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Experimental Investigation on Strength Properties of Concrete with Partial Replacement of Cement by Metakaolin and Alccofine

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ABSTRACT: The demand and use of concrete have led to much research into improving its strength, workability, and many more. Enhancing the strength of concrete is paramount in the construction of basic infrastructure in a bid to make it sustainable. In this study, the influence of partial cement replacement by Metakaolin (MK) and Alccofine (AF) was investigated and the effects on strength properties were determined. Namely, two types of pozzolans have opted for this study which are Metakaolin and Alccofine. This research aimed to lower the cost of cement, a key and costly ingredient in concrete production while enhancing sustainability in the construction industry. Cement was partially replaced with Metakaolin (MK) at varying levels of 0%, 5%, 10%, 15%, and 20%, alongside a constant 0%, 5%, and 10% replacement with Alccofine (AF). The study analyzed the compressive, split tensile, and flexural strengths of MK-AF concrete in comparison to high-strength M60 grade concrete. The goal was to identify the optimal strength values for each property. Strength properties were assessed at 3, 7, and 28 days.

KEYWORDS: Metakaolin; Alccofine; Compressive strength, Split tensile strength, Flexural strength.

I. INTRODUCTION

1.1 General:

In the past decade, supplementary cementitious materials have become essential for creating high-strength, high-performance concrete. These materials, sourced from natural origins, industrial by-products, or waste, often provide greater efficiency in both energy use and production time. The inclusion of fine pozzolanic materials in high-strength concrete reduces the formation of crystalline compounds like calcium hydroxide, resulting in a thinner and more compact interfacial transition zone. This increased density improves load transfer between the cement mortar and coarse aggregate, thereby boosting the concrete’s overall strength. In ultra-high strength concrete, where the matrix is extremely dense, aggregate strength can become the limiting factor. Recent advances have seen the use of pozzolanic materials such as Ground Granulated Blast Furnace Slag, Silica Fume, Fly Ash, Metakaolin, and Alccofine to produce stronger concrete with improved workability and reduced permeability. This study specifically utilized Metakaolin (MK) and Alccofine, and their combination was found to significantly enhance the mechanical properties of the concrete.

1.2 Objectives of Research:

The following are the key goals of this investigation:

1. To investigate the Compressive, Split, and Flexural Strength acquired by the mix at 3 days,7 days, and 28 days respectively.
2. To reduce environmental pollution by utilizing solid wastes.
3. To make an ecologically sustainable concrete mix.
4. To know the optimum cement replacement percentage corresponding to which strength has increased

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II. REVIEW OF LITERATURE

Abhishek Sachdeva, Rajesh Kumar, experimented on partially replacing cement with Alccofine and observed significant improvements in the concrete's performance. The study demonstrated that substituting cement with Alccofine notably enhances concrete's fresh and hardened properties, confirming its effectiveness as a superior Supplementary Cementitious Material. Alccofine was found to improve the workability, strength, and durability of the concrete, with the optimal replacement level identified as 15%.

K. Gayathri, K. R. Chandran, and J. Saravanan (2016), research focused on the impact of replacing cement in concrete with Alccofine on its strength. The study revealed that a 15% substitution of cement with Alccofine led to a significant improvement in strength, whereas other replacement levels did not produce as favorable results. Additionally, they found that incorporating Alccofine as a partial cement replacement enhances the early strength of the concrete.

Mohd. Hamraj The study investigated partially replacing cement with Alccofine 1203 and adding crimped steel fibers of varying aspect ratios to M50-grade concrete. Tests were conducted with 5%, 10%, 15%, and 20% Alccofine. The optimal Alccofine content was found to be 15%, enhancing the strength, workability, and durability of the concrete. This blend proved more durable against acid attack compared to normal concrete.

Vineeth Kumar, Akash Prakash, The study aimed to evaluate the compressive and split tensile strengths of concrete at 7, 14, and 28 days by partially replacing cement with Metakaolin and marble powder. An initial M30 mix was designed, followed by trials where cement was replaced with different combinations of Metakaolin and marble powder: 5% MK + 5% MP, 10% MK + 10% MP, 12.5% MK + 12.5% MP, and 15% MK + 15% MP. Results showed that the highest compressive and split tensile strengths were achieved with a 10% Metakaolin and marble powder replacement.

M Praneeth Kumar,B Ajitha(2021), The study examined the strength of M60 concrete by replacing cement with Metakaolin in proportions ranging from 0% to 20% and completely substituting fine aggregate with steel slag sand. Standard 150 mm x 150 mm x 150 mm cubic specimens were used for testing. Results indicated that the optimal strength was achieved with a 15% replacement of cement by Metakaolin and 100% replacement of fine aggregate with steel slag sand. Beyond 15% Metakaolin substitution, the concrete's strength diminished. The use of Metakaolin not only enhances concrete performance but also contributes to environmental sustainability by promoting green concrete production.

Ch. Jyothi Nikhila, J.D Chaitanya Kumar, the goal was to assess the strength of the cement mix while being substituted with Metakaolin with cement. The concrete mix grade used was M70. The percentages of replacement-induced replacement were 0%, 5%, 10%, 15%, 20%, and 25%.

III. EXPERIMENTAL WORK

3.1 Materials:

A. Cement: In this study, Ordinary Portland Cement (OPC) 53-grade from Sri Chakra, with a specific gravity of 3.14, was selected due to its easy market availability. The cement's characteristics were tested according to IS – 8112:1989 specifications, resulting in the following findings: Fineness of 5% (≤10% limit), consistency at 29%, an initial setting time of 65 minutes (≥30 minutes), and a final setting time of 550 minutes (≤600 minutes).

B. Fine Aggregate: For this study, high-quality river sand was used as the fine aggregate, which was sieved through a 4.75mm mesh. The sand's characteristics were tested, yielding the following results: specific gravity of 2.65, bulk density of 1890.81 kg/m³, fineness modulus of 2.52, and a water absorption rate of 1%.

C. Coarse Aggregate: The coarse materials utilized in this research are 20 mm natural stone coarse aggregates that are locally available. Laboratory tests on coarse aggregate were performed as per IS: 2386 (part III)- 1963 to determine different characteristics like specific gravity, and water absorption were obtained as 2.74, and 0.5% respectively.

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D. Water: Concrete should be mixed using clean water free from harmful levels of oils, acids, alkalis, organic materials, or other detrimental chemicals. In this study, potable tap water from the college campus water facility, compliant with IS456-2000 standards, was utilized for both casting and curing the concrete specimens.

3.2 Mineral admixtures

A. Alccofine: Alccofine is a modern mineral admixture with a micro-fine particle size significantly smaller than traditional hydraulic materials such as cement, silica fume, fly ash, and GGBS. It is a key component for achieving high-strength concrete, enhancing both workability and strength. Alccofine is user-friendly and can be directly mixed with cement. Its optimized particle size distribution boosts concrete performance at the fresh stage. Manufactured under strictly controlled conditions with specialized equipment, Alccofine's unique particle size optimization contributes to its effectiveness in accelerating strength development.

B. Metakaolin: In this study, Metakaolin was obtained from Astra Chemicals, Chennai. It was sieved, and only the portion that passed through a 100µ sieve was utilized for the experiments. The chemical and physical characteristics of Metakaolin (MK), Alccofine, and Ordinary Portland Cement (OPC) are provided in Table 1.

3.3 Chemical Admixture:

A. Super Plasticizer: Superplasticizers are incorporated into cement concrete during mixing to achieve the desired properties in both the plastic and hardened states. For this study, Polycarboxylate Ether Superplasticizer from Chemcon Tech SYS was utilized. It meets the standards of IS: 9103 – 1999 and has a specific gravity of 1.2.

Table 1: Physical and Chemical Properties of MK and AF.

Properties	OPC 53grade	MK	Alccofine
Physical			
Specific gravity	3.14	2.6	2.9
Average particle size	20µm	2.5µm	6µm
Specific area m^2/kg	325	13000	12000
Color	Grey	Off- white	White
PH	12	5.5	8
Chemical Composition %			
SiO2	21.54	52	35.30
Al2O3	4.68	46	21.40
Fe2O3	2.46	0.60	1.03
TiO2	-	0.65	-
CaO	62.58	0.09	32.20
MgO	1.08	0.03	8.20
Na2O	0.24	0.10	1.8
K2O	0.87	0.03	-
Loss on ignition	2.58	1.00	0.13%

3.4 Mix proportions: To achieve M60 grade concrete, the mix was designed according to IS 10262-2009 with a water-to-cement ratio of 0.38. Different mixtures were prepared by replacing cement with 0%, 5%, 10%, 15%, and 20% Metakaolin (MK), and 0%, 5%, and 10% Alccofine, which was kept constant. The compressive, split, and flexural strengths of each mix were evaluated by casting and testing six cubes, cylinders, and beams at curing periods of 3, 7, and 28 days.

3.5 Testing methods

3.5.1. Workability test: The workability of the concrete was evaluated using slump and compaction factor tests. These assessments were carried out for each of the concrete mixes.

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3.5.2. Compression test: The testing procedure involved casting 150 x 150 mm concrete cubes to assess performance. M60 grade concrete was formulated using Ordinary Portland Cement (OPC), natural river sand, coarse aggregate (sized between 20mm and 4.75mm), along with Metakaolin (MK) and Alccofine. For each mix, three specimens were prepared to obtain average values. After 24 hours, the specimens were demolded and placed in curing for periods of 3, 7, and 28 days. Strength tests were conducted thereafter to evaluate the concrete's overall performance, as detailed below.

3.5.3 Split Tensile Test: The testing method involved casting cylindrical concrete specimens measuring 100mm in diameter and 300mm in height. M60 grade concrete was produced using Ordinary Portland Cement (OPC), natural river sand, coarse aggregate (sized between 20mm and 4.75mm), Metakaolin (MK), and Alccofine. Three cylinders were prepared for each mix to determine average results. After 24 hours, the specimens were demolded and placed in curing for 3, 7, and 28 days. Strength tests were then conducted to assess the concrete's performance, as described in the following sections.

3.5.4 Flexural Test: The testing program consisted of casting and evaluating concrete beam specimens with dimensions of 100mm x 50mm x 50mm. M60 grade concrete was produced using Ordinary Portland Cement (OPC), natural river sand, coarse aggregate (sized between 20mm and 4.75mm), Metakaolin (MK), and Alccofine. Three beams were cast for each mix to obtain average results. After 24 hours, the beams were demolded and subjected to curing for 3, 7, and 28 days. Strength tests were conducted to evaluate the concrete's performance, as outlined in the subsequent sections.

IV. TEST RESULT AND DISCUSSIONS

4.1. Workability:

The workability of both the control mix and the MK-AF blended concrete was assessed following IS standards. Figure 1 illustrates the workability of concrete at various levels of MK-AF replacement. The results show that the control mix exhibited a higher slump value compared to the MK-AF concrete blends.

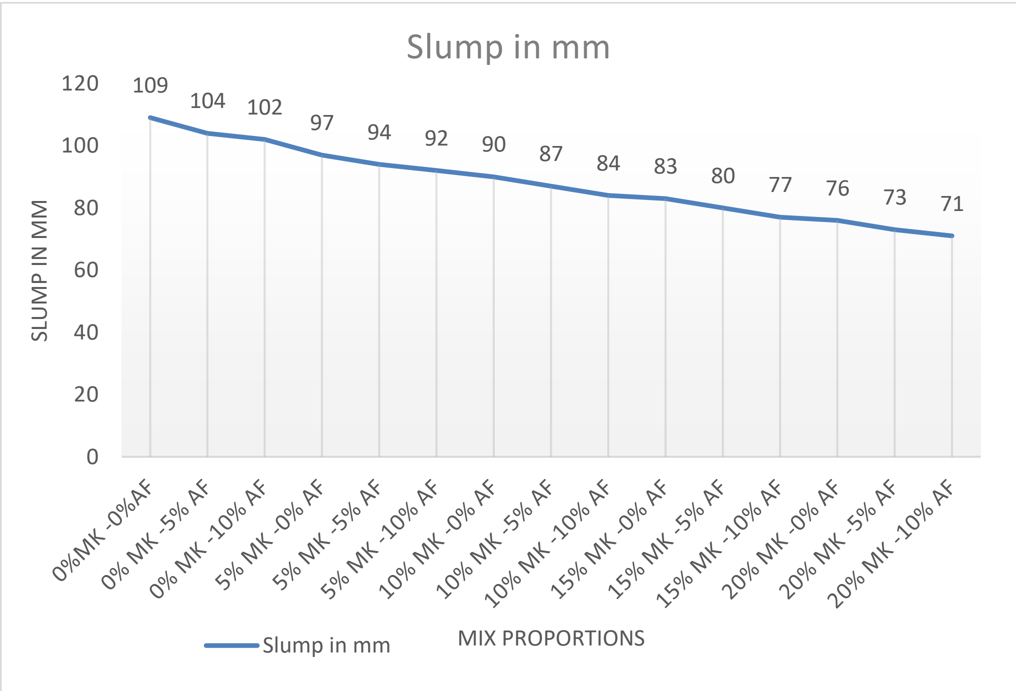

Figure 1: Slump with different mixed proportions of MK-AF.

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4.2 Casting of specimens:
Before use, the molds for casting cubes, cylinders, and beams were meticulously cleaned. To prevent adhesion and reduce leakage, a light layer of oil was applied to the interior surfaces of the molds. The concrete was subsequently poured into the oiled molds for cubes, beams, and cylinders, utilizing a tamping rod to achieve optimal compaction. Testing was conducted after curing periods of 3, 7, and 28 days.

4.3 Curing:
Curing is the process of maintaining conditions that facilitate the effective setting and hardening of concrete. Once the specimens are demolded, they are completely submerged in a water pond, ensuring at least 50 mm of water covers them until they are transported to the testing laboratory. If possible, the temperature should be maintained between 10°C and 25°C during this period.

4.4 Compressive strength: Figure 2 illustrates the outcomes of the uniaxial compressive strength tests. In comparison to the control mix, the compressive strength of the concrete incorporating Metakaolin (MK) and Alccofine (AF) demonstrated a gradual increase of up to 9.44% before experiencing a decrease. The study determined that the most effective combination was 15% MK and 10% AF.

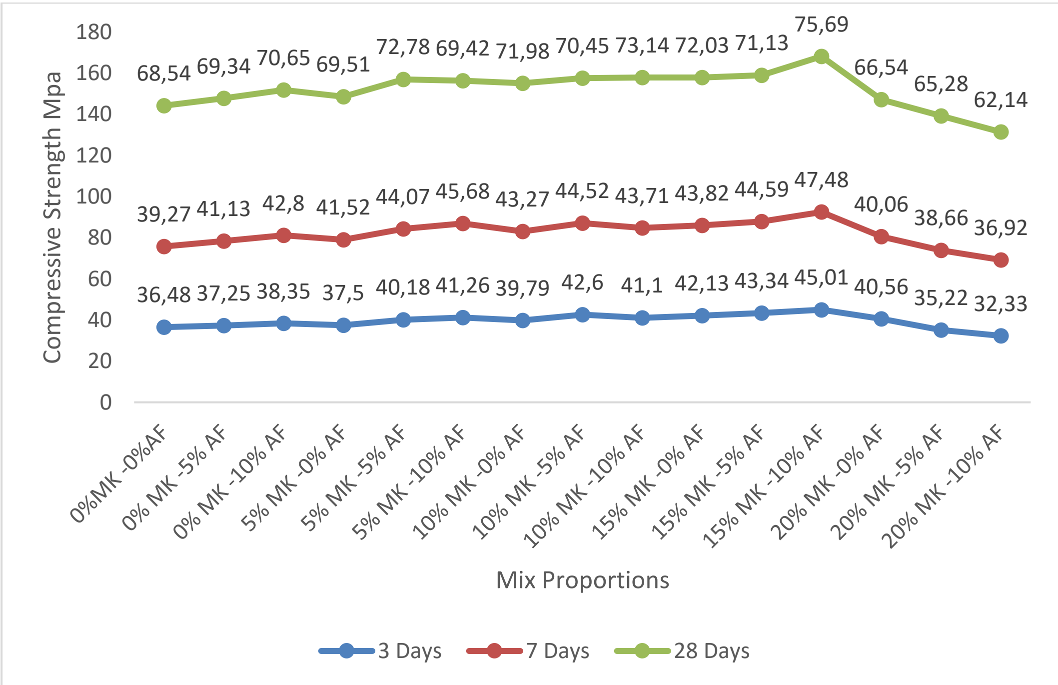

Figure 2: Compressive strength with different mixed proportions of MK-AF.

4.5 Split Tensile Strength: Laboratory results revealed that the split tensile strength peaked when cement was substituted with 15% Metakaolin (MK) and 10% Alccofine (AF). When compared to the control mix, the split tensile strength of the MK-AF concrete exhibited a consistent increase of up to 18.67% before experiencing a decline. The study concluded that the optimal mix was 15% MK combined with 10% AF.

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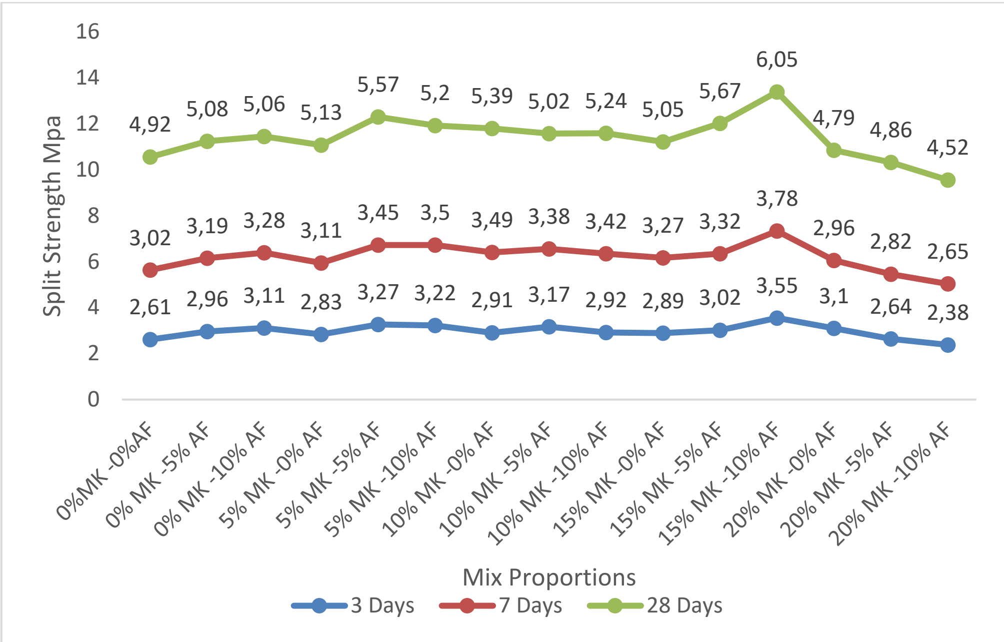

Figure 3: Split strength with different mixed proportions of MK-AF.

4.6 Flexural Strength: Laboratory findings indicated that the flexural strength reached its peak when 15% of the cement was substituted with Metakaolin (MK) and 10% with Alccofine (AF). In comparison to the control mix, the flexural strength of the MK-AF concrete showed a consistent increase of up to 7.6% before starting to decline. The study concluded that the most effective combination was 15% MK and 10% AF.

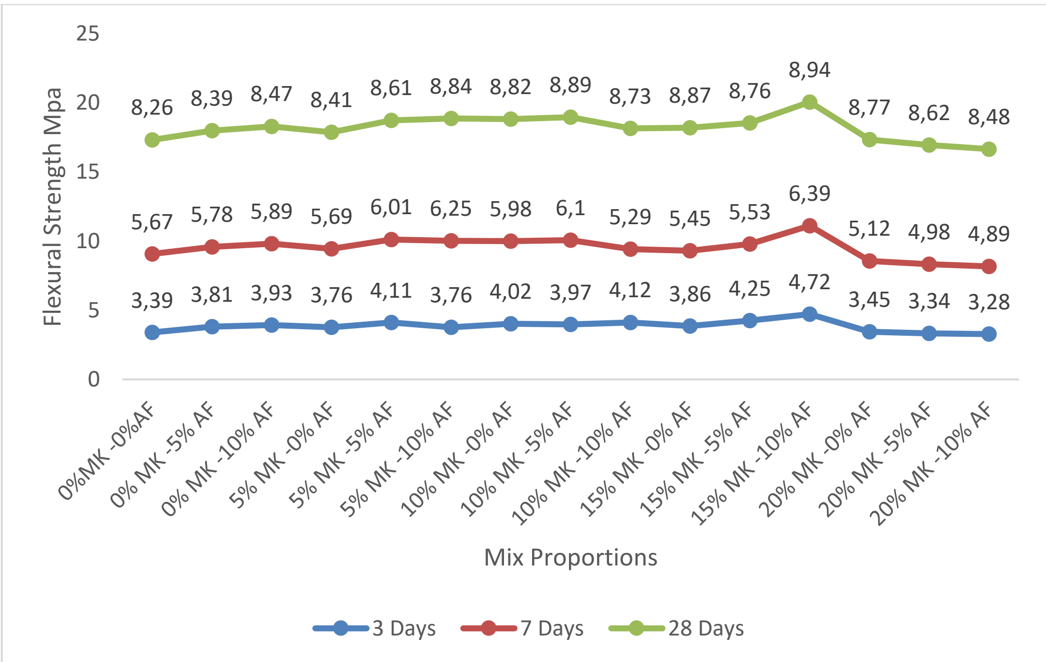

Figure 4: Flexural strength with different mixed proportions of MK-AF.

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V. CONCLUSION

In this study, M60-grade concrete was formulated and approximately 108 specimens—cubes, cylinders, and beams—were cast to evaluate the compressive, split, and flexural strengths of the concrete. The analysis of the results led to the following conclusions:

1. The slump tests indicated that increasing the replacement levels of Metakaolin (MK) and Alccofine (AF) led to a decrease in slump. These results fall within the expected range for concrete workability.
2. Concrete incorporating MK and AF demonstrated enhanced strength over time. Specifically, the compressive strength of MK and AF concrete exceeded that of conventional concrete by 9.44%.
3. The maximum split tensile strength in cylinders was observed with 15% MK and 10% AF replacement. Beyond this proportion, strength values decreased across all curing ages. The split tensile strength improved by approximately 18.67% compared to the control mix.
4. The highest flexural strength for beams was achieved with a mix of 15% MK and 10% AF, showing a strength increase of around 7.6% compared to the standard mix.
5. The study identifies 15% MK and 10% AF as the optimal replacement percentages for cement.
6. The incorporation of MK and AF resulted in higher water absorption rates compared to OPC concrete.
7. Experimental findings suggest that blending cement with MK and AF can lead to optimal concrete mixes, enhancing overall performance.

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