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AN INVESTIGATION INTO THE STRUCTURAL BEHAVIOR OF CONCRETE REINFORCED WITH POLYPROPYLENE FIBERS

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ABSTRACT

In the past few decades, small fibers are increasingly used in reinforcement of concrete as an enhancement or alternative to steel bars. The addition of plastic fibers in the concrete matrix improves performance, reduces material costs and provides better working conditions on site such as reduction in concrete mixing noise in residential areas. Fibers attenuate the formation of cracks in concrete and enhance the structural behavior with increased shear, ductility, flexural capacity as well as compressive strength. This paper examines the effects of incorporation of macro synthetic fibers on the properties of fresh concrete and structural behavior in hardened state.

For this purpose, polypropylene fibers were added at a dosage of 0.25%, to 1% to the concrete mix. To assess the performance of polypropylene (PP) fiber reinforced concrete, the samples were compared with identical plain concrete members. From the experimental investigations, it was noted that the workability of concrete with a constant mix design was adversely affected by the increase in fiber content. The slump tests with fresh concrete showed a slump of 50mm for plain concrete and decreased to zero slump for the same mix proportions with the addition of 1% of polypropylene fibers. The effects of fiber volume and type on hardened concrete were evaluated using standard strength tests. There was no significant effect on the compressive strength. However, at low fiber content of 0.5%, the results exhibited an increase in compressive strength. The flexural performance of small concrete beams showed improvement with the addition of low volume of plastic fibers. With the

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addition of fibers, there is a change in the pattern of failure, wherein even upon reaching the ultimate load the beams failed in a pseudo-ductile manner. This was attributed to the concrete crack bridging properties of the fibers. On the basis of the experiments and data analysis, the results have clearly showed enhancement in the structural and mechanical behavior of concrete reinforced with plastic fibers as compared to plain concrete.

Key words: Fibers, Polypropylene, Concrete, Workability, Compression, Flexure.

Introduction

The construction industry is the second largest consumer of plastics after the packaging industry [1]. Concrete is the most widely used construction material in the world with production of over 2 billion tons per year [2]. Therefore, the use of recycled plastics in concrete provides a huge scope for the re-utilization of waste plastic on an industrial scale. In this research paper, the focus is on the usage of recycled plastic fibers as reinforcement in concrete and comparing the structural properties with concrete reinforced with virgin plastic fibers as well as plain concrete.

Fiber Reinforced Concrete

In recent years, fibers have been added as reinforcement in concrete. This type of concrete is popularly known as fiber reinforced concrete (FRC). Fibers act as a crack controlling agent and improve the strength and durability of the concrete members. It is well documented by previous researchers [3, 4, 5] that the incorporation of plastic fibers is an effective method to improve the toughness of concrete which also enhances the energy absorption capacity of concrete. Short cut fibers in the range of 45-60 mm in length are added to the concrete matrix in low volume fractions of 0-2%. The tensile strength, ductility and the extent of post-cracking behavior of concrete depend on the type and characteristics of fibers. These attributes are distinctly relevant in places where structures are required to possess high energy absorption, bending capacity and plastic deformation. Commercially, there are many types of fibers available in the market with different properties for reinforcement of concrete. They are divided into 3 categories – Steel, Synthetic and Natural fibers.

Recycled Plastic Fibers

Polypropylene fibers are a form of synthetic fibers that are the preferred plastic fibers for reinforcement of concrete due to their light weight, water, and alkali resistance [6]. The recycled PP fibers used in this research have been obtained from segregation of carpet yarns which are the most common source of recycled plastic fibers that are presently available for research purposes. Carpet fibers used by previous researchers

[7, 8, 9,] are mainly PP fibers but also contained nylon, latex and other impurities that contribute to uncertainty in the behavior of these fibers for different structural parameters. However, in this research to minimize the effect of such factors on the performance of concrete members, the PP fibers were sourced from a specialized recycling facility that separate the different plastics in the carpets and process the fibers to produce recycled plastic fibers with more than 95% polypropylene composition.

Experimental Program

The specimens were prepared for investigating the structural properties of plain and fiber reinforced concrete. 24 standard 100mm cubes were cast for compressive strength tests. A total of 32 beams with dimensions 150x150x500 mm were fabricated for flexural tests.

Material Properties

The materials that are used in this experimental investigation are according to the standard specifications for concrete mix design by British Standards. Ordinary Portland cement with a compressive strength of 40 MPa was utilized for all the concrete mixes. The coarse aggregates were uncrushed and have a maximum size of 20mm along with natural washed sand as fine aggregates. A macro-synthetic virgin polypropylene fiber type was used in the concrete mix with varying content ranging from 0-1 %. The recycled PP fibers were ordered with similar physical properties. The properties of the fibers are displayed in Table 1.

Table 1 : Properties of Polypropylene fibers (Bonar, 2014; Belrey Fibers NV, 2004)

Type of Fiber	**Virgin Polypropylene**	**Recycled Polypropylene**
Length (mm)	45	45
Shape/Type	Monofilament/Macro	Twisted
Absorption	Nil	Nil
Specific Gravity	0.91	0.91
Electrical Conductivity	Low	Low
Acid Resistance	High	High
Melting Point	164	160-170
Ignition Point	> 550	> 500
Thermal Conductivity	Low	Low
Alkali Resistance	Alkali proof	Alkali proof

Mix Design

The concrete mix design was kept constant for the entire series irrespective of the fiber content. This aided in noting the effects of addition of different volumes of fibers to a conventional concrete mix. The mix was designed according to BS 8500 [10] to attain a target mean strength of 43Mpa. The mix was designed for a slump of 10-30 mm with a vibration time of 1-2 minutes. The fine aggregate and coarse aggregate content were calculated according to the British Standards by noting the quantity of fine aggregates passing through the 600 μm sieve after sieve analysis. The fine aggregates used for the sieve analysis were oven dried to ensure dry sampling of aggregates for testing.

Mixing and Casting

The concrete mixes were prepared in a rotating pan mixer. Coarse aggregates and fine aggregates were dry mixed initially for a period of one minute followed by the addition of cement for a further one more minute. After an acceptable composition of the mix was noted, the plastic fibers were added by hand in equal amounts to ensure optimal distribution of fibers in the mix. The ingredients were allowed to be dry mixed for a minute for even dispersion in the drum. It was noticed that the addition of fibers in the dry mix lowered the noise levels of the mixing. In the end, water was added to the mix and the mixer was allowed to run for five minutes before casting.
The specimens were covered with plastic sheets and left for 24 hours in the moulds before curing. Subsequently, the beams and cubes were removed from the casts and immersed in a curing tank for 28 days before testing.

Effects on Fresh Concrete

The workability of fresh concrete is measured using the inverted cone slump test. The test was carried out according to BS EN 12350 – 2:2009 [11], testing fresh concrete to determine the proper workability of the concrete mix. A true slump was obtained for most samples except for the samples with the highest fiber volumes which yielded zero slumps. This is noted in the graph below which shows a linear decrease in slump of concrete with increase in fiber content which is attributed to the orientation of the fibers in the matrix and their balling effect that does not allow the concrete to flow freely. Therefore, it shows that with the same mix design the workability of the concrete decreases with increase in fiber volume.

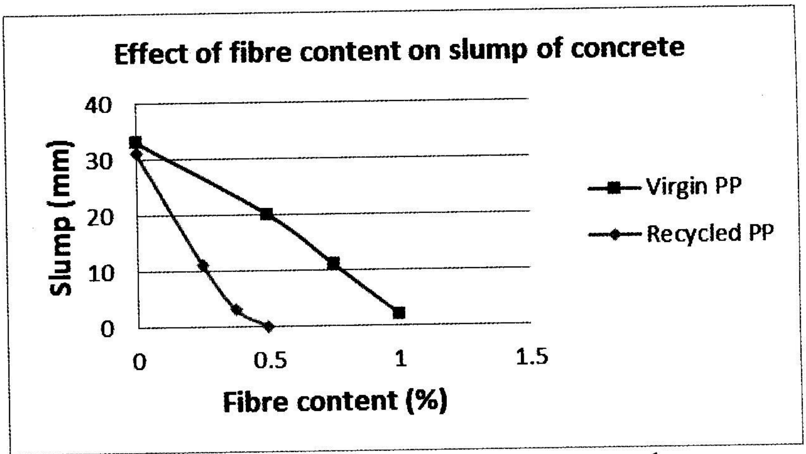

Figure 1 : Effect of fiber content on concrete slump

Since, fibers impart considerable stability to fresh concrete the slump cone test is not an accurate index of workability [12]. Therefore, the Vebe test was conducted on the samples of recycled fiber reinforced concrete according to the BS EN 12350-3:2009 [13] and the results are compared in table 2. It can be seen that the Vebe test indicated minor increases in the slump values. However, according to the British Standard, samples with Vebe time greater than 30 seconds are too compact to be tested for workability using the Vebe test. Hence, samples with fiber content greater than 0.25% are highly consolidated for a good workability.

Table 2 : Comparison of slump and Vebe test results

Fiber content (%)	Slump (mm)	Vebe time (seconds)	Vebe slump (mm)
0	31	6	35
0.25	11	29	15
0.375	3	36	4
0.5	0	66	0

Results and Analysis

The hardened structural properties of concrete were analysed through compressive strength and flexural strength tests. The compressive strength tests were carried out according to BS EN 12390-3:2009 [14] using a universal testing machine. The procedure stated in BS EN 12390-5:2009 [15] was adopted to conduct the flexural strength tests.

Compressive Strength

The inclusion of short virgin PP fibers in the concrete did not yield significant effects on the compressive strength of the concrete at 28 days. At a low fiber content of 0.5%, there was an increase of 5% in compressive strength as compared to the control specimens as seen in figure 2. The increase in the compression strength at a low volume of 0.5% is attributed to the fiber properties such as the thin, monofilament and crimped structure of the virgin fibers that bind the concrete matrix and increase the toughness to withstand higher loads without altering the mechanical properties of the concrete significantly. However, at higher volumes these fibers leave voids in the concrete structure and induce porosity which weakens the concrete. This characteristic has been noted in previous studies with plastic FRC [16]. With the addition of recycled PP fibers in the concrete mix design, the compressive strength of concrete decreased linearly with increase in fiber content as shown in figure 2. This behavior is attributed to the lower density of the recycled fibers and the "matte effect" that they have in the concrete mix which leads to lower mass per unit volume of concrete and additional air voids. The reduction of compressive strength with the increase in recycled fibers is also due to the decrease in content of coarse aggregates which are replaced by these fibers which have a larger surface area due to their twisted shape and yarn structure.

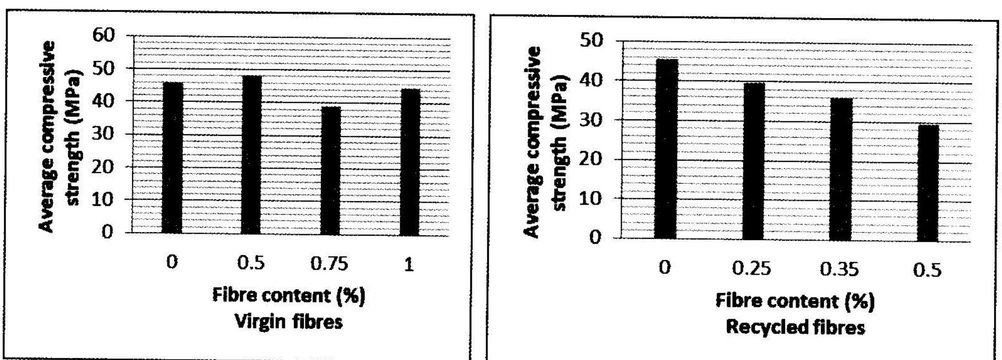

Figure 2 : Effect of fiber content on the compressive strength of concrete cubes.

At 0.5% fiber content the compressive strength of concrete with virgin PP fibers increased, while it decreased significantly in case of recycled PP fibers. This effect is attributed to the difference in the fiber properties such as the shape, orientation in the mix and the fiber surface area. It results in uneven mixing in the matrix and the coagulation of concrete mix around the fiber surface leaving higher amounts of void in the matrix as seen in Figure 3.

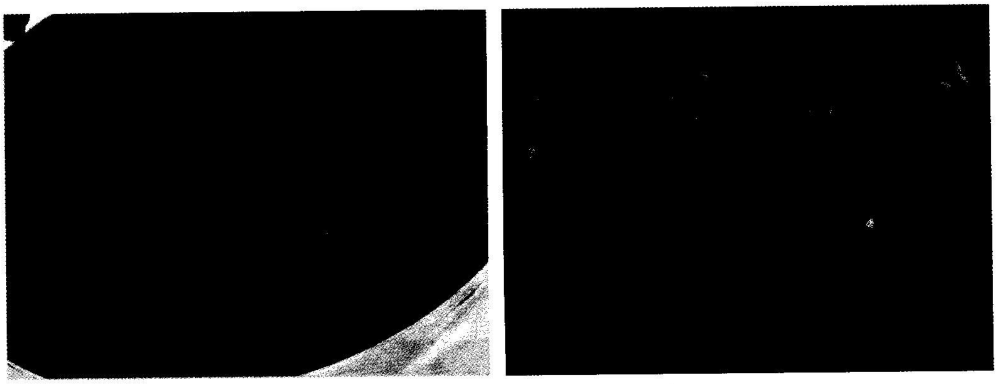

Figure 3 : Fiber coagulation in mixing drum and cross section view of a tested specimen showing void content.

<u>Flexural Strength</u>

The flexural strength of the concrete beams was measured using the Modulus of Rupture test in a four point bending system. According to the data obtained, the average flexural strength of specimens containing virgin PP fibers at 0.75% and 1% improved by 10% and 8% respectively as compared to the control specimens while there was a decrease of 9% for fiber content of 0.5% as seen in figure 4. With an increasing content, fibers act as a crack bridging mode in the concrete structure and improve the load bearing capacity in bending tests and sustain a higher ultimate load before failure in a ductile manner.

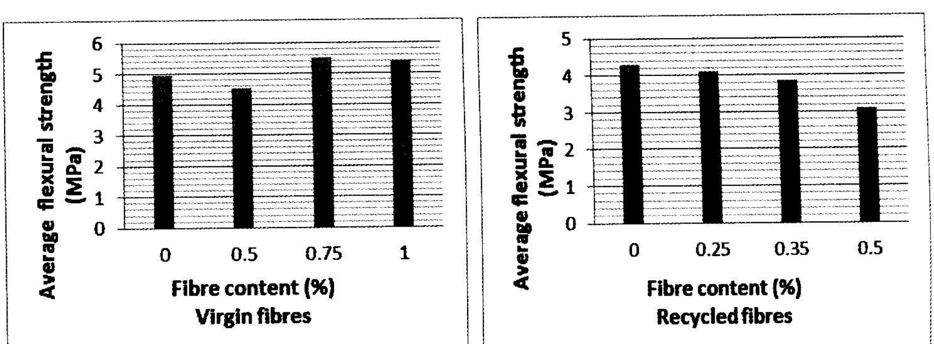

Figure 4 : Effect of fiber content on average flexural strength of small concrete beams.

With the inclusion of recycled PP fibers, there was no significant change in the flexural strength of concrete. At lower fiber content of 0.25% - 0.35%, the results showed a decrease of 4% - 9% in the average flexural strength of the specimens as compared to conventional concrete. However, as seen in figure 3. at 0.5% the flexural strength decreased by 28% due to the "matte effect" of the fibers in the concrete mix. This phenomenon causes a weak interface between the cement paste and the recycled plastic fibers with the aggregates and affects the cohesive properties resulting in poor bending capacity with increase in fiber content.

During the tests it was observed that, with an increase in fiber volume the beams failed with reduced crack sizes in a pseudo-ductile manner as compared to the control specimens [17]. Such an effect is due to the binding properties of the fibers which lead to prevention of brittle failure of the concrete members as seen in figure 5.

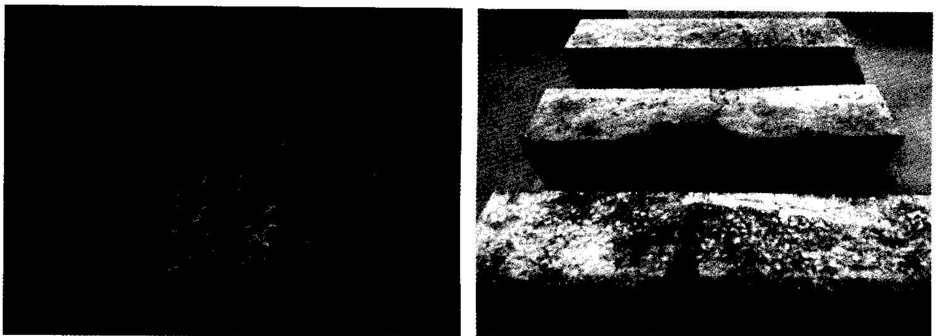

Figure 5 : Ductile failure and crack attenuation effect of fiber reinforced concrete.

Conclusions

Following the investigation of the structural behavior of concrete reinforced with plastic fibers, it can be concluded that the inclusion of plastic fibers for reinforcement of concrete provides a unique dimension to sustainable development in the construction industry. With the correct volumes and fiber structures, plastic fibers can be added to concrete as a cost effective alternative reinforcement to steel bars. They provide the opportunity to reduce plastic waste and conserve steel.

From the experimental investigation it was deduced that the design of fiber reinforced concrete mix is distinct to each fiber type. Virgin PP fibers and recycled PP fibers have different workability requirements in the concrete matrix and require optimization of mix design to obtain desired fresh and hardened concrete properties and structural behavior during testing. For the same fiber content as virgin PP fibers, recycled PP fibers require a higher dosage of water, cement and fine aggregates. The "matte effect" of the recycled PP fibers in concrete as mentioned in the study is similar to the "balling effect" of virgin fibers. It is defined as the concentration of concrete paste near the rough surface of the fibers in the matrix resulting in uneven distribution of fibers in the concrete mix leading to higher porosity. This can be reduced by changing the fiber structure which is currently a non-conventional process and requires further studies.

The investigation of the compressive strength has indicated that concrete with virgin PP fibers at the 0.5% volume, same as recycled PP fibers have greater compressive strength by 38%. However, at low volumes of 0.25% and 0.35% recycled PP fibers did not significantly affect the compressive strength as compared to the control specimen. Thus, with the increase in recycled fiber content the compressive strength decreases with a constant mix design.

The addition of virgin PP fibers showed an improvement in the flexural strength of concrete specimens at 0.75% and 1% fiber content. This is attributed to the crack bridging capacity of the fibers that allow the concrete beams to retain greater load before failure in bending. However, with the inclusion of recycled PP fibers at 0.25% did not affect the flexural strength while at 0.35% and 0.5% there was a significant decrease. The fiber reinforced concrete specimens showed reduced crack sizes and a smoother mode of failure.

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