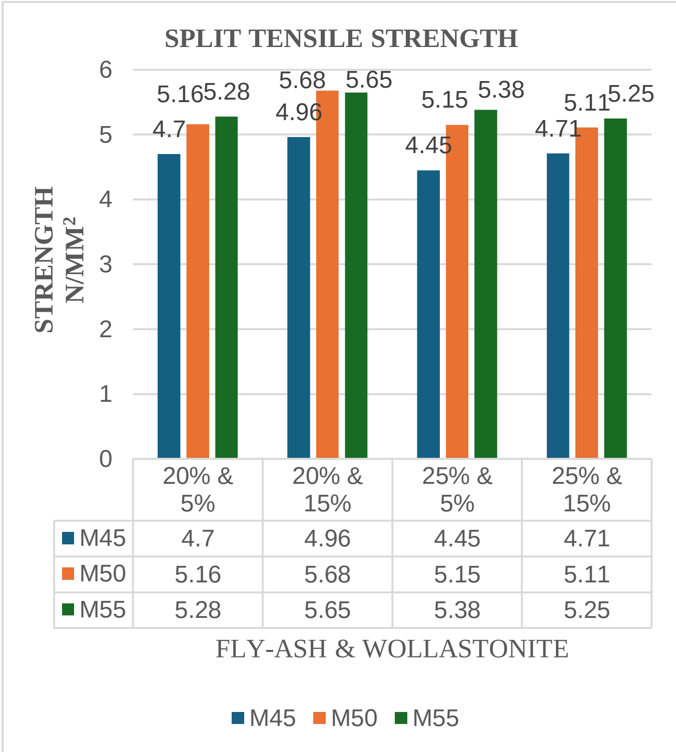

Chart -5: Split Tensile Test Result for 28-days

3.4 Durability Test Results

- The concrete cubes measuring 150mm were molded and allowed to cure for 28 days. Following the curing period, the surfaces of the cubes were cleaned and their weights recorded. The samples were then submerged in a sodium sulfate solution. This solution was monitored at regular intervals.

- Following the 28-day period, the samples were taken out of the sodium sulphate. The weight loss percentage was calculated along with the strength loss percentage.

For this test, a mixture was created using 5% sodium sulphate by volume combined with regular drinking water.

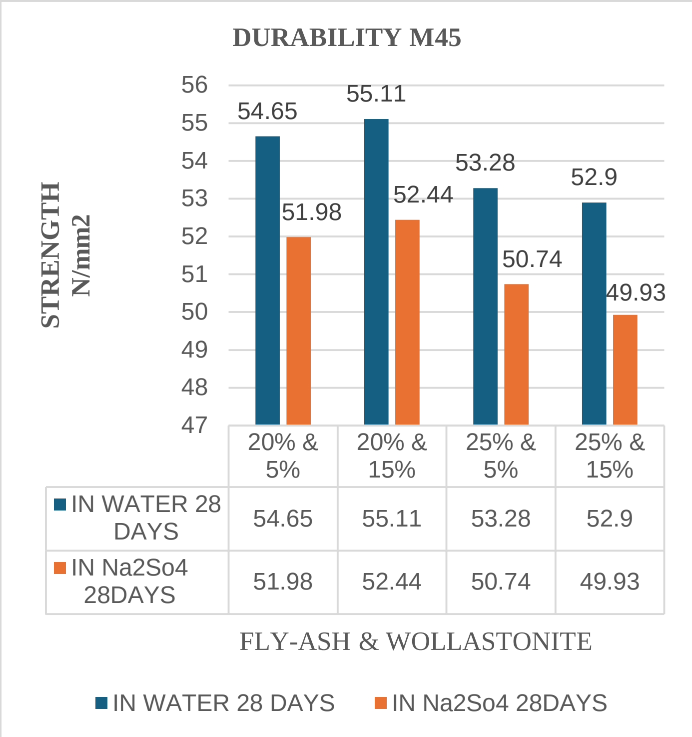

Chart -6: Durability Test Result for 28-days(M45)

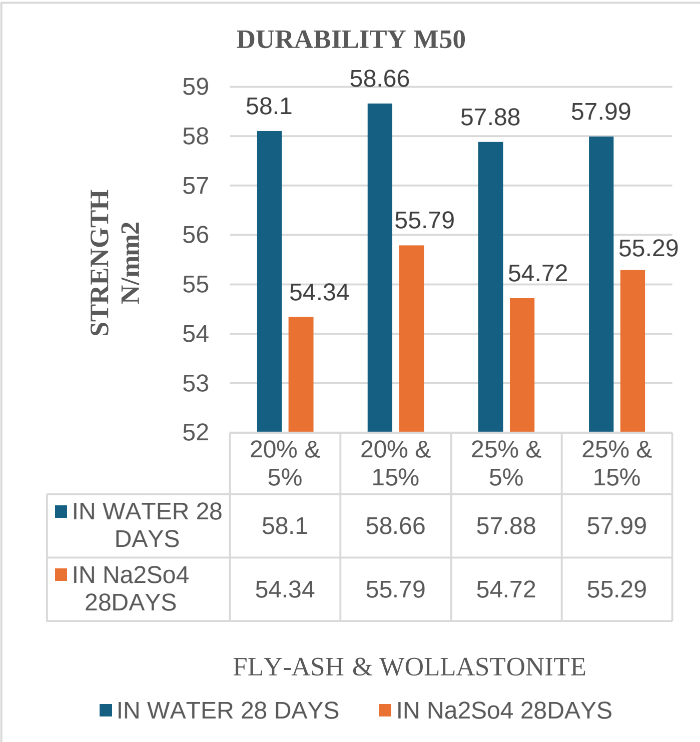

Chart -7: Durability Test Result for 28-days (M50)

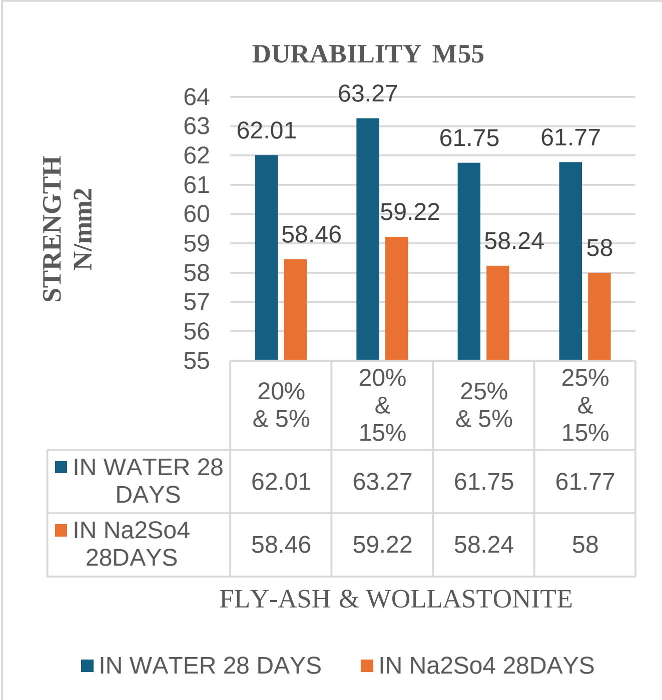

Chart -8: Durability Test Result for 28-days(M55)

4. CONCLUSIONS

I. The workability improves when incorporating 15% and 20% of wollastonite and fly ash, respectively, in the M45, M50, and M55 concrete mixes based on the weight of cement.

II. For the M45 grade concrete containing 15% wollastonite and 20% fly ash, the maximum compressive strength achieved an increase of up to 7. 66% when these materials replaced cement by weight.

III. In the M50 grade concrete with 15% wollastonite and 20% fly ash, the optimal compressive strength rose by as much as 6.52% following the substitution of wollastonite and fly ash for cement based on weight.

IV. For the M55 grade concrete that includes 15% wollastonite and 20% fly ash, the highest compressive strength increased by 4.93% when wollastonite and fly ash were used as replacements for cement by weight.

V. The split tensile strength of concrete increases by 4. 96%, 5. 68%, and 5. 65% for M45, M50, and M55 grades respectively when cement is replaced with wollastonite and fly ash.

VI. In durability testing with a Na2SO4 solution, the results indicate that the average strength loss in normal M45, M50, and M55 grade concrete is 6. 70%, 7. 52%, and 6. 79% respectively.

VII. The ideal proportions for wollastonite and fly ash are determined to be 15% and 20%.

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