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Experimental Study On The Effects Of Metakaolin And Polypropylene Fibers On The Mechanical Properties Of Concrete.

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Abstract: This experimental study investigates the combined influence of Metakaolin (MK) and Polypropylene (PP) fibers on the mechanical properties of M30 grade concrete. Ordinary Portland Cement (OPC) was partially replaced with MK at 0%, 5%, 10%, and 15% by weight, while PP fibers were added at 0%, 0.1%, and 0.2% by volume of concrete. A constant water–binder ratio of 0.42 was maintained, and a polycarboxylate-based superplasticizer (0.8% bwob) was used to ensure adequate workability. Concrete specimens—cubes (150×150×150 mm), cylinders (150×300 mm), and prisms (100×100×500 mm)—were cast and water-cured. Tests were conducted for compressive, split-tensile, and flexural strength at 7, 14, and 28 days.

The results demonstrated that the inclusion of MK enhances strength through pozzolanic reactions and refinement of the microstructure, while PP fibers improve crack resistance and post-crack ductility. The optimum mix (10% MK + 0.1% PP fibers) exhibited the highest mechanical performance with an 18% increase in compressive strength, 26% improvement in split-tensile strength, and 33% enhancement in flexural strength compared to the control mix. However, higher MK content (15%) slightly reduced strength due to dilution effects, and 0.2% PP fiber content marginally decreased compressive strength due to workability issues. The synergistic use of 10% MK and 0.1% PP fibers is therefore recommended for producing durable and high-performance M30 concrete with superior crack resistance and toughness.

Key Words*:* Metakaolin, Polypropylene fibers, M30 grade concrete, Compressive strength, Pozzolanic reaction, Workability, Crack resistance, Mechanical properties.

I. INTRODUCTION

Concrete, though the most widely used construction material, suffers from limitations such as brittleness and low tensile strength. Supplementary cementitious materials (SCMs) and fibers are often introduced to overcome these drawbacks. **Metakaolin (MK)**, a highly reactive pozzolanic material derived from the calcination of kaolin clay, improves the microstructure and strength of concrete through secondary hydration reactions. **Polypropylene (PP) fibers**, on the other hand, control crack propagation, enhance ductility, and improve the toughness of concrete.

The combined incorporation of MK and PP fibers aims to produce a durable, crack-resistant, and high-strength concrete mix suitable for structural applications. This study investigates their synergistic effect on the mechanical properties of M30 grade concrete.

1.1 Objectives of the Study

The main objective of this research is to investigate the combined influence of **Metakaolin (MK)** and **Polypropylene (PP) fibers** on the **mechanical performance of M30 grade concrete**. The specific objectives of the study are:

1. **To evaluate the effect of Metakaolin as a partial replacement of cement** (at 0%, 5%, 10%, and 15%) on the compressive, split-tensile, and flexural strengths of concrete.
2. **To examine the influence of Polypropylene fibers** (at 0%, 0.1%, and 0.2% by volume) on the tensile and flexural behavior of concrete, particularly in controlling crack formation and propagation.
3. **To identify the optimum combination** of Metakaolin and PP fiber content that yields maximum improvement in mechanical strength and durability without adversely affecting workability.
4. **To compare the mechanical properties** of MK and PP fiber-modified concrete with those of the control (conventional) M30 concrete mix.
5. **To assess the synergistic effects** of Metakaolin and Polypropylene fibers on the microstructure, ductility, and toughness characteristics of concrete.
6. **To provide recommendations** for practical implementation of MK and PP fiber-based concrete in structural applications requiring enhanced strength and crack resistance.

1.2 Scope of the Study

The present experimental investigation focuses on enhancing the **mechanical properties and crack resistance** of M30 grade concrete by using **Metakaolin (MK)** as a partial replacement of cement and **Polypropylene (PP) fibers** as secondary reinforcement.

The scope of the study includes:

1. **Material Selection:** Utilization of Ordinary Portland Cement (53 grade), Metakaolin as a supplementary cementitious material, and Polypropylene fibers in controlled proportions.
2. **Mix Proportioning:** Design of M30 grade concrete mix with a constant water–binder ratio of 0.42 and variable percentages of MK (0%, 5%, 10%, 15%) and PP fibers (0%, 0.1%, 0.2%).
3. **Specimen Preparation:** Casting and curing of cube, cylinder, and prism specimens for testing compressive, split-tensile, and flexural strength.
4. **Testing and Evaluation:** Determination of mechanical properties at **7, 14, and 28 days** to analyze the influence of MK and PP fibers individually and in combination.
5. **Performance Optimization:** Identification of the optimum mix proportions offering maximum strength and ductility with satisfactory workability.
6. **Comparative Analysis:** Evaluation of results with respect to control concrete to assess improvement in performance and material efficiency.

1.3 Literature Review Summary

- **Khatib and Wild (1996)** reported that replacing cement with up to 10% metakaolin enhances compressive strength and reduces permeability due to improved particle packing.
- **Ambroise et al. (1994)** observed that MK contributes to the formation of additional C–S–H gel, resulting in denser concrete microstructure.
- **Sivakumar and Santhanam (2007)** demonstrated that PP fibers enhance the ductility and post-crack behavior of concrete without significantly altering compressive strength.
- **Patel et al. (2019)** combined metakaolin (10%) and PP fibers (0.1%) and observed a synergistic increase in flexural and tensile strengths by over 25%.
- **Thomas and Bhattacharjee (2010)** concluded that excessive fiber content (>0.2%) reduces workability, leading to poor compaction and reduced strength gains.

From the literature, it is evident that the optimal dosage of MK lies between 5–15%, and PP fibers around 0.1–0.2% enhance ductility. However, limited research is available on their combined use, motivating this experimental study.

II.METHODOLOGY

The methodology adopted in this experimental study is designed to systematically evaluate the influence of **Metakaolin (MK)** and **Polypropylene (PP) fibers** on the mechanical properties of **M30 grade concrete**. The experimental program involves material characterization, mix design formulation, casting, curing, and testing of specimens under controlled laboratory conditions.

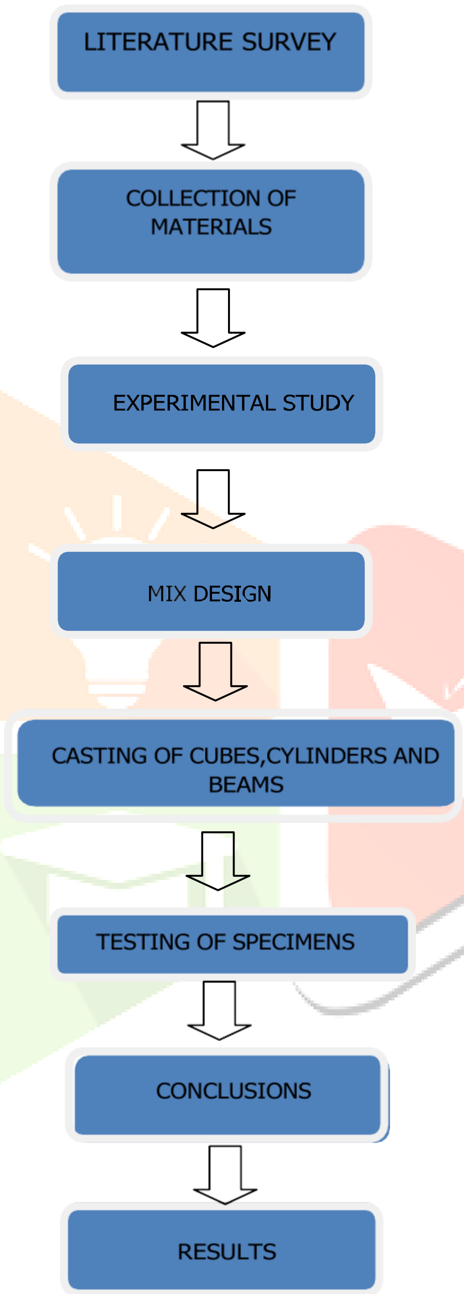

Fig.2.1 Flowchart of methodology

III. MATERIAL TESTING RESULTS

3.1 Cement (Ordinary Portland Cement – 53 Grade)

Property	Test Result
Fineness (m^2/kg)	320
Standard Consistency (%)	31
Initial Setting Time (min)	35
Final Setting Time (min)	480
Compressive Strength (MPa) – 28 days	55

3.2 Fine Aggregate (Zone II, River Sand)

Property	Test Result
Specific Gravity	2.64
Water Absorption (%)	1.2
Fineness Modulus	2.65

3.3 Coarse Aggregate (Crushed Granite, 20 mm down)

Property	Test Result
Specific Gravity	2.70
Water Absorption (%)	0.8
Impact Value (%)	21
Crushing Value (%)	24

IV.MIX DESIGN

- Grade **of Concrete:** M30
- Target **Mean Strength:** 38.25 MPa
- Water–**Cement Ratio:** 0.42
- Cement **Content:** 394 kg/m^3
- Water **Content:** 165 kg/m^3
- Fine **Aggregate:** 681 kg/m^3
- Coarse **Aggregate:** 1204 kg/m^3
- Superplasticizer **(PCE-based):** 0.8% by weight of binder
- Mix **Proportion (by weight):** 1 : 1.73 : 3.06 : 0.42
- Metakaolin **Replacement:** 0%, 5%, 10%, 15% (by weight of cement)
- PP **Fiber Content:** 0%, 0.1%, 0.2% (by volume of concrete)
- Optimum **Mix:** 10% Metakaolin + 0.1% PP fibers

V.TESTS ON CONCRETE

5.1 Compressive strength

The concept of compressive resistance, which refers to a material or structure's ability to withstand surface loads without cracking or deflecting. When a material is subjected to compression, it tends to shrink in size, whereas in tension, it elongates. The test procedure for determining compressive resistance involves...

Fig 5.1: Compressive strength test

Table 5.1 Cube Compressive Strength for 7-Days, 14-Days & 28-days

Mix ID	% Metakaolin	% PP Fiber	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
M0	0	0	30.4	35.2	41.1
M1	5	0.1	33.2	38.9	45.8
M2	10	0.1	35.5	41.2	**48.6**
M3	15	0.1	33.7	39.5	45.0
M4	10	0.2	34.0	40.1	47.2

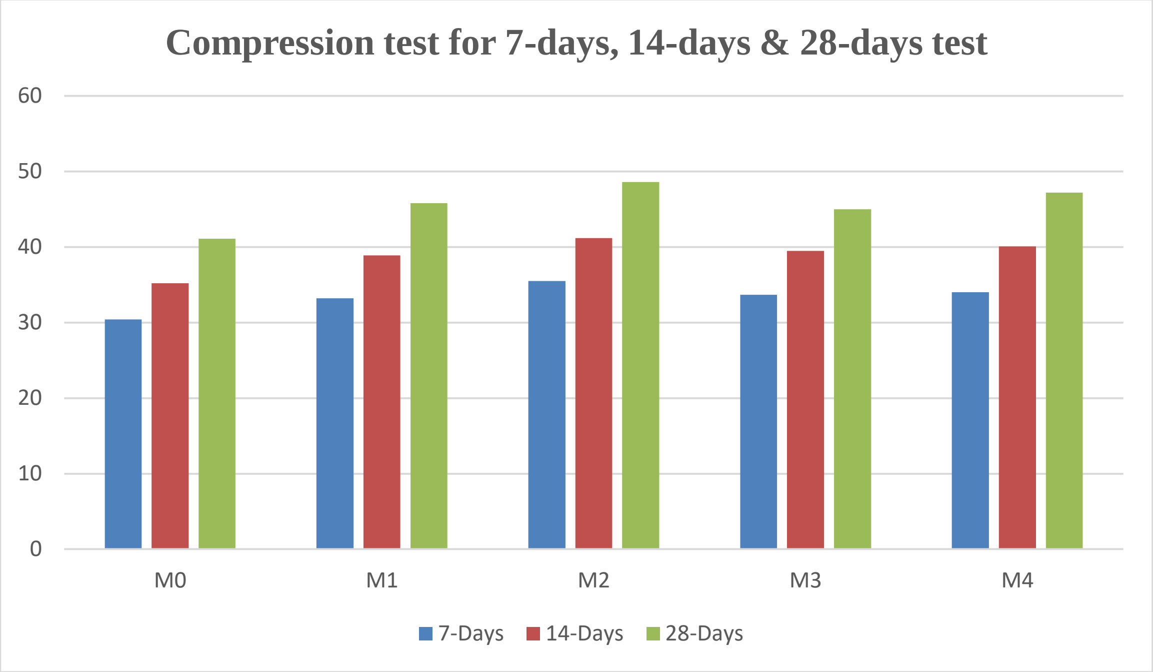

Fig.5.2 Compression test for 7-days, 14-days & 28-days test

V.CONCLUSION

- All mixes showed strength gain with age.
- The **optimum mix (10% MK + 0.1% PP)** achieved the **maximum 28-day strength (48.6 MPa)**, about **18% higher** than the control.
- Higher MK (15%) or PP fiber (0.2%) content slightly reduced compressive strength due to workability and dispersion issues.

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