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Design of Rigid Pavement Using Geosynthetic Material

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Abstract: The present experimental study investigates the influence of incorporating polypropylene fibre (PPF) as a partial replacement for cement in concrete, with a primary focus on evaluating the mechanical strength and overall performance of the resultant mix. In this research, various percentages of PPF—ranging from 0.5% to 12% by weight of cement—were introduced to examine their effect on concrete properties. The results demonstrate that lower dosages of PPF, specifically 0.5% and 1%, yield a significant improvement in the compressive strength and durability characteristics of concrete when compared to conventional Plain Cement Concrete (PCC). These improvements can be attributed to the fibre's ability to bridge micro-cracks, enhance the ductility, and reduce shrinkage-related issues. However, the study also indicates that increasing the PPF content beyond 2%, particularly in the range of 6% to 12%, results in a marked reduction in strength and performance metrics. This deterioration is likely due to the excess volume of fibre interfering with the homogeneity and workability of the concrete mix, leading to voids and weak zones. As such, it can be concluded that there exists an optimal threshold—up to a maximum of 2%—for the effective and beneficial use of polypropylene fibre in concrete. Beyond the performance benefits, the use of PPF as a cement substitute also offers considerable environmental advantages. Since cement production is highly energy-intensive and contributes significantly to carbon dioxide emissions, reducing its usage through partial replacement with polypropylene fibres contributes to more sustainable construction practices.

Keywords: Polypropylene Fibre (PPF); Partial Replacement of Cement; Sustainable Concrete; Fibre-Reinforced Concrete; Compressive Strength.

I. INTRODUCTION

The demand for long-lasting and low-maintenance transportation infrastructure has led to the widespread use of rigid pavements, especially in highways, airports, and industrial roads. Rigid pavements, typically constructed from Portland cement concrete (PCC), are known for their durability and load-carrying capacity. However, concrete's inherent weakness in tension and its brittle nature makes it prone to cracking under heavy traffic loads, thermal expansion and contraction, and shrinkage during curing. To address these limitations, various forms of reinforcement have been explored. Among them, the use of fibre-reinforced concrete (FRC) has emerged as a promising solution to enhance concrete's structural and durability properties. The incorporation of fibres helps control crack propagation, increase tensile strength, and improve ductility. Within the category of FRC, the application of geosynthetic materials, particularly polypropylene fibres, is gaining traction for use in pavement systems due to their lightweight nature, corrosion resistance, chemical inertness, and cost-effectiveness. This study explores the use of polypropylene fibre as a geosynthetic reinforcement material in rigid pavement construction. The integration of polypropylene fibre in concrete can significantly improve flexural strength and fatigue resistance, thus enabling more durable and efficient pavement systems. It is essential to understand its impact not only through experimental testing but also by integrating those improvements into actual design calculations using standards like IRC:58.

II. LITERATURE REVIEW

Several studies have been conducted to evaluate the effectiveness of geosynthetic materials in rigid pavement design. Researchers have explored the role of geotextiles in enhancing the bond between pavement layers, the contribution of geogrids in reinforcing subgrade stability, and the impact of geocomposites on drainage improvement. Various experimental and numerical modeling approaches have been adopted to analyze pavement performance with geosynthetics. This section provides an overview of key findings from previous research, addressing aspects such as material selection, structural behavior, and cost-benefit analysis.

Erol Tutumlueret.al (2025), Geosynthetics have emerged as a sustainable and efficient solution for improving the performance, durability, and cost-effectiveness of transportation infrastructure, including road pavements, railways, and airfields. The study by Tutumluer, Kang, and Qamhia (2025) in Transportation Geotechnics highlights the critical role of geosynthetics in mechanical stabilization by optimizing the interaction between soil or unbound aggregate geomaterials and geosynthetic products. Despite the widespread use of geogrids, geotextiles, and geocells across various transportation applications, the effectiveness of geosynthetic stabilization depends significantly on proper design methodologies tailored to specific ground conditions. This keynote paper comprehensively reviews the state-of-the-practice in geosynthetic applications, design approaches, and recent research advancements, particularly in subgrade restraint and unbound aggregate stabilization. One of the key contributions of this study is the discussion on how geosynthetics enhance bearing capacity and provide lateral restraint mechanisms, ultimately leading to significant improvements in pavement and track stability. Over the past two decades, research efforts at the University of Illinois and other institutions have focused on quantifying the mechanical benefits of geosynthetics using advanced technologies, including bender element shear wave transducer technology. This technology has been successfully employed to evaluate stiffness enhancement in the vicinity of geosynthetic materials through both laboratory testing and full-scale field instrumentation. The research findings indicate that geosynthetic stabilization techniques not only improve load distribution and minimize deformations but also extend the service life of transportation infrastructure. Additionally, the study reports on real-world implementations of geosynthetic stabilization in road and airfield pavements across the United States, providing valuable insights into the effectiveness of these materials in large-scale infrastructure projects. The comprehensive analysis presented in this paper underscores the importance of geosynthetics as a viable alternative to conventional stabilization methods, offering significant economic and environmental benefits in the construction and maintenance of transportation networks.

VarshaSri et al. (2024) conducted a comparative study on lightweight concrete using light expanded clay aggregate (LECA) and pumice stone to improve compressive strength while reducing thickness and weight. The study aimed to analyze the properties of M20-grade lightweight concrete in both fresh and hardened states. The research involved the preparation of unique concrete mixes, with each mix containing three cubes and three cylinders to measure compressive and flexural strength. Additionally, the study investigated the effects of incorporating different mineral admixtures into the concrete mixture. The experimental results demonstrated that strength and weight loss improved simultaneously across multiple trials. Among the materials tested, lightweight expanded clay aggregate (LECA) exhibited superior properties compared to pumice stone and conventional concrete, making it a more effective lightweight aggregate. The findings highlight the potential of LECA as a sustainable and efficient alternative in lightweight concrete applications.

Danrong Wang et.al (2023), Geosynthetic materials, including geogrids, geotextiles, and other geocomposites, have gained significant attention in pavement engineering due to their multifunctional roles in reinforcement, crack mitigation, fatigue life extension, and drainage improvement. Despite their widespread application in road construction, limited studies have explored their installation techniques and immediate effects during construction. Wang et al. (2023) conducted a full-scale field study to evaluate the impact of geosynthetic-reinforced pavements, constructing three trial sections where different geosynthetic materials were embedded at various pavement layers. In this study, a fiberglass geogrid was placed within the asphalt binder course, while a geogrid composite was positioned at the subgrade-base interface. A control section without any geosynthetic reinforcement was also included for comparative analysis. To monitor real-time structural behavior, instrumentation was employed to measure subgrade pressure, strain in the asphalt binder course, temperature, and moisture levels within the pavement structure. Post-construction field testing was also conducted to assess pavement stiffness and structural resilience. The findings revealed that geosynthetic-reinforced pavements effectively mitigated disturbances caused by construction activities, maintaining overall pavement integrity. The geogrid embedded in the asphalt layer significantly reduced subgrade pressure from paving equipment by 70% compared to the control section. Moreover, the longitudinal and transverse strain at the bottom of the asphalt layer was reduced by 54% and 99%, respectively, indicating enhanced load distribution and stress reduction within the pavement. Additionally, the geogrid composite installed at the subgrade level demonstrated improved drainage and an indirect insulation effect, which could potentially mitigate freeze–thaw damage in colder climates. These results reinforce the advantages of geosynthetics in pavement construction, highlighting their ability to enhance pavement durability, reduce stress concentrations, and improve overall structural stability. Given the increasing emphasis on sustainable infrastructure, geosynthetics offer a cost-effective solution for improving pavement lifespan while minimizing maintenance and rehabilitation costs. The study by Wang et al. (2023) provides crucial insights into geosynthetic applications in modern road construction and paves the way for further research into optimizing their usage in various environmental and traffic conditions.

Shantanu Upadhyaya et.al (2023), Geosynthetics, particularly geotextiles, have gained significant attention in pavement design due to their ability to reinforce weak subgrades, improve drainage, and enhance overall pavement longevity. However, comprehensive full-scale studies on their impact remain limited, necessitating further investigation into their cost-effectiveness and performance. Upadhyaya and Jaysawal (2023) conducted a full-scale study to examine the effects of geotextile reinforcement in pavement design. The research involved eight lanes of pavement test sections subjected to accelerated testing, focusing on the influence of geotextile reinforcement on sand-based subgrades. The study addressed critical aspects of pavement stabilization, including dry compaction techniques, subgrade structural combinations, and construction methodologies. Over the past three decades, geotextiles have been commonly employed to reinforce weak subgrades in minor road construction. However, despite the recognized benefits of geotextile reinforcement, a comprehensive Life Cycle Cost Analysis (LCCA) is essential to evaluate its economic viability. The research applied two distinct design methodologies to assess the long-term benefits of incorporating geotextiles in secondary road flexible pavements. A structured LCCA framework was developed to calculate both current and future costs associated with 25 sample low-volume road designs. The study emphasized that subgrades must be firm, stable, well-drained, and resistant to moisture-induced volume changes to prevent premature pavement failure. It was observed that pavement deterioration in the study region predominantly resulted from structural failures rather than material or functional deficiencies. The findings highlight that while geotextile reinforcement offers technical advantages such as improved load distribution and subgrade stabilization, an economic analysis is crucial to justify its widespread adoption. The study underscores the need for further research into LCCA methodologies that incorporate agency costs, user costs, and maintenance expenses over a pavement's lifespan.

Mohit et.al (2023), Geosynthetics have emerged as a crucial component in modern pavement engineering, offering benefits such as reinforcement, stress absorption, and moisture control. Various studies have explored their applications in both flexible and rigid pavement structures, emphasizing their role in improving durability and reducing maintenance costs. Mohit, Singh, and Singh (2023) examined the use of geosynthetics in road construction, particularly in flexible pavements, highlighting their ability to hinder fluid movement, absorb stress, and provide structural support. The study emphasized that geosynthetics significantly enhance durability and prevent degradation, while also creating employment opportunities in the construction sector.

Šeputytė-Jucikė et al. (2023) investigated the performance characteristics of lightweight concrete (LWC) incorporating porous aggregates such as expanded glass (EG) from glass waste and crushed expanded polystyrene waste (CEPW) derived from packaging waste. The study aimed to evaluate the impact of these lightweight aggregates on the density, thermal conductivity, mechanical properties, water absorption, deformation behavior, and freeze–thaw resistance of LWC. The research focused on modifying the mix composition by varying the proportions of EG and CEPW while maintaining ordinary Portland cement (OPC) as the binder. The results demonstrated that incorporating CEPW led to a significant reduction in the thermal conductivity of LWC, decreasing from 0.0977 W/(mK) to 0.0720 W/(mK), making it more suitable for thermal insulation applications. Additionally, the presence of CEPW did not adversely affect the compressive and bending strengths, nor did it increase the water absorption of LWC. The freeze–thaw resistance of the LWC was evaluated using two methods: one-side freezing and compressive strength reduction after 25, 100, and 200 freeze–thaw cycles. The findings showed that modifying the LWC structure with CEPW aggregates enhanced durability and reduced deformations, making it a promising material for sustainable and resilient construction.

Abhishek M et al. (2022) conducted a parametric study to evaluate the strength characteristics of lightweight concrete (LWC) incorporating sugarcane bagasse ash (SCBA) and expanded polystyrene (EPS) beads as partial replacements for cement and coarse aggregates, respectively. The study aimed to develop a sustainable lightweight concrete mix by reducing the use of conventional materials while maintaining structural integrity. The research followed the IS 10262:2009 mix design guidelines for M30-grade concrete. EPS beads were replaced at varying percentages (0%, 10%, 20%, 30%, and 40% by volume), while bagasse ash replacement was kept constant at 10% by weight of cement. A chemical admixture was added to achieve the desired slump. Experimental results indicated that compressive strength decreased with increasing EPS bead content. However, the optimum mix was found to be 10% bagasse ash and 10% EPS beads, which provided satisfactory strength while enhancing the lightweight properties of concrete. The study highlights the potential of EPS beads and SCBA in producing eco-friendly and lightweight concrete for various construction applications, such as repairing wooden floors, low thermal conductivity walls, bridge decks, and floating structures.

Adhikary et al. (2022) reviewed the advancements in lightweight self-compacting concrete (LWSCC), highlighting its potential for structural and non-structural applications in civil engineering. The study focused on the effects of different types of lightweight aggregates (LWA) on the density, strength, and workability of LWSCC. The review found that larger cell sizes in lightweight aggregates tend to decrease density and mechanical strength.

However, LWA contributes to internal curing, positively influencing cement hydration and improving long-term performance. Additionally, the study noted that incorporating nano-materials can enhance the strength properties of LWSCC, while the use of ultrafine particles reduces water absorption, leading to improved durability. It was demonstrated that LWSCC can be developed even with a density below 1000 kg/m³ while maintaining its self-compacting characteristics. Moreover, LWSCC exhibits excellent frost resistance, making it suitable for applications in extreme weather conditions. The review serves as a comprehensive resource for understanding the development and future prospects of LWSCC, promoting its broader acceptance in the construction industry.

Shashank Kumar et.al (2022), Geosynthetics have become an essential component in modern road and subgrade engineering due to their ability to enhance pavement performance, durability, and cost-efficiency. The application of geosynthetics, particularly geotextiles, in flexible pavement construction has been widely researched, demonstrating their effectiveness in soil stabilization, separation, and moisture control. Kumar et al. (2022) conducted an experimental study to evaluate the impact of geotextile membranes on subgrade performance. The study involved collecting three soil samples from different locations and subjecting them to primary geotechnical tests, including natural moisture content determination, sieve analysis, compaction, and the California Bearing Ratio (CBR) test. A flexible pavement model incorporating geotextile materials was constructed with a 4% slope to simulate camber and facilitate proper drainage. The experimental results showed that soil samples reinforced with geotextiles exhibited significantly lower moisture content compared to a control sample without geotextile reinforcement. Specifically, moisture content values for the three reinforced soil samples were recorded as 25.7%, 20.4%, and 18.7%, while the unreinforced control sample exhibited a moisture content of 30.6% after eight weeks of exposure to external weather conditions. These findings highlight the ability of geotextiles to reduce water infiltration and improve subgrade stability, ultimately enhancing pavement longevity. Furthermore, the study reinforced the importance of selecting geotextile materials based on sound engineering principles to ensure their long-term effectiveness in road construction. The incorporation of geotextiles in pavement design not only minimizes the need for excessive borrow materials but also strengthens the subgrade, reducing maintenance costs and extending the roadway's service life. These benefits align with the broader applications of geosynthetics in transportation infrastructure, where their use contributesto sustainable, resilient, and cost-effective pavement systems.

R. Dharmara et. al. (2021)- Concrete is one of the most widely used materials in modern construction, primarily due to its versatility, durability, and cost-effectiveness. However, concerns about sustainability and resource efficiency have led researchers to explore alternative materials that enhance the mechanical properties of concrete while incorporating industrial waste products. Dharmaraj (2021) conducted an experimental study to analyze the impact of iron scrap and fly ash on the strength and durability properties of concrete. The research investigated the effects of varying percentages of iron scrap (ranging from 2.5% to 15% by volume) in an M20 concrete mix. The study demonstrated that incorporating iron scrap enhanced compressive and flexural strength, with an optimal aspect ratio of 100. Additionally, the inclusion of fly ash as a supplementary material further improved performance, contributing to increased sustainability in concrete production. The study further evaluated durability aspects such as Dorry's abrasion resistance, demonstrating the potential of iron scrap to enhance wear resistance in concrete applications. The findings suggest that utilizing industrial waste steel strips as reinforcement in concrete is both a cost-effective and structurally viable solution for various civil engineering applications. Several studies have explored the integration of alternative materials in concrete to improve mechanical properties and reduce environmental impact. Researchers have previously investigated the influence of steel fibers and fly ash on concrete strength and durability, supporting the assertion that these materials can improve performance characteristics. The findings by Dharmaraj (2021) align with prior research indicating that industrial waste incorporation in concrete not only enhances strength but also promotes sustainability in construction practices.

Md Jihad Miah et. al. (2020)- Sustainable construction practices have increasingly focused on integrating industrial waste materials into cementitious composites to enhance mechanical performance and durability while reducing environmental impact. One such approach involves using recycled iron powder (RIP) as a replacement for natural sand (NS) in mortar, an area explored in recent research. Miah et al. (2020) investigated the effects of incorporating RIP as a fine aggregate in mortar, analyzing its mechanical strength, shrinkage behavior, durability, and residual compressive strength at elevated temperatures (20°C to 600°C). The study incorporated various replacement levels of NS with RIP (ranging from 0% to 50%) and found that an optimal replacement level of 30% resulted in significant improvements in mechanical properties. The 28-day compressive strength increased by 30%, tensile strength by 18%, and flexural strength by 47% compared to conventional mortar. Additionally, the inclusion of RIP led to reduced porosity (by 36%) and capillary water absorption (by 48%), indicating enhanced durability performance. The study also highlighted the thermal resistance of RIP-incorporated mortar, showing that strength degradation was more pronounced at temperatures above 250°C, especially for mixtures containing 50% RIP.

Shrinkage behavior varied, with higher RIP content inducing both shrinkage and expansion effects. The research concludes that RIP, when used up to 30% replacement of NS, offers structural benefits while improving durability and sustainability in mortar applications.

III. PROPOSED METHODOLOGY

A. Materials Used

- Aggregate
- Cement
- Sand
- Water
- Polypropylene fibre

1) Aggregate

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are essential ingredients in concrete. For a good concrete mix, aggregates must be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. The purpose of aggregates within the mixture is to provide a rigid skeletal structure and to reduce the space occupied by the cement paste. Both coarse aggregates, having particle sizes ranging from 20 mm to 4.75 mm, and fine aggregates, with particle sizes less than 4.75 mm, are required; however, the proportions of different sizes of coarse aggregates will vary depending on the specific mix required for each individual end use. Since aggregates occupy about 70 to 80 percent of the volume of concrete, their influence on various characteristics and properties of concrete is undoubtedly significant. Generally, aggregates can be classified as normal weight aggregates, lightweight aggregates, and heavyweight aggregates. Normal weight aggregates can be further categorized into natural aggregates and artificial aggregates. Additionally, aggregates can be classified based on size, dividing them into coarse aggregates and fine aggregates, each playing a vital role in determining the strength, durability, and overall performance of the concrete structure.

a) Coarse Aggregate

Aggregates, most of which are retained on a 4.75-mm BIS Sieve, are known as coarse aggregates. The various types of coarse aggregates can be described as:

- uncrushed gravel or stone, which results from the natural disintegration of rock;
- crushed gravel or stone, which results from the mechanical crushing of gravel or hard stone; and
- partially crushed gravel or stone, which is produced by blending uncrushed and crushed materials. Graded coarse aggregates are identified by their nominal sizes, commonly 40 mm, 20 mm, 16 mm, and 10 mm.

Regarding the characteristics of different types of aggregates, crushed aggregates tend to improve the strength of concrete due to the interlocking of angular particles, whereas rounded aggregates enhance the workability of concrete due to lower internal friction. In the experimental study, crushed stone aggregates of nominal sizes 20 mm and 10 mm, mixed in a 50:50 proportion, were used consistently. Before use, the aggregates were thoroughly washed to remove dust and dirt and then dried to a surface dry condition to ensure consistency and reliability in the test results.

Fig.3.1: Coarse aggregate

b) Fine Aggregate (Sand)

Aggregates most of which passes 4.75-mm BIS Sieve known as fine aggregates

- Natural sand - Fine aggregates resulting from the natural disintegration of rock andwhich have been deposited by streams or glacial agencies.
- Crushed stone sand - Fine aggregates produced by crushing hard stone.
- Crushed gravel sand - Fine aggregates produced by crushing natural gravel.

According to the size, the fine aggregates may be classified as coarse, medium or fine aggregates. Depending upon the particle size distribution, the fine aggregates are divided into four grading zones as per BIS: 383-1970 that are zone I, zone II, zone III and zone IV. The grading zones become finer from grading zone I to grading zone IV. The sand confirming to zone II was used.

Fig.3.2: Fine aggregate

2) Cement

Portland pozzolana cement is a clinker-blended cement produced either by intergrinding Ordinary Portland Cement (OPC) clinker along with gypsum and pozzolanic materials in specific proportions, or by grinding the OPC clinker, gypsum, and pozzolanic material separately and then thoroughly blending them in the required proportions. Pozzolana is a natural or artificial material that contains silica in a reactive form. It can be described as a siliceous or siliceous and aluminous material which, by itself, possesses little or no cementitious properties but, when finely divided and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. It is crucial that pozzolana be in a finely divided state because it is only in such a form that the silica can effectively combine with the calcium hydroxide (which is liberated during the hydration of Portland cement) in the presence of water to form stable calcium silicates, thereby imparting strength and durability to the cementitious matrix.

The pozzlanic material commonly used are:

- Volcanic Ash
- Calcined clay
- Fly Ash
- Silica Fumes
- The Indian standards for Portland pozzolana cement have been issued in two parts based on the type of pozzolanic material to be used in manufacturing of Portland pozzolana cement as given below:
- IS 1489 (Part 1) 1991, Portland pozzolana cement- specification (fly ash based)
- IS 1489 (Part 2) 1991, Portland pozzolana cement-specification (calcined clay based) the quality of fly ash or calcined clay to be used in manufacturing of PPC is also specified by BIS in the following standards:
- IS 3812 1981- specification for fly ash as pozzolana and admixture IS 1334 1981-specification for calcined clay pozzolana in view of the availability of good quality fly ash in abundant quantity, the use calcined clay based pozzolana cement is progressively decreasing. The fly ash is a waste product of thermal power plant which creates disposal problems at thermal power plant site. The yearly production of fly ash in india is about 70 million tonnes per annum.

This would increase in future depending upon the new local based thermal power plants to be installed in the country. The present utilization of fly ash in production of blended cement in India is meager.

The Portland pozzolana cement makes concrete more impermeable and denser as compare to ordinary Portland ceament. The Portland pozzolana cement produces less heat of hydration and offers greater resistance to the attack of aggressive water than normal Portland cement. Moreover, it reduces the leaching of calcium hydroxide liberated during the setting of hydration of cement. The percentage of pozzolanic material used in the preparation should be between 10 to 30. If the percentage is exceeded, the strength of cement is reduced. This type of cement is used more than 80% for construction purposes.

Advantages of Portland pozzolana cement:

- These cement gains compressive strength with age.
- It is highly resistant to sulphates.
- It gives better workability during preparation of concrete.
- It evolves low heat during setting.
- It gains high tensile strength.
- It is resistant to expansion.
- It is cheap and affordable.

3) Water

Fresh and clean tap water was used for casting the specimens in the present study. The water employed was relatively free from organic matter, silt, oil, sugar, chlorides, and acidic materials, in accordance with the requirements specified in BIS: 456-2000. Ensuring the quality of water was crucial, as impurities can adversely affect the setting time, strength development, and durability of the concrete.

4) Polypropylene Fibre

Polypropylene fibre was first used to reinforce concrete in the 1960s. Polypropylene, a synthetic hydrocarbon polymer, is manufactured using extrusion processes by hot-drawing the material through a die. Polypropylene fibres are produced as continuous monofilaments with a circular cross-section that can be chopped to the required lengths, or as fibrillated film tapes with a rectangular cross-section. These fibres are hydrophobic and therefore exhibit disadvantages such as poor bond characteristics with the cement matrix, a low melting point, high combustibility, and a relatively low modulus of elasticity. Long polypropylene fibres can also be difficult to mix due to their flexibility and tendency to wrap around the leading edges of mixer blades. Although polypropylene fibres are tough, they possess low tensile strength and a low modulus of elasticity, displaying a plastic stress-strain behavior. Monofilament polypropylene fibres inherently develop a weaker bond with the cement matrix because of their relatively small specific surface area, whereas fibrillated polypropylene fibres, which are slit and expanded into an open network, offer a larger specific surface area and thereby improved bond characteristics. Polypropylene fibre contents up to 12% by volume have reportedly been used successfully with hand-packing fabrication techniques, but even at lower dosages, such as 0.1% of 50 mm fibre, a significant slump loss of around 75 mm has been observed. Nevertheless, polypropylene fibres have been reported to effectively reduce unrestrained plastic and drying shrinkage of concrete at fibre contents ranging from 0.1% to 0.3% by volume. For the present study, polypropylene microfibres were procured from Bajaj Reinforcement, Nagpur, and specifically engineered fibres manufactured at an ISO 9001-2000 certified facility were used as concrete reinforcement at a recommended dosage rate of 1 kg per cubic meter to achieve effective performance.

Fig.3.3: Polypropylene Micro Fibre

IV. RESULTS AND DISCUSSION

A. *Procedure of Casting Cubes*

In this study, an effort was made to assess the compressive strength of concrete by conducting compression tests on cubes prepared from freshly mixed concrete in which cement was partially replaced with marble powder. Along with this replacement, varying proportions of polypropylene fibre were incorporated into the mix to evaluate their combined effect on the compressive strength of the concrete. The polypropylene fibre was added in different percentages, specifically 0.5%, 1%, 2%, 6%, 8%, and 12%, to analyze how each level of fibre content influenced the mechanical behavior of the concrete. The test specimens were cast accordingly and subjected to standard curing before being tested under compressive loads. Through this methodical experimental approach, the study aimed to identify the optimal percentage of polypropylene fibre that can be effectively used in combination with marble powder to enhance the compressive strength of concrete while also promoting the sustainable use of industrial waste materials.The method adopted for determining the compressive strength of concrete cubes involved a systematic procedure to ensure accurate and reliable results. Concrete cube specimens were cast using standard moulds of size 15 cm × 15 cm × 15 cm. These moulds, made of metal, were designed to be easily assembled and dismantled by bolting and unbolting, facilitating the preparation and demoulding process. The freshly prepared concrete mix was placed into the moulds in layers, each layer being hand compacted initially to remove air voids and then further compacted using a machine to achieve uniform density. After casting, the surface of the concrete cubes was leveled and they were covered with wet gunny bags for 24 hours to prevent moisture loss during the initial setting period. Following this, the specimens were demoulded and transferred into a curing tank containing clean, fresh water, where they were fully immersed for curing durations of 7, 14, and 28 days. At the end of each curing period, the specimens were removed and tested for compressive strength using a compression testing machine. The ultimate compressive strength was calculated by dividing the maximum load at failure by the cross-sectional area of the cube, which is 225 cm². For each curing period, at least two specimens were tested to provide a reliable indication of the rate of strength development. As a general trend, Ordinary Portland Cement concrete typically gains about 70% of its final strength within the first 7 days, with the remaining strength developing gradually over the subsequent days. This progressive gain in strength was carefully observed and recorded through the 7-, 14-, and 28-day tests, and necessary modifications or evaluations of the mix design were considered based on the outcomes. To ensure statistical accuracy, three specimens were tested for each curing period, and the results were correlated to determine consistency and reliability. Additionally, based on these results, other important properties such as durability, impermeability, and overall quality of the concrete mix were inferred, thereby providing comprehensive insights into the performance of the partially replaced cement concrete with polypropylene fibre and marble powder.

B. *Experimental Setup*

The testing procedure for all specimens followed a standardized approach to ensure consistency and accuracy in evaluating the mechanical properties of the concrete mixes. Initially, all test specimens, including cubes, cylinders, and beams, were subjected to curing for specific durations, primarily for 7 days and 28 days, to assess the development of strength over time. For evaluating compressive strength, cube specimens were tested using a Compressive Testing Machine (CTM), which applied a gradually increasing load until the specimen failed, and the maximum load was recorded to calculate the compressive strength. Similarly, for assessing the split tensile strength, cylindrical specimens were tested using the same CTM with a specific split tensile attachment, which applies a diametrical compressive load to induce tensile stress across the vertical diameter of the cylinder until failure occurs. For flexural strength testing, beam specimens were tested using a two-point loading setup. This arrangement allowed the application of load at two points symmetrically placed on the beam to simulate realistic bending conditions. Prior to loading, lines were carefully marked on the beam at one-third (L/3) of the span length from the left support to ensure accurate placement of the load points. This setup helped in determining the modulus of rupture of the beam specimens by simulating a pure bending zone between the two load points. The entire testing protocol was carefully followed for each specimen to ensure the reliability of the experimental results, providing a comprehensive understanding of the behavior of concrete modified with polypropylene fibre and marble powder under various loading conditions.

Fig.4.1: Testing of Cube Specimen in Process

1) Testing of Specimen

All six sets of concrete cube specimens were tested systematically to evaluate the effect of polypropylene micro fibre on the compressive strength of concrete. Each set consisted of six cube samples, ensuring statistical reliability and consistency in the test results. Among these, one set served as the control mix, representing conventional concrete without any fibre addition, while the remaining five sets included varying proportions of polypropylene micro fibre as a partial replacement or additive. The fibre content in these five sets was adjusted to study the impact of different dosage levels on the strength behavior of the concrete. All cube specimens were tested under a compression testing machine after being cured for specified periods, mainly 7 and 28 days, to observe the strength development over time. The results from these tests were carefully recorded and analyzed. The data obtained from the compressive strength tests have been systematically furnished and tabulated, and a detailed interpretation and discussion of these results have been presented in the next chapter to derive meaningful conclusions regarding the performance and suitability of polypropylene fibre-reinforced concrete.

2) Testing of Concrete Cube

The testing of concrete cubes was carried out to determine the compressive strength of the different concrete mixes after specified curing periods. The figures presented in this section illustrate the experimental setup used during the testing process as well as the typical failure patterns observed in the concrete cubes. The cubes were tested after 7 and 28 days of curing; however, special emphasis was placed on the 28-day compressive strength results, as per the guidelines of IS 456:2000, which states that concrete generally achieves its maximum characteristic strength after 28 days of proper curing. The compression testing machine applied a gradually increasing axial load until failure occurred. The failure patterns of the cubes post-testing, as shown in the figures, provide insight into the mode of failure and the quality of the concrete. These visual observations, along with the numerical data obtained from the tests, are critical in understanding the behavior of polypropylene fibre-reinforced concrete and have been used in the subsequent chapters to support analysis and conclusions.

Fig.4.2: Testing of Concrete Cube by using UTM

The experimental study was conducted on M20 concrete cubes cured for 28 days, with varying fiber compositions to observe the crack development and failure patterns under applied loads. The conventional concrete cube, without any fiber addition, exhibited cracks primarily near the center under a load of 600 kN, following an inclined pattern. This central cracking was attributed to the absence of fibers, which led to a lack of reinforcement within the concrete matrix. When 1% polypropylene micro fiber was introduced, the cracks appeared mostly on the outer faces of the cube under the same load of 600 kN. This was due to the polypropylene micro fibers not being completely homogeneously mixed, causing fiber separation during mixing, which in turn led to crack initiation at the corners of the cube. Similarly, with 1% polypropylene macro fiber, the concrete cube experienced failure at an applied load of 660 kN, with cracks forming predominantly on the outer surface. The macro fibers tend to ball up and, because of their low density, do not mix uniformly, resulting in localized weak zones and crack propagation on the cube's exterior. In contrast, the specimen containing 0.5% polypropylene micro fiber exhibited a much-improved performance, where cracks developed at 660 kN load were fine and inclined, appearing on the outer face but showing significantly better fiber bonding within the concrete matrix. This improved homogeneity, facilitated by the availability and proper mixing of 0.5% polypropylene micro fiber, prevented fiber separation and thus enhanced the crack resistance. Finally, another specimen with 0.5% polypropylene micro fiber also demonstrated that while macro cracks were present on the cube's face, the number of micro cracks was greatly reduced due to the fiber's effective distribution and bonding. Overall, the inclusion of polypropylene fibers, especially at 0.5% micro fiber dosage, contributed to better crack control, improved load resistance, and more homogeneous mixing, which was reflected in the different crack patterns and failure behaviors observed after testing.

C. Compressive Strength of Concrete

The compressive strength test is one of the most important and widely used tests to evaluate the overall quality and performance of concrete. It provides a clear indication of whether the concrete has been properly mixed, placed, and cured, reflecting its ability to withstand loads without failure. This single test offers valuable insight into various characteristics of the concrete, such as its durability, strength, and structural integrity. For conducting this test, concrete specimens are typically prepared in the form of cubic molds measuring 150 mm by 150 mm by 150 mm. After the specified curing period, these cubes are subjected to compressive loading until failure, and the resulting data is recorded. The compressive strength values obtained from these specimens serve as a fundamental measure for assessing the adequacy of the concrete mix and the effectiveness of the construction process. The results of all tested specimens are systematically compiled and presented in the accompanying table for further analysis and comparison.

Table 4.1: Compressive Strength (MPa) of Polypropylene fibre Concrete

Age	0.5%	1%	2%	6%	8%	12%	Plain M20
7 days	19.78 MPa	21.38 MPa	22.44 MPa	22.89 MPa	18.22 MPa	8.89 MPa	12.44 MPa
14 days	26.22 MPa	24.89 MPa	26.22 MPa	11.78 MPa	17.78 MPa	8.89 MPa	12.89 MPa
28 days	29.33 MPa	26.67 MPa	27.11 MPa	10.67 MPa	18.22 MPa	11.56 MPa	21.33 MPa

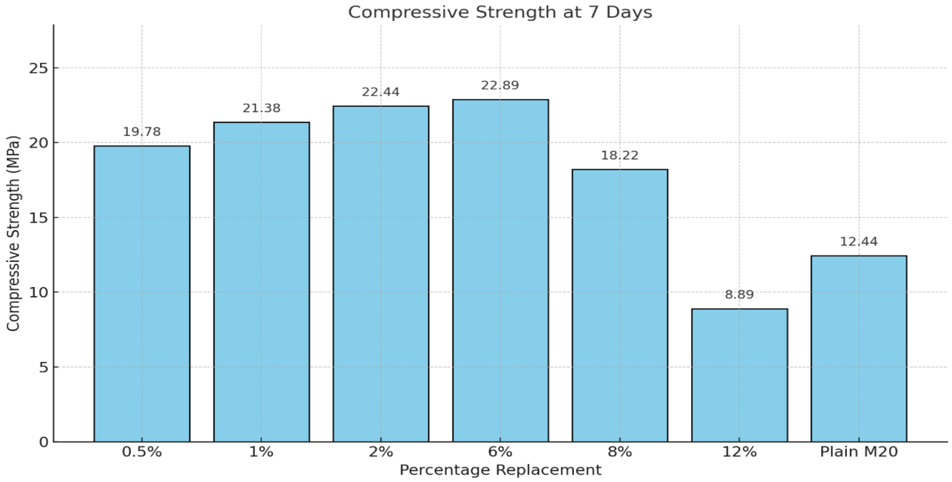

Fig.4.3: Compressive Strength at 7 Days

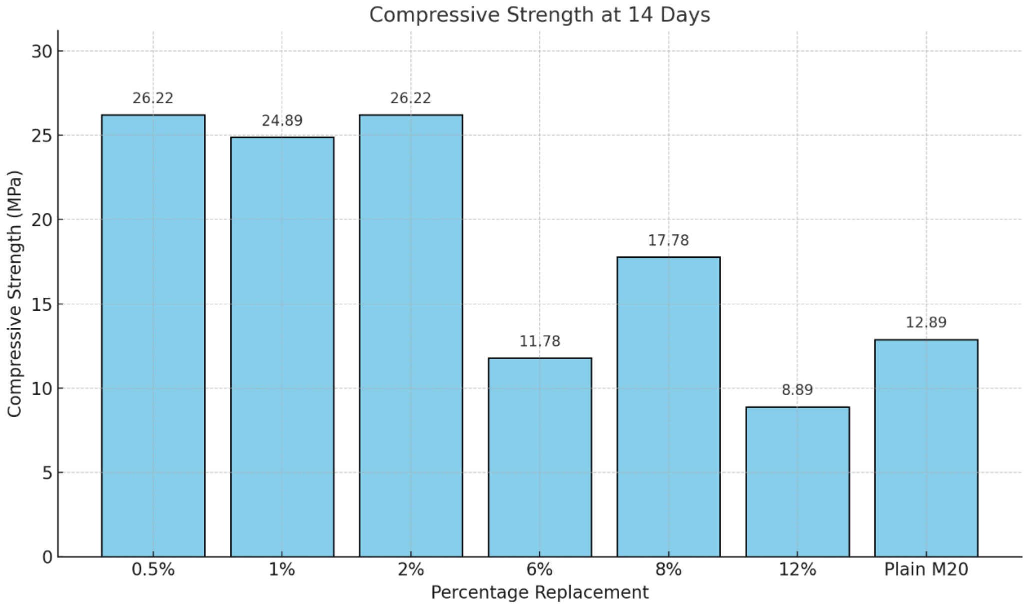

Fig.4.4: Compressive Strength at 14 Days

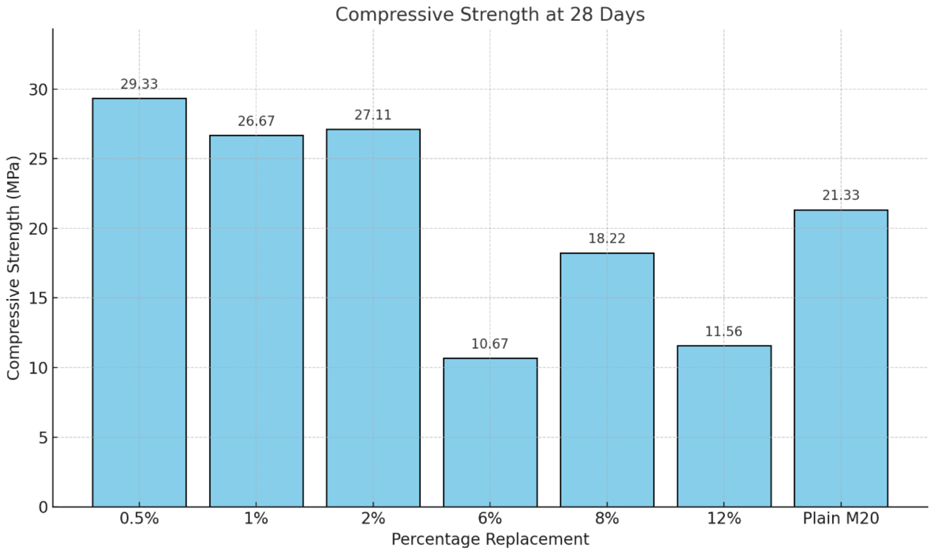

Fig.4.5: Compressive Strength at 28 Days

V. CONCLUSION

From the experimental study, it has been observed that incorporating 0.5% and 1% polypropylene fibre as a partial replacement of cement yields better results in terms of strength and performance when compared to Normal Plain Cement Concrete. However, as the proportion of polypropylene fibre increases from 6% to 12% and beyond, a noticeable decline in performance is recorded, with results falling significantly below those of Normal Plain Cement Concrete and mixes with 0.5% and 1% fibre content. This suggests that an optimal limit exists for the effective use of polypropylene fibre in concrete, and based on the findings, it can be concluded that the use of polypropylene fibre as a partial replacement of cement should be limited to a maximum of 2% to maintain or enhance the desirable properties of the concrete mix. Therefore, it is proposed that a small percentage of cement in concrete may be effectively replaced with polypropylene fibre. This not only helps in reducing the overall consumption of cement—a material whose production is energy-intensive and contributes significantly to carbon emissions—but also allows for the beneficial use of waste materials within the construction industry.

By incorporating such waste-derived fibres into concrete, a dual benefit is achieved: promoting sustainability in construction practices and mitigating environmental pollution through effective waste management. Further research and investigation from a practical and field-oriented perspective will be carried out to assess long-term performance, durability, and feasibility of using polypropylene fibre in real-life construction applications.

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