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AN EXPERIMENTAL INVESTIGATION OF POLYPROPYLENE FIBRES ON PAVEMENT QUALITY CONCRETE (PQC)

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ABSTRACT :
This experimental study investigates the influence of polypropylene fibres on the properties and performance of Pavement Quality Concrete (PQC). The primary objective is to evaluate how the inclusion of varying proportions of polypropylene fibres affects key parameters such as compressive strength, flexural strength, workability, and durability. This study specifically focuses on the enhancement of compressive strength of pavement quality concrete when added polypropylene fibres. A series of concrete mixes were prepared with different fibre contents (0%, 0.25%, 0.50%, and 0.75% by weight of cement) and tested under standard conditions. The results indicate that the addition of polypropylene fibres significantly enhances the flexural strength and crack resistance of PQC, with marginal impact on workability. The optimum fibre content was identified as 0.50%, which offered the best balance between strength improvement and workability. The study concludes that polypropylene fibre-reinforced concrete presents a viable option for enhancing the mechanical performance and durability of pavement structures, making it a promising material for modern road construction.
Keywords: Polypropylene fibres, concrete, compressive strength.

INTRODUCTION:
Pavement Quality Concrete (PQC) is a high-strength, durable concrete used primarily in the construction of rigid pavements, especially in highway and airport runways. Its primary function is to withstand the high stresses imposed by heavy traffic loads and environmental conditions over long periods. Traditionally, PQC is designed to exhibit high compressive and flexural strength, low permeability, and long-term durability. However, concrete as a material is inherently brittle and prone to cracking under tensile stress and temperature-induced shrinkage. This has led researchers and engineers to explore various methods for improving its toughness and resistance to cracking, one of which is fibre reinforcement. Among the different types of fibres available, polypropylene fibres have gained attention due to their lightweight nature, corrosion resistance, low cost, and ease of mixing with concrete. These synthetic fibres act as crack arresters by bridging micro-cracks that develop during the early stages of concrete curing, thus enhancing the overall ductility and impact resistance of the concrete. Unlike steel fibres, polypropylene fibres do not corrode, making them suitable for environments where moisture and chemicals may be present. The use of polypropylene fibres in PQC is particularly promising as it can reduce the likelihood of early-age cracking, increase post-cracking strength, and potentially extend the service life of pavements. Despite these advantages, the inclusion of fibres can also affect other properties such as workability and compaction, which are critical in pavement construction. Therefore, a comprehensive study is necessary to evaluate the impact of polypropylene fibres on the mechanical and physical properties of PQC.This research focuses on analysing the behaviour of PQC modified with different dosages of polypropylene fibres. The study aims to determine the optimal fibre content that offers improved performance without significantly compromising the workability and finishability of the concrete. Through a series of controlled laboratory experiments, the effect of fibre addition on compressive strength, flexural strength, workability, and surface quality is assessed. The findings of this study are intended to contribute to the growing body of knowledge on fibre-reinforced concrete and support the practical application of polypropylene fibres in pavement construction.

AIM AND OBJECTIVES OF THE STUDY :

The primary aim of this experimental study is to evaluate the effect of polypropylene fibre incorporation on the mechanical and physical properties of Pavement Quality Concrete (PQC). Specifically, the research seeks to determine how varying percentages of polypropylene fibres influence key performance parameters such as compressive strength, flexural strength, workability, and durability of PQC used in rigid pavement applications.

The study is designed to:

1. Investigate the influence of polypropylene fibres on the strength characteristics of PQC, with particular focus on compressive and flexural strength, which are critical for pavement performance under traffic loading.
2. Examine the impact of fibre content on the workability of concrete mixtures, as fibre addition can alter the handling, mixing, and placing characteristics of PQC.
3. Identify the optimal fibre dosage that provides the most beneficial balance between enhanced mechanical performance and acceptable workability, ensuring practical applicability in field conditions.
4. Assess the crack-resistance behaviour of fibre-reinforced PQC, especially its ability to control shrinkage-induced cracks and improve post-cracking toughness.
5. Provide recommendations for the effective use of polypropylene fibres in pavement concrete, aiming to enhance durability, structural integrity, and service life of concrete pavements.

The main objective of this experimental investigation is to analyse the effect of polypropylene fibre addition on the performance of Pavement Quality Concrete (PQC). In support of this, the study is guided by the following specific objectives:

1. To design concrete mixes incorporating different dosages of polypropylene fibres (e.g., 0%, 0.25%, 0.50%, and 0.75% by weight of cement) and ensure they meet the standard requirements for PQC in terms of grade, water-cement ratio, and aggregate proportions.
2. To evaluate the compressive strength of fibre-reinforced PQC at various curing ages (typically 7, 14, and 28 days), in order to understand how fibre content influences the material's load-bearing capacity.
3. To assess the flexural strength of PQC containing polypropylene fibres, as this property is crucial for pavements subjected to bending stresses from traffic loads.
4. To study the impact of polypropylene fibres on the workability of fresh concrete, using standard tests such as the slump test, and to analyse the trade-offs between improved mechanical properties and ease of placement.
5. To examine the cracking behaviour and durability of fibre-reinforced PQC, particularly with regard to shrinkage crack control and resistance to environmental factors that can lead to degradation over time.
6. To identify the optimum percentage of polypropylene fibre addition that enhances concrete performance without adversely affecting its workability or leading to difficulties in mixing and compaction.
7. To compare the performance of conventional PQC and fibre-reinforced PQC to determine the practical benefits of using polypropylene fibres in pavement applications.
8. To contribute practical recommendations for the use of polypropylene fibres in pavement construction, with the goal of improving the service life, structural performance, and cost-effectiveness of rigid pavements.

LITERATURE REVIEW:

In this study, Self-Compacting Concrete (SCC) is defined as a fresh concrete mix that flows easily under its own weight without the need for external vibration to achieve proper compaction. As the fibre content in the mix was increased, various fresh and hardened properties improved progressively. Notably, the mixtures containing polypropylene fibres demonstrated enhanced tensile strain capacity, indicating improved ductility. Overall, the inclusion of polypropylene fibres contributed significantly to the quality enhancement of the concrete. [1]

This research primarily investigates the workability, mechanical performance, and durability characteristics of concrete intended for rigid pavements in rural road applications, which typically require lower load-bearing capacities. The study emphasizes the use of waste materials to develop cost-effective and sustainable concrete solutions. Specifically, plastic waste was utilized as a partial replacement for coarse aggregates, while industrial by-products such as fly ash and Ground Granulated Blast Furnace Slag (GGBS) were used as partial substitutes for cement. The objective is to create durable, eco-friendly rigid pavements that are economically viable for rural infrastructure. It was observed that as the percentage of plastic waste aggregates increased, there was a corresponding reduction in flexural strength. However, a 20% replacement of coarse aggregates with plastic waste (PPE) still achieved a flexural strength above the required minimum of 3.8 MPa. Additionally, the incorporation of mineral admixtures significantly improved the flexural strength, bringing it in line with or exceeding that of conventional concrete mixes. [2]

In this study, Coir fibre and Alkali-Resistant (AR) glass fibre were incorporated separately into concrete mixes to evaluate their performance. The results indicated that Coir fibre-reinforced concrete exhibited higher compressive strength compared to mixes containing AR-glass fibres. A similar trend was observed in split tensile strength tests, where the Coir fibre mix achieved superior results. Furthermore, the impact resistance test demonstrated that fibre-reinforced concrete, in general, showed significantly greater resistance to impact loads than conventional concrete. The enhanced impact resistance was measured by counting the number of hammer drops required to initiate cracking in the specimen, with a higher number of drops indicating better resistance. Coir fibre mixes consistently required more drops to form cracks, confirming their superior performance under impact loading conditions. [3]

This study focuses exclusively on evaluating the compressive behaviour of plain concrete (PC), polypropylene fibre-reinforced concrete (PPFRC), and polypropylene fibre fabric-reinforced concrete (PPFFRC), while the analysis of tensile strength and fracture toughness is reserved for future investigation. The use of polypropylene fibres (PPF), particularly with a length of 19 mm, has become increasingly common due to its positive influence on concrete performance. Incorporating waste fibre fabric into the concrete mix was found to enhance its compressive strength. Similarly, the inclusion of PPFF in concrete resulted in improved compressive performance. However, it was noted that for a constant water-cement ratio, the slump values of both PPFRC and PPFFRC decreased, indicating reduced workability with fibre addition. [4]

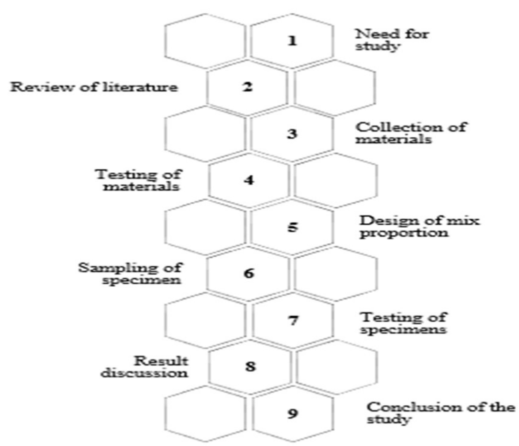

Figure 1: Order of methodology

METHODOLOGY

Experimental Analysis:

Parameter	Specification
Grade of Concrete	M40
Characteristic Compressive Strength	40 MPa at 28 days
Grade of cement	OPC 53
Cement Content	360 – 425 kg/m³ (as per design, not less than 350 kg/m³)
Water-Cement Ratio	0.35 – 0.40 (maximum 0.40 to ensure durability)
Water Content	140 – 160 litres/m³ (as per mix design and workability requirement)
Maximum Aggregate Size	26.5 mm or 31.5 mm (machine-crushed, angular aggregates recommended)
Fine to Coarse Aggregate Ratio	Typically, 35:65 to 40:60 (depends on gradation and mix optimization)
Slump (Workability)	0 – 25 mm (very low; suitable for slip-form paver placement)
Admixtures	Superplasticizers (optional, for workability); Mineral admixtures like fly ash may be used
Polypropylene Fibers (if used)	0.25% – 0.50% by weight of cement
Curing Method	Continuous wet curing for minimum 14 days or membrane curing compound
Modulus of Elasticity	~30–35 GPa (depending on aggregate type and mix)
Flexural Strength (Modulus of Rupture)	≥ 4.5 MPa at 28 days (as per IRC requirements)
Drying Shrinkage	Should be minimized (< 0.04%) – fibre addition helps control it
Placement Method	Usually by slip-form paving machines or fixed formwork
Pavement Thickness	Typically, 300 mm to 350 mm (depends on traffic load and design life)

Table 1: Design Specifications table for M40 Grade Pavement Quality Concrete (PQC), based on standard practices and guidelines from IRC:15-2017, IS 456:2000, and IS 10262:2019

The experimental procedure was conducted to evaluate the compressive strength of traditional concrete and concrete modified with varying percentages of polypropylene fibres. The mixes tested included 0% (control), 0.25%, 0.5%, and 0.75% polypropylene fibre content by weight of cement. All sampling and specimen preparation were carried out in accordance with IS 1199:1959, IS 516:1959, and IS 456:2000.

MATERIAL PREPARATION :

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Ordinary Portland Cement (OPC) of 53 grade was used as the binding material. Well-graded river sand conforming to Zone II was used as fine aggregate, and crushed angular coarse aggregates of 20 mm maximum size were used as coarse aggregate. Potable water was used for mixing. Polypropylene fibres of 19 mm length were used for the fibre-reinforced mixes. All materials were tested prior to use to ensure compliance with standard quality parameters.

MIX PROPORTIONING :

The mix design was prepared to achieve M40 grade concrete, using guidelines from IS 10262:2019. A constant water-cement ratio was maintained across all mixes to ensure uniformity. Four different mix batches were prepared:

- Mix A: 0% polypropylene fibre (control)
- Mix B: 0.25% polypropylene fibre by weight of cement
- Mix C: 0.5% polypropylene fibre by weight of cement
- Mix D: 0.75% polypropylene fibre by weight of cement

MIXING PROCEDURE:

All dry ingredients (cement, sand, and aggregates) were first mixed thoroughly in a mechanical mixer for about 2 minutes to ensure uniform distribution. Polypropylene fibres were weighed precisely and gradually introduced into the dry mix to prevent clumping. Water was added slowly while mixing continued for an additional 2–3 minutes until a homogeneous and workable concrete mix was obtained.

SPECIMEN CASTING:

For each mix, 150 mm × 150 mm × 150 mm cube moulds were cleaned, oiled, and prepared for casting. The fresh concrete was poured into the moulds in three layers, with each layer compacted using a tamping rod. In mixes with fibres, extra care was taken to ensure proper compaction due to slightly reduced workability.

CURING:

After casting, all specimens were covered with wet burlap and left to set for 24 hours under room temperature conditions. After demoulding, the specimens were placed in a water-curing tank maintained at a temperature of 27 ± 2°C for curing periods of 7 and 28 days.

TESTING:

At the end of each curing period, the specimens were tested for compressive strength using a calibrated compression testing machine (CTM) as per IS 516:1959. The average of three specimens was taken as the final compressive strength for each mix and curing age.

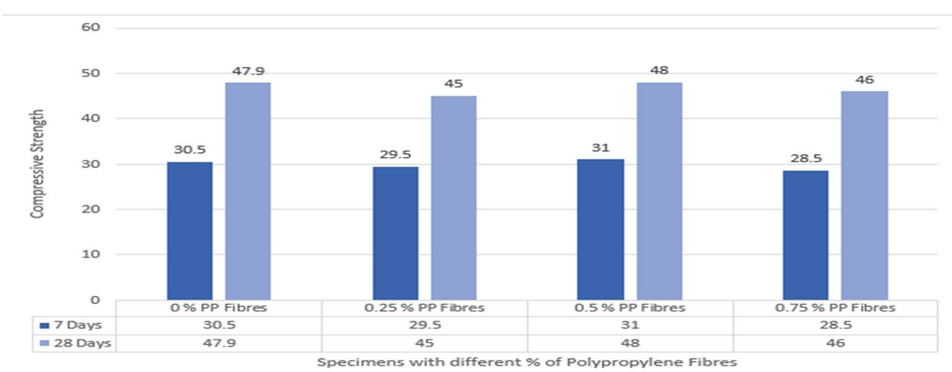

Figure 2: Comparison of compressive strength at 7 days and 28 days for 0 % to 0.75 % PP Fibres in N/mm^2

RESULT ANALYSIS :

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The experimental results provide insight into how varying dosages of polypropylene fibres affect the compressive strength of M40 grade Pavement Quality Concrete at 7 and 28 days of curing:

7-Day Compressive Strength:

- The control mix (0% fibres) achieved a strength of 30.5 N/mm², which sets the baseline.
- At 0.25% fibre addition, strength slightly decreased to 29.5 N/mm², likely due to reduced workability and possible entrapped air during compaction.
- The mix with 0.5% fibres exhibited the highest early-age strength of 31.0 N/mm², suggesting an optimal balance between crack resistance and matrix integrity.
- At 0.75% fibre content, the strength dropped to 28.5 N/mm², likely due to fibre clumping and poor compaction, which hindered uniform stress distribution.

28-Day Compressive Strength:

- The control mix reached a strength of 47.9 N/mm², slightly above the target for M40 concrete.
- The 0.25% fibre mix showed a reduction to 45.0 N/mm², which may reflect inadequate fibre dispersion or minor disruption in the hydration process.
- At 0.5% fibre content, the strength peaked at 48.0 N/mm², indicating that this dosage not only supports early-age strength but also enhances long-term performance through effective micro-crack control.
- The 0.75% mix again saw a decline to 46.0 N/mm², reinforcing the notion that excessive fibre content can negatively impact strength due to poor compaction and reduced density.

Fiber Content (% by weight of cement)	**Observed Effect**
0.0 % (Control)	Baseline properties of PQC
0.25 %	Moderate increase in compressive strength, slight impact on workability
0.50 %	Significant strength gain, good crack resistance, workability still manageable
0.75 %	Workability and compaction may become challenging

CONCLUSION:

From the analysis of compressive strength data at both 7 and 28 days, it can be concluded that the addition of 0.5% polypropylene fibres by weight of cement provides the most favourable outcome for Pavement Quality Concrete. This dosage enhances early-age and long-term compressive strength, likely due to effective micro-crack bridging and improved internal resistance to stress development.

Conversely, fibre contents lower than 0.5% do not contribute significantly to strength improvement, while higher dosages (0.75%) tend to reduce compressive strength, possibly due to poor fibre distribution, reduced workability, and compaction difficulties. Therefore, 0.5% polypropylene fibre can be considered the optimum dosage for enhancing compressive strength in M40 grade PQC without compromising workability and durability.

FUTURE SCOPE OF THE STUDY:

The present study highlights the beneficial impact of polypropylene fibres on the compressive strength of Pavement Quality Concrete (PQC), particularly at an optimal dosage of 0.5%. However, further research and development can broaden the understanding and practical application of fibre-reinforced concrete in pavement construction. The following points outline potential future scope for continued study:

1. Investigation of Flexural and Tensile Strength: While compressive strength is critical, pavements are more susceptible to flexural and tensile stresses due to traffic loads. Future studies should evaluate how polypropylene fibres influence flexural strength, split tensile strength, and fracture toughness of PQC.
2. Long-Term Durability and Performance Studies: Extended studies under real-world conditions, including environmental exposure (temperature fluctuations, freeze-thaw cycles, chemical attacks), would help assess the long-term durability of fibre-reinforced PQC.
3. Effect on Shrinkage and Crack Resistance: Since polypropylene fibres are known to reduce plastic and drying shrinkage, future work should quantify their impact on shrinkage behaviour and crack propagation in pavements.
4. Optimization Using Hybrid Fibers: Research can explore the combined use of polypropylene fibres with other types (e.g., steel, basalt, or glass fibres) to achieve synergistic improvements in mechanical and durability properties.
5. Impact on Workability and Construction Practices: Detailed studies on the effect of fibre addition on concrete workability, compaction effort, and finishing techniques could help improve construction practices and address on-site challenges.
6. Life Cycle Cost Analysis (LCCA): An economic evaluation of fibre-reinforced PQC, considering material cost, maintenance savings, and service life extension, would provide a comprehensive view of its feasibility for large-scale infrastructure projects.
7. Use of Recycled Polypropylene Fibers: Exploring the use of recycled or waste polypropylene fibres can promote sustainability and reduce environmental impact while maintaining or improving concrete performance.
8. Field Trials and Performance Monitoring: Implementing pilot pavement sections using optimized fibre content and monitoring their in-service performance will validate laboratory findings and support broader industry adoption.

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