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Effect of Metakaolin and Fly Ash Addition on Fresh and Hardened Cement Concrete

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***Abstract*: The building material that is most often utilised worldwide is concrete. In infrastructure projects, it is frequently employed. Due to the rapid speed of construction operations in India, the major goal of this study is to find other sources of cement that would lower the amount of cement needed for construction. Cement is partially replaced with metakaolin and fly ash. It has a variety of pozzolanic qualities that have beneficial impacts on the final characteristics of concrete. These characteristics lead calcium hydroxide, a byproduct of cement hydration, to chemically react with the active ingredients.The primary goal of this research is to partially replace OPC with Metakaolin and Fly ash. This research aims to examine the qualities of M-30 grade concrete, concrete manufactured with metakolin, and concrete made with fly ash while they are both fresh and hardened. The weight of cement has partially replaced metakoalin in the ratios of 5%, 10%, 15%, and 20%. The weight of cement has replaced a portion of the fly ash in the amounts of 7.5%, 15%, 22.5%, and 30%. Slump testing is done to investigate the new qualities. Compressive and split tensile strength tests are carried out on concrete after 28 and 56 days of curing to examine its hardened qualities.**

***Keywords*: Fly ash, metakaolin, compressive strength, split tensile strength, slump test, fine aggregate, coarse aggregate.**

1. Introduction

Fine and coarse aggregate are combined to form concrete, a composite material, which is then joined by a fluid cement (cement paste) that eventually solidifies (cure). Concrete is the most often used building material and the second most utilised substance in the world after water. Concrete's consistency is aided by inspection and monitoring at each stage. It is created by combining cement, water, and an inert sand and gravel matrix. It then goes through a number of processes, including shipping, placement, compacting, finishing, and curing. Cement, water, and inactive materials made up of fine and coarse aggregates make up the components.

OPC is substituted in part with metakaolin and fly ash. High-quality pozzolanic substance is metakaolin. At temperatures between 650°C and 850°C, pure or refined kaolinite clay is calcined to create metakaolin. When it is employed in the concrete, it will serve as filler penetrating into the spaces (space) between cement particles hence leading into a more impermeable concrete. One of the byproducts of the burning of pulverised coal in thermal power plants is fly ash, which is made up of tiny particles that ascend with the gases. Fly ash is created when molten ash quickly cools and solidifies.

Fig. 1. Cement

The most often used type of cement is portland cement. It is a fundamental component of many plasters, mortar, and concrete. In 1824, British mason Joseph Aspdin received a patent for Portland cement. Because of its colour resemblance to Portland limestone, which is extracted from the English Isle of Portland and extensively utilised in London construction, it was given that name. It is composed of various calcium silicate (alite, belite), aluminate, and ferrites compounds, which combine calcium, silicon, aluminium, and iron in ways that will react with water. Clay or shale, which are sources of silicon, aluminium, and iron, are heated with limestone, a source of calcium, to create Portland cement, which is then ground with a sulphate source (most commonly gypsum).

Many cutting-edge innovations are employed in contemporary cement kilns to reduce fuel usage per tonne of clinker produced. Cement is the most expensive to create in terms of energy costs out of all the elements necessary to make a certain amount of concrete. For a tonne of clinker to be produced and subsequently ground into cement, even the most sophisticated and effective kilns need between 3.3 and 3.6 gigajoules of energy. Utilized tyres are the most popular trash that may be used to fuel a variety of kilns. Even difficult-to-use fuels may be burned entirely and effectively in cement kilns due to the extremely high temperatures and extended periods of time at those temperatures.

2. Literature Review

[1] This study examines the impact of adding more cementitious materials to binary and ternary mixes on the characteristics of self-compacting concrete while it is new and

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after it has hardened (SCC). Four mixes with a water/cementitious ratio of 0.36 and a cum retarder dose of 0.9% by weight were created for this purpose. The other combinations included binary and ternary cementitious blends of OPC, MK, and FA, whereas the controlled designed mix used solely Ordinary Portland Cement (SCC) as the binder. Following mixing, the slump flow, v-funnel flow duration, and L-Box ratio of the SCC were measured. Additionally, the hardened concrete's compressive and split tensile strengths were assessed after 7, 28, 90, and 180 days. The drop flow spread rises when the dosage of FA is increased, but it reduces when the replacement levels of MK are raised. Up to 20% of the MK dose can be used for the L-box test; anything more resulted in solid obstruction. Up to 30%, the FA doses are acceptable; after that, bleeding and segregation occur. Comparatively to the standard SCC, the combination of MK and FA increased compressive strength and split tensile strength up to 35% (15% MK and 10% FA).

[2] For the experimental tests in his work, cement is used in place of fly ash. A design mix of M25 and M30 grade concrete was employed for the experiment. The concrete's compressive strength was tested after 7, 14, 21, and 28 days of curing. The percentage of fly ash replaced by cement varies from 0% to 40% with a 10% increase. The control mix is used for the comparison. The study's findings lead to the conclusion that adding more fly ash weakens concrete.

[3] This study summarises the findings of an experimental inquiry done to determine whether MK & FA were suitable for making concrete. OPC 53 grade was used to create the traditional concrete M25, and MK and FA were used to create the other mixes in place of some of the OPC. The replacement MK levels were 5%, 10%, 15%, 20%, and 25%, with fly ash at 5% for the whole mix. Prisms and cube cylinders were cast, and tests on the compressive, split tensile, and flexural strengths were done after 28 days. The following conclusions were drawn from the results: for all mixtures, compressive strength and flexural strength rise as the proportion of MK increases, however for FA, strength increases up to 15% replacement level before beginning to decline.

[4] The mix design for M40 grade SCC was completed in this study. A variation of 3%, 6%, and 9% MK was used to replace 5%, 15%, and 25% of the cement in SCC with FA. On recently laid concrete, tests such the V-funnel, L-box, U-box, and J-ring were conducted. On hard concrete, tests for compressive strength, split tensile strength, and flexural strength were performed. Tests were done on beams, cylinders, and cubes that were cast. According to the findings, the compressive strength and flexural strength of SCC cubes improve up to 24% (F15%+M9%) and then decline as the proportion of cement replacement rises. For a percentage of cement replacement, the split tensile strength of cylinders at 28 days is 14 (F5%+M9%).

[5] The impact of fly ash and M sand on concrete is investigated in this research. Fly ash is used in lieu of the cement, and M sand is used in place of natural sand. The comparison is being looked at. For varied curing times of 7, 14, and 28 days, basic mechanical strength metrics such compressive strength, split tensile strength, and flexural strength are being determined. The grade of the mix that was employed was M25. The fly ash was totally replaced and the natural sand was refilled to a depth of 25 to 35% with a 5% increment.

[6] In this essay, the effects of admixtures that substitute cement while maintaining the same water-to-cement ratio for both regular concrete and modified concrete are discussed. 30% of FA and MK were replaced in part with cement at 0, 5, 10, 15, and 20. M20 grade concrete mix was utilised for the experimental inquiry. The concrete underwent tests to determine its flexural and compressive strengths. Slump cone testing, compaction factor testing, and Vee Bee Constometer testing are used to measure how workable fresh concrete is. After 7 days and 28 days of cure, the cubes and beams underwent testing. These outcomes were attained. Compressive strength rapidly decreases when FA replacement percentage is increased and gradually increases when Metakaolin is added.

[7] Through the partial replacement of cement, the article examines the impact of fly ash and Metakaolin. Metakaolin and fly ash are chosen as the additional cementitious ingredients because they exhibit strong pozzolanic activity and the ability to produce concrete with a high strength. Metakaolin and fly ash were used as replacement of cement in percentages of 0, 5, 10, 15, and 20. For the experimental investigation, a concrete mix of grade M20 was employed with various amounts of cementitious ingredients. After 7 days and 28 days of curing, the specimens, cubes and cylinders, were examined for compressive strength and split tensile strength. According to the experimental results, cementitious materials' strength decreased by more than 10%.

[8] Without using any additional cement, M25 of reference concrete was constructed for this study. 20% of fly-ash and 0, 5, 10, and 15% of metakaolin in cement were used to partially replace the same grade. On cubes, beams, and cylinders cured for 7, 28, and 90 days, an investigation was conducted to determine the characteristics of fresh and hardened concrete. After testing it was discovered that compressive strength, split tensile strength, flexural strength increased compared to standard mix cement concrete specimens due to inclusion of fly-ash and Metakaolin. The best percentage for increasing strength is seen when metakaolin is used to replace cement in amounts of 10%. For good strength, metakaolin up to 10% and fly ash up to 20% can be used in place of cement. 15% cement substitution with another material resulted in a significant decline in strength.

3. Experimental Result

The test was done on fresh, hardened control concrete as well as concrete that had metakaolin and fly ash used in place of some of the cement. The slump test is used to determine if concrete is workable. The accompanying chart illustrates the variance in slump value.

The following Designation Mix are used for current experimental study:

- M0: 100% Cement + 0% Metakaolin + 0% fly ash +100% fine aggregate + 100% coarse aggregate

- M1: 87.5% Cement + 5% Metakaolin+ 7.5% fly ash + 100% fine aggregate + 100% coarse aggregate
- M2, 75% Cement + 10% Metakaolin+ 15% fly ash + 100% fine aggregate + 100% coarse aggregate
- M3, 62.5% Cement + 15% Metakaolin+ 22.5% fly ash + 100% fine aggregate + 100% coarse aggregate
- M4, 50% Cement + 20% Metakaolin+ 30% fly ash + 100% fine aggregate + 100% coarse aggregate

Slump values for standard concrete and concrete produced by partially substituting fly ash and metakaolin for cement.

Table 1
Slump values

S. No.	Mix Designation	Slump in mm
1	M0	90
2	M1	105
3	M2	105
4	M3	110
5	M4	115

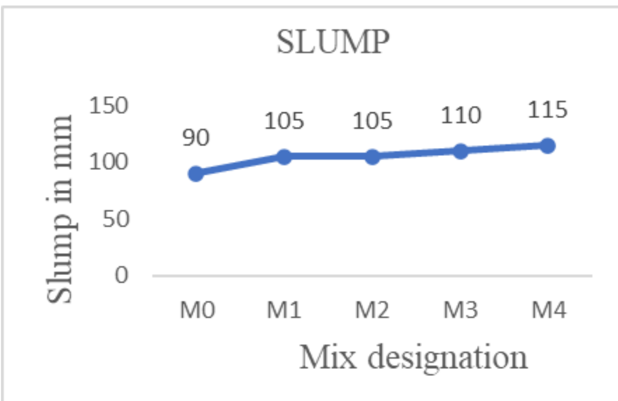

Fig. 2. Slump test

The slump values for control concrete and concrete produced by partially substituting Metakaolin and Fly ash for cement are shown on the Fig. 2.

Results of a compression strength test:

Three 150x150x150 mm cubes are used to test the compressive strength of each concrete mix at 28 and 56 days after curing.

The results of the compressive strength test for control concrete and concrete created by partially substituting cement with metakaolin and fly ash are shown in the table below (Table 2).

Table 2
Results of compressive strength overall

S. No.	Mix Designation	Compressive strength (MPa)	
		28 days	56 days
1	M0	31.33	32.74
2	M1	41.69	41.63
3	M2	38.96	39.11
4	M3	26.66	27.47
5	M4	16.06	20.14

Fig. 3 shows the graph compares the 28-day compressive strength of control and concrete prepared by partially substituting Metakaolin and Fly ash for cement.

After 28 days and 56 days of curing, the test was performed.

According to IS: 5186-1999, split tensile tests on cylinders 150mm and 300mm in length were performed. The split tensile test results for control concrete and concrete prepared by partially substituting cement with metakaolin and fly ash are shown in the table below (Table 3).

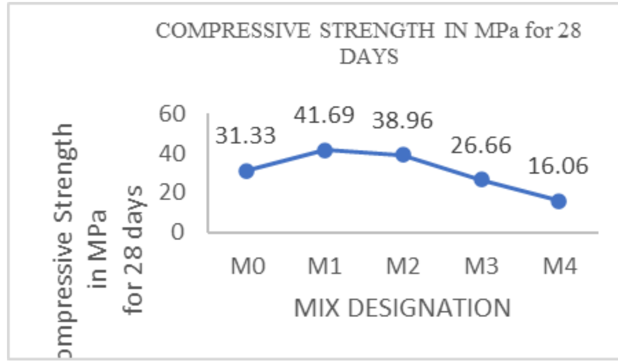

Fig. 3. 28 days compressive strength

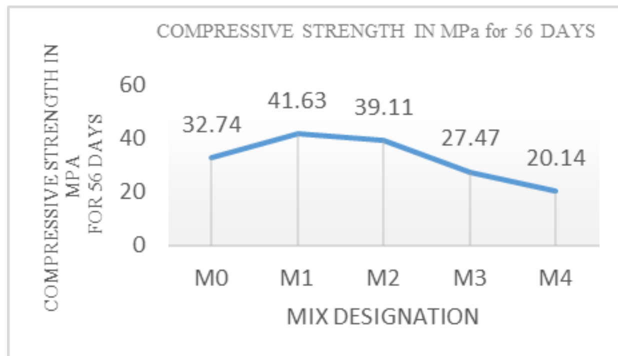

Fig. 4. 56 days compressive strength

Table 3
Overall results of split tensile strength test

S. No.	Mix Designation	Split tensile strength (MPa)	
		28 days	56 days
1	M0	2.33	2.57
2	M1	2.78	2.97
3	M2	2.57	2.87
4	M3	2.16	2.35
5	M4	1.85	1.95

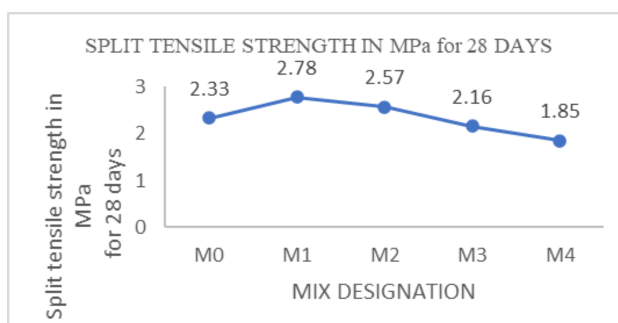

Fig. 5. 28 days split tensile strength

The Fig. 5 compares the 28-day split tensile strength of control and concrete prepared by partially substituting Metakaolin and Fly ash for cement. The Fig. 6 compares the 56-day split tensile strength of control and concrete prepared by partially substituting Metakaolin and Fly ash for cement.

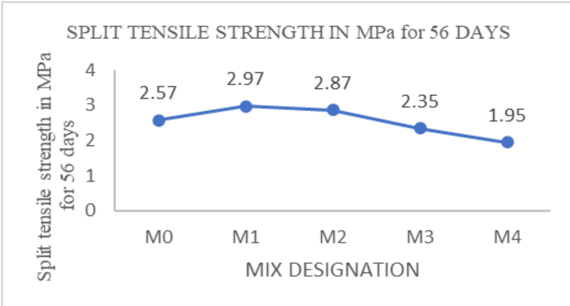

Fig. 6. 56 days split tensile strength

4. Observations and Discussions

The impact of adding metakaolin and fly ash to fresh and hardened cement concrete is examined in the current work, and the tests conducted led to the following findings.

The test's findings indicate that all blends' workability has improved. When compared to control concrete, the compressive strength of mixes M1 and M2 rose by 33.06% and 24.35%, respectively, after 28 days of curing. M3 and M4 contrast negatively with the control concrete by 14.90% and 48.73%, respectively. Additionally, after 56 days of curing, the compressive strengths of mixes M1 and M2 were 27.15% and 19.45% higher, respectively, than those of the control concrete. M3 and M4 contrast negatively with the control concrete by 16.09% and 38.48%, respectively.

The split tensile strength of mixes M1 and M2 rose by 19.30% and 10.30%, respectively, during 28 days of curing time as compared to the control concrete. M3 and M4 contrast negatively with the control concrete by 7.29% and 20.60%, respectively. Additionally, after 56 days of curing, mixes M1 and M2's split tensile strength improved by 15.56% and 11.67%, respectively, in comparison to control concrete. M3 and M4 contrast negatively with the control concrete by 8.56% and 24.12%, respectively.

We can infer from the experimental results of compressive strength and split tensile strength of control concrete and concrete made with Metakaolin and fly-ash that the latter performs better than the former, yielding higher strength at 12.5% (5% Metakaolin + 7.5% fly-ash) and 25% (10% Metakaolin + 15% fly-ash) replacement levels to the former, while at 37.5% (15% M + 15% F) replacement levels to the former, the former is less effective.

5. Conclusion

The following conclusion may be reached from the fresh concrete qualities and restricted strength testing.

- Workability is increased when fly ash and metakaolin are combined with cement.
- When compared to the control concrete, the strength of the M1 and M2 mixes had improved by 33.06% and 24.35%, respectively, after 28 days of curing.
- The strength of the M1 and M2 mixes rose by 27.15% and 19.45%, respectively, at 56 days of curing when compared to the control concrete.
- When compared to the control concrete, the strength of the M1 and M2 mixes had grown by 19.30% and 10.30%, respectively, after 28 days of curing.
- Split tensile testing after 56 days of curing revealed that the strength of the M1 and M2 mixes had risen by 15.56% and 11.67%, respectively, in comparison to the control concrete.
- The concrete made with replacing cement by Metakaolin and fly-ash is performing better than the control concrete, yielding higher strength at 12.5% (5% Metakaolin + 7.5% fly-ash) and 25% (10% Metakaolin + 15% fly-ash) of replacement level to the control concrete, according to experimental results of compressive strength and split tensile strength of control concrete and concrete made with Metakaolin and fly-ash replacing cement.
- The concrete made with replacing cement by Metakaolin and fly-ash shows negative values at 37.5% (15% Metakaolin + 22.5% fly-ash) and 50% (20% Metakaolin + 30% fly-ash) of replacement level to the control concrete, according to experimental results of compressive strength and split tensile strength of control concrete and concrete made with Metakaolin and fly-ash replacing cement.
- These findings lead us to the conclusion that the strength rises up to a 25% cement replacement level with metakaolin and fly ash, and that strength decreases beyond that compared to the control mix.

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