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Assessment of Fresh and Hardened Properties of Concrete Containing Polypropylene Fibers

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***Abstract* - This study examines the influence of polypropylene fibers on the performance of fresh and hardened concrete. Incorporating polypropylene fibers enhances concrete properties by mitigating crack initiation and propagation, which subsequently decreases permeability and improves durability. The objective of this research was to evaluate the effects of polypropylene fiber addition at varying dosages of 0.05%, 0.15%, 0.25%, and 0.35% by weight of concrete. Experimental investigations included compressive strength testing at 7 and 28 days for hardened concrete, and slump testing to assess workability in the fresh state. Findings indicated that polypropylene fiber addition reduced workability as fiber content increased. Compressive strength initially improved with fiber addition, reaching 34.3 MPa at 0.05% and a peak of 34.4 MPa at 0.15% fiber content. Beyond this dosage, compressive strength declined significantly, dropping to 28 MPa at 0.25% and 19.1 MPa at 0.35%. Based on the results, the optimum polypropylene fiber dosage for maximizing compressive strength while maintaining acceptable workability lies between 0.05% and 0.15%**

Keywords - Concrete, polypropylene fibers, Workability, Compressive strength.

I. NTRODUCTION

Concrete remains the dominant construction material globally owing to its low cost, versatility, high compressive strength, and extensive applicability. Nevertheless, conventional concrete suffers from inherent weaknesses such as poor tensile strength, inadequate crack resistance, and limited ductility, which restrict its performance in structural applications (Banthia2006, Bentur2007)

Recently, the application of fiber-reinforced concrete has expanded significantly in large-scale infrastructure, such as highways, airport pavements, massive foundations experiencing substantial deformations, and tunnel linings. (Bentur 2007). More recently, unreinforced concrete incorporating fibers has been utilized in precast tunnel segments to mitigate cracking (Plizzari and Tiberti, 2006; de la Fuente et al., 2012). However, studies indicate that the inclusion of fibers can reduce compressive strength (Bentur and Mindess, 2007). This decrease is attributed to the accumulation of calcium hydroxide at the interfacial transition zone between the hydrated cement paste and various fiber types, such as steel, carbon, polyester, and polypropylene fibers (Li, 2003).

Polypropylene (PP) is a thermoplastic polymer widely used in various applications, including packaging and textiles such as ropes, thermal wear, and carpets. (Mehta and Monteiro, 2014 Polymer concrete is defined as a composite where polymeric materials serve as a binder, either partially or completely replacing Portland cement (Fowler, 1999). (Ohama, 1997). Polypropylene fibers (PPF) are produced via conventional melt spinning from propylene gas, a petroleum or natural gas by-product. Polymerization under high temperature and pressure using specialized catalysts forms 100% virgin homopolymer monofilament microfibers composed of pure hydrocarbon C_3H_6 (Zollo, 1997; Sadiqul Islam and Gupta, 2016).

Various researchers have examined fiber-matrix interaction mechanisms using multiple models to evaluate the bond between fibers and the cement matrix, which critically governs composite behavior. However, fibers can interfere with concrete finishing. Thirumurugan and Sivakumar (2013) reported that the workability of concrete decreases with increasing polypropylene fiber content, though this can be mitigated by incorporating high-range water-reducing admixtures. While adding water improves workability, it may reduce compressive strength. This strength reduction can result from excess water or increased entrapped air (Balaguru and Shah, 1992).

They observed that compressive strength increased with fiber content up to 1% for all three grades. Murahari and Rao (2013) tested 500 × 100 × 100 mm specimens under three-point loading per ASTM C78 and found that flexural strength increased with fiber content up to 0.3%. Specimens exhibited higher strength at 28 days compared to 56 days. Polypropylene fibers inhibit intrinsic cracking in concrete. By enhancing matrix cohesion, fibers promote ductile, gradual failure in fiber-reinforced deep beams. Peng Zhang et al. (2006) incorporated 0.04%, 0.06%, 0.08%, 0.1%, and 0.12% polypropylene fibers in concrete containing 15% fly ash and 6% silica fume. Three-point bending tests on beam specimens showed that fiber addition significantly improved fracture parameters of the composite, including fracture toughness, fracture energy, effective crack length, maximum mid-span deflection, and critical crack opening displacement. Embedded fibers influence stress-strain response, enhance stress redistribution, and reduce strain localization

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II. EXCEPREMENTAL WORK

This study was conducted in several stages. In the initial stage, all required materials and equipment were collected and checked for availability. Subsequently, concrete mixes were prepared according to the predefined proportions. The concrete specimens were then subjected to standard tests, including cube compressive strength tests. Finally, the obtained results were analyzed to draw conclusions.

High performance concrete was designed by using BSI curing method. Trail control mixes for 28 days with adding polypropylene *fiber* with different percentages *0.05%, 0.15%, 0.25%, and 0.35% by weight of concrete*. The results of laboratory experiments were analyzed and discussed to investigate the refractory brick residues on workability of fresh concrete and compressive strength of hardened

A. Material Used:

Cement: The cement used was Ordinary Portland Cement (OPC) Type I, commonly utilized in concrete structures. The selected cement is tested conforming to BS: 1996 to assess its suitability for use in concrete and the results of the tests are tabulated in table 1 and figure 1

TABLE 1: RESULTS OF CEMENT TESTS

Type of testing	Results of testing	Ref.BS12:1996
Standard of cement paste	31%	W/C ≥ 26% and ≤33%
Initial setting time	135 min	≥45 *min*
Final setting time	180 mins	≤ 8 *hrs*
Fineness of cement	3.05%	≤10%
Soundness of cement	1.5mm	≤10 *mm*

Fig -1*:* cement and tests equipment's

Fine Aggregate: The sand used was natural sand passed through a sieve to remove any particles larger than the specified size. Subsequently, several tests were conducted on it in accordance with BS 12:1996 to determine its suitability for use in the concrete mix, as shown in Figure 2. The test results were recorded in Table 2.

Coarse Aggregate: The coarse aggregate used was natural uncrushed gravel used for the study was of 20mm size maximum. It is conforming BSI: 882-1997. It was retrieved from a local quarry. The shape and quality of aggregate was uniform throughout the project work and the specific gravity was found to be 2.60. Table 2 shows the results of tests of impurities, specific gravity and water absorption of coarse and fine aggregates (Figure 2)

TABLE 2: PROPERTIES OF AGGREGATES

Experiment name	Fine aggregate	Coarse aggregate
Impurities	% 2.05	-
Specific gravity	2.50	2.55
Water Absorption	1.03%	2.30%

Fig 2: Coarse and fine aggregate

Water: The used water from Khartoum city water distribution system

Polypropylene fibers: Polypropylene fibers are considered among the most widely used types of fibers. They are organic in origin and are one of the cheapest polymeric materials, as their raw material, polypropylene, is a by-product of the petroleum cracking process. Figure 3 illustrates the polypropylene fibers used in this study, while Table 3 below presents the specifications of these fibers, and Table 4 shows the chemical analysis of the polypropylene fibers.

TABLE 3: PROPERTIES OF POLYPROPYLENE FIBERS

Property	Value
Density (g/cm^3)	0.91
Fiber Length (mm)	12
Fiber Diameter (mm)	0.02
Specific Surface Area (m^2/kg)	250
Tensile Strength (MPa)	300-400
Modulus of Elasticity (MPa)	5000-8500

Fig - 3: Polypropylene fibers

TABLE 4: CHEMICAL ANALYSIS OF POLYPROPYLENE FIBER

Property	Value %
CaO	1.19
Fe_2O_3	0.04
SrO	0.02
TiO_2	0.02
PdO	0.02
Sb_2O_3	0.02
Assay	98.68

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B. ix Design Method

Concrete mix design was performed according to the BSI method for preparing test cubes. Several concrete specimens were cast with different percentages of polypropylene fibers. The mix proportions and corresponding test results at 7 and 28 days are detailed in the following sections.

The aggregate dry density used was 1785 kg/m^3, and the maximum aggregate size use in all mixes was 20 *mm.* using standard cubes moulds (150*150*150) mm^3 cubes representing each ratio, were casted and tested at age 7 and 28 days.

C. Components of mix materials:

The concrete mix to resist compression design (30 N / mm^2), the quantities of materials for all the mixtures as illustrated table5: Mix design: (density of 2340 kg / m^3).and table 6.

TABLE 5: AMOUNTS OF THE MIXTURE OF DESIGN

Mix Materials	Weight(kg/m^3)
Cement content	375
Fine aggregate content	643
Coarse aggregate content	1142
Water content	180

TABLE 6: THE QUANTITIES OF MATERIALS

Mix	% of Polypropylene fibers	Course Agg (*kg*)	Fine Agg (*kg*)	Cement (*kg*)	Water (*L*)
M_1	00	27	15.2	9	4.3
M_2	0.05	27	15.2	9	4.3
M_3	0.15	27	15.2	9	4.3
M_4	0.25	27	15.2	9	4.3
M_5	0.35	27	15.2	9	4.3

D. Concrete Mixing:

The mixing process was carried out in the laboratory using an electric pan mixer. For the control concrete cubes containing no polypropylene fibers, the mixing procedure was as follows: coarse aggregate was placed first, followed by cement and then fine aggregate. Dry mixing was performed for one minute, after which water was added and mixing continued for an additional two minutes. The total mixing time was three minutes.

For mixes incorporating polypropylene fibers, the mixing sequence was modified. Half of the mixing water was added first, followed by the polypropylene fibers, and then the remaining water. Mixing was continued for two and a half minutes, resulting in a total mixing time of three minutes. This sequence was adopted to prevent fiber dispersion due to their low density, as adding fibers after the full water content would cause them to float and result in poor distribution. After mixing, a slump test was performed, and the fresh concrete was then placed into molds within a short time period.

III. ESULTS OF EXPERIMENTS OF FRESH AND HARDENED CONCRETE:

Slump tests were conducted on fresh concrete, and compressive strength tests using cube molds were conducted on hardened concrete, as shown in figure 4, figure 5, and figure 6. The mixes incorporated different addition percentages of polypropylene fibers. The results are presented in tables 7 to table 10 and illustrated graphically in figure 7 to figure 11.

Fig - 4: Slump test

Fig - 5: Concrete cubes

Fig - 6: Compressive Strength machine

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TABLE 7: AVERAGE FOR RESULTS OF SLUMP TESTS

Mix	% of Polypropylene fibers	Slump (*mm*)
M_1	00	100
M_2	0.05	40
M_3	0.15	30
M_4	0.25	15
M_5	0.35	10

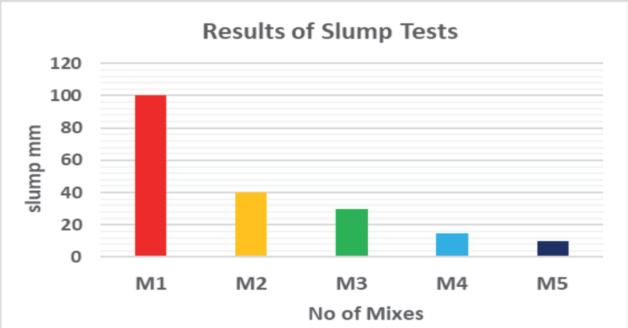

Fig - 7: Relation between slump and number of mixes

TABLE 8: AVERAGE FOR RESULTS OF DENSITY

Mix		% of Polypropylene fibers	Density (*kg/m³*)
M_1		00	2409
M_2		0.05	2393
M_3		0.15	2378
M_4		0.25	2369
M_5		0.35	2353

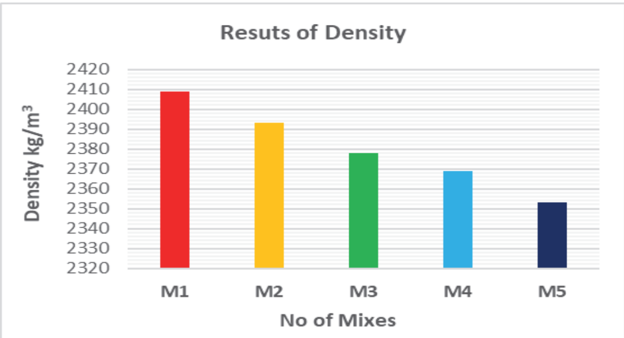

Fig 8 Relation between Density and number of mixes

TABLE 9: AVERAGE FOR RESULTS OF COMPRESSIVE STRENGTH AT 7 DAYS

Mix	% of Polypropylene fibers	Compressive Strength N/mm²
M_1	00	25
M_2	0.05	26.4
M_3	0.15	24.6
M_4	0.25	22.1
M_5	0.35	19.2

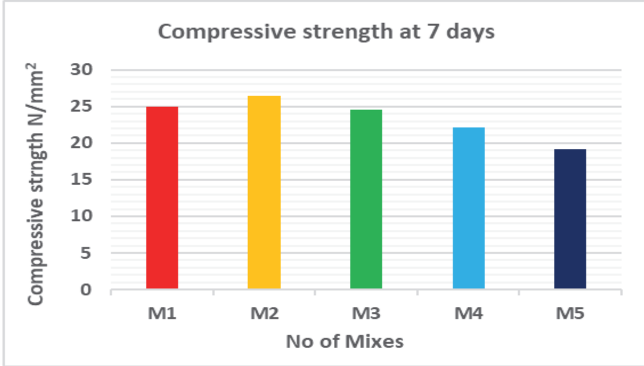

Fig - 9: Relation between compressive strength and number of mixes at 7 days

TABLE 10: AVERAGE FOR RESULTS OF COMPRESSIVE STRENGTH AT 28 DAYS

Mix	% of Polypropylene fibers	Compressive Strength N/mm²
M_1	00	32.1
M_2	0.05	33.5
M_3	0.15	34.4
M_4	0.25	29.6
M_5	0.35	28

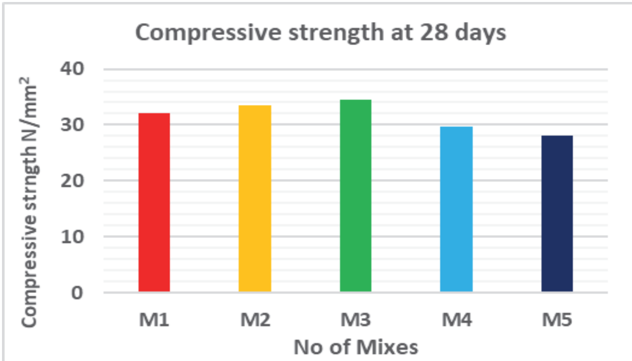

Fig - 10: Relation between compressive strength and number of mixes at 28 days

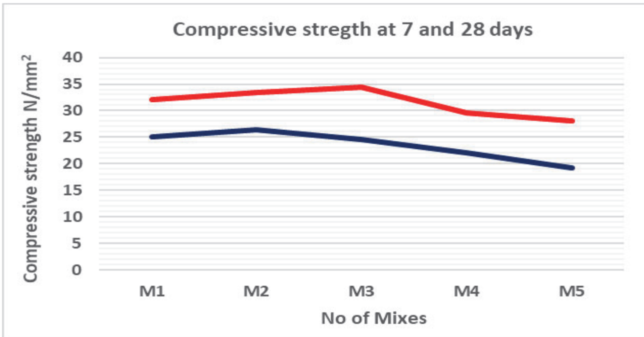

Fig - 11: Relation between compressive strength and number of mixes at 7 and 28 days

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IV. DISCUSSION OF RESULTS

The results obtained from the different tests are summarized and discussed as following:

Fresh Concrete: From the results presented in Table 7 and Figure 7, it is observed that as the percentage of polypropylene fibers increases, the slump of the concrete mix decreases. When concrete is to be placed using pumps, a plasticizer is used.

Hardened Concrete: Table 9 presents the compressive strength results and the corresponding polypropylene fiber percentages. figure 9 and figure 11 illustrate the relationship between the polypropylene fiber content and compressive strength. The results indicate that the concrete compressive strength increased by 5.5% at a fiber dosage of 0.05% compared to the control mix without fibers. However, the compressive strength began to decrease at a fiber content of 0.15%, showing a 1.6% reduction relative to the control mix. At a dosage of 0.25%, the strength decreased by 12.3%, and at 0.35%, it decreased by 22.2% compared to the control mix. function of the polypropylene fiber content, where ST represents the concrete compressive strength and PP represents the polypropylene fiber percentage:

$ST = -2961.9PP^4 + 2419.5PP^3 - 694.31PP^2 + 57.03PP + 25$…. (1)

with a coefficient of determination $R^2=1$.

` Table 10 presents the compressive strength results and the corresponding polypropylene fiber percentages. Figure 10 and figure 11 illustrate the relationship between polypropylene fiber content and compressive strength.

From the results, it is observed that the concrete compressive strength at a fiber dosage of 0.05% increased by 4% compared to the control mix without fibers. The strength also increased at a fiber content of 0.15% by 7% relative to the control mix. However, the compressive strength began to decrease at a fiber dosage of 0.25%, showing an 8% reduction compared to the control mix. At a dosage of 0.35%, the strength decreased further relative to the control mix.

From Figure 11, the following equation was derived using Excel to calculate the compressive strength as a function of the polypropylene fiber content, where ST represents the concrete compressive strength and PP represents the polypropylene fiber percentage:

ST=6047PP4−3354.8PP3+347.4PP2+18.244PP+32.1…. (2)

with a coefficient of determination $R^2=1$.

Table 8 and Figures 10 present the relationship between polypropylene fiber content and concrete density. The results demonstrate an inverse relationship, where increasing the fiber percentage leads to a reduction in density.

Cracks in Cubes :The crack patterns observed in the tested cubes are shown in figure 12 through figure 16 for mixes containing varying percentages of polypropylene fibers. The visual inspection indicates that increasing the fiber dosage effectively reduces crack width and propagation, demonstrating the crack-bridging effect of polypropylene fibers.

Fig - 12: Crack Pattern at 0.0% Polypropylene Fiber Content

Fig - 13: Crack Pattern at 0.05% Polypropylene Fiber Content

Fig - 14: Crack Pattern at 0.15% Polypropylene Fiber Content

Fig - 15: Crack Pattern at 0.25% Polypropylene Fiber Content

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Fig - 16: Crack Pattern at 0.35% Polypropylene Fiber Content

V. CONCLUSION AND RECOMMENDATION

In this study the Polypropylene Fiber were used to investigate its effect on Concrete through the measure of workability for fresh concrete and compressive strength for hardened concrete in 7 and 28 days. Based on the results it can be concluded that:

- The compressive strength of concrete increases with the addition of polypropylene fibers up to a certain limit. Beyond a fiber dosage of 0.25%, the compressive strength decreases.
- As the polypropylene fiber content increases, the slump of the concrete mix decreases. Therefore, the use of a plasticizing admixture is recommended when incorporating polypropylene fibers to maintain workability.
- The density of concrete decreases as the polypropylene fiber content increases.
- It was found that the addition of polypropylene fibers reduces cracking in reinforced concrete.
- The optimum dosage of polypropylene fibers is 0.15%, which yields a 1.3% increase in compressive strength compared to the control mix.

Based on the experimental results, the optimal polypropylene fiber content is recommended to be within the range of 0.05% to 0.15% by volume of concrete. Dosages exceeding 0.25% are not recommended due to the reduction in compressive strength and workability.

Further research is recommended to investigate the effectiveness of polypropylene fibers in the remediation and control of concrete cracking.

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