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AN EXPERIMENTAL STUDY ON FIBERLY REINFORCED CONCRETE USING POLYPROPYLENE FIBRE WITH VIRGIN AND RECYCLED ROAD AGGREGATE

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Abstract

This research work mainly focuses on improving the concrete strength based on fiber reinforcement both in compression and tension. Concrete with various mix proportions containing dosage of Polypropylene (PP) fiber of lengths ranging from 13 to 25 mm with coarse aggregate replacement levels at 10%, 20%, and 30% by dismantled road aggregate were made and the compressive and tensile strengths were investigated. The experimental test results revealed high compressive and tensile strength at curing period of 28 and 56 days. The specimens tested observed that due to addition of fiber, the fibers could hold the matrix together even after extensive cracking and crushing. Net result of all these is to impart to the fiber composite pronounced post-cracking ductility which is absent in traditional concrete. In order to provide base for comparison, concrete specimens as a reference were cast without the addition of polypropylene fiber. Test result revealed that by adding polypropylene fibers at 6grams per one kg of cement a considerable improvement in the strength of concrete of 37.68 MPa and 43.59 MPa at 28 and 56 days respectively with 10% coarse aggregate replacement by recycled aggregate is achieved.

Streszczenie

W artykule przedstawiono badania, których celem było zwiększenie wytrzymałości betonu na ściskanie i rozciąganie przed dodatek zbrojenia rozproszonego w postaci włókien polipropylenowych. W badaniach wytrzymałości na ściskanie i rozciąganie próbek betonowych stosowano różnorodne mieszanki betonowe z dodatkiem włókien polipropylenowych (PP) o długościach od 13 do 25 mm i z dodatkiem kruszywa wtórnego pochodzącego z rozbiórki nawierzchni drogowych zastępującego kruszywo grube w ilościach: 10%, 20% i 30%. W badaniach, po 28. i 56. dniach twardnienia betonu, uzyskano wysoką wytrzymałość na ściskanie i rozciąganie. Dzięki dodatkowi włókien zaobserwowano, że matryca cementowa jest utrzymana nawet wówczas, gdy ma miejsce intensywne zarysowanie i zmiażdżenie próbki. W badaniach stwierdzono zatem ciągliwość po zarysowaniu kompozytu betonowego zbrojonego włóknami, której pozbawiony jest tradycyjny beton. Do badań porównawczych, wykonano próbki betonowe bez dodatku włókien polipropylenowych. W badaniach porównawczych, dzięki dodatkowi włókien polipropylenowych w ilości 6 g/kg cementu uzyskano znaczną poprawę wytrzymałości betonu – o 37.68 MPa i 43.59 MPa, odpowiednio po 28. i 56. dniach i przy 10% zastąpieniu kruszywa grubego kruszywem drogowym, z recyklingu.

Keywords: **Polypropylene; Concrete; Fiber; Cubes; Cylinders; Strength.**

1. INTRODUCTION

Polypropylene fiber is the first stereo regular polymer which has obtained remarkable importance in industries. The fibers from Polypropylene (PP) were first introduced to the textile arena in the 1970s and have got significant importance in the rapidly growing family unit of synthetic fibers. At present Polypropylene stands at fourth place behind the other most important fiber classes, i.e. acrylic, nylon and polyester. Polypropylene (PP) is a thermoplastic material. It is produced from propylene gas when catalyst such as titanium chloride is present [1]. Fiberly reinforced concrete (FRC) is basically made of hydraulic cements, aggregates and discrete reinforcing fibers. Suitable reinforcing fibers for concrete have been produced from glass, steel, and organic polymers (synthetic fibers). Sisal and Jute are naturally occurring asbestos fibers and mineral fibers which are also used as reinforcing materials in concrete. The bases for concrete could be mortars, normally proportioned mixtures, or mixtures specifically formulated for a particular application. If properly engineered, one of the greatest benefits to be gained by using fiber reinforcement is improved long-term serviceability of the structures [2]. Addition of fibers in concrete reduces crack width thus increasing the durability of the concrete structures. As compared to normal cement concrete fiber-reinforced concrete is much stronger and more resistant to impact. Its major role is to enhance the energy absorption capability and stiffness of the material, however it also increases the tensile as well as the flexural strength of concrete. Concrete is the most versatile material used for construction. Construction activities deplete large amount of natural resources causing harmful effects to the environment. Depletion of natural resources has captivated to recycle wastes of any materials into a useful product. Many researchers have worked on recycling the road material of construction and demolished activities for the preparation of concrete. Recycling of waste debris will be economical for infrastructure development saving the natural resources by making green environment. Fibers of any material play a significant role in improving the strength and deformation properties of the cement matrix in which they are incorporated. The research work conducted by many experts and technology reveal that the engineering advantages of mixing fiber in cement concrete may improve the stiffness, fracture, fatigue resistance, flexural strength, compressive strength, impact resistance, thermal crack resistance, shear strength, rebound loss, and so on. The improvement in such properties depend both upon the amount and the type of fiber used [3, 4]. Research has been done to use recycled aggregate to normal concrete and it is found out that up to 30% replacement of natural aggregate is recommended [5]. Fiber reinforced concrete is widely used in different kinds of sectors in Pakistan such as, public and industrial buildings, water reservoirs, steel free road pavements, fiber reinforced concrete pavements, fiber reinforce canal linings, fiber reinforced sewage channels, Plaster, fiber reinforced steel free concrete and in fiber reinforced industrial flooring.

2. PRESENT INVESTIGATION

In the present study, polypropylene fibers ranging in length from 13 to 25 mm are used in developing concrete made with recycled aggregates. Polypropylene fiber acts as a secondary reinforcement to enhance the tensile properties of concrete. The recycled aggregates chosen for this work vary in the range of 0 to 30% at increments of 10% as a substitute of normal coarse aggregates in making concrete. Further the strength characteristics of polypropylene fiber reinforced recycled aggregate concrete is studied for different ages in days. In the present research, an effort has been made to fix the optimum replacement of coarse aggregates by recycled aggregate procured from the waste debris used for developing concrete without compromising the hardened properties of concrete. Adding fibers in cement concrete may be of current interest, however, it is concept. On the other hand, recycled road aggregate is produced by hammering the clods of dismantled aggregate to re-shape the aggregate. Utilization of recycled aggregate may be economical for local governments and other purchasers, which could also create further business opportunities, save energy when recycling is done on site, conserve diminishing resources of urban aggregates, and may support local governments.

3. MATERIALS, METHODOLOGY AND EXPERIMENTAL PROGRAM

3.1. Materials

3.1.1. Cement

Ordinary Portland cement (OPC) under the brand name Lucky from Lucky cement factory Karachi, Pakistan, was used in all mix proportions. Care was taken for the manufacture date of the cement and freshly made cement was bought and used during this experimental work. Physical tests of cement were also conducted the details of which are given in Table 1.

Table 1.
Physical test results of cement

S.NO.	TESTS	RESULTS
1	Specific Gravity	3
2	Consistency	30%
3	Initial Setting Time	45 minutes
4	Final Setting Time	600 minutes

3.1.2. Coarse and Fine aggregate

Locally available material having water absorption 2 percent was used as coarse aggregate in the concrete mix. Similarly, locally available river sand was used as fine aggregate. Both materials were sieved and were brought to the required size i.e. 19 mm. Tests regarding the specific weight and water absorption for both virgin and recycled aggregate were conducted, the details of which are given in Table 2.

3.1.3. Recycled Road Aggregate

Dumped road aggregate was attained and brought to the structural laboratory from Rehabilitation project on National Highway near Sukkur city in Sindh. This material was attained by removal of wearing as well as base coarse from a section of National Highway (N-5). Large chunks were broken down into required size of 19 mm. Sieves of sizes 25, 19 and 13 mm respectively were used to obtain the desired size i.e. 19 mm [6–10].

Table 2.
Test Results of Virgin and Recycled Aggregates

S. NO.	Tests	Virgin Aggregates	Recycled Aggregates
1	SPECIFIC GRAVITY	2.7	2.6
2	WATER ABSORPTION	2%	3%

3.1.4. Mixing Water

Potable water was used in the concrete mix as needed. Fresh tap water was used after testing it for pH which gave an average value of 7.1. Therefore, the tap water was found to fit our experimental work [11-13].

3.1.5. Polypropylene Fiber

Polypropylene fiber used in this experimental work was obtained from Matrix co. Karachi Pakistan. The obtained fiber was in two different lengths i.e. 13 mm and 25 mm. Further properties of used polypropylene fiber are shown in Table 3.

Table 3.
Properties of polypropylene fiber [18]

S.No.	Properties	Dosage
1	Shrinkage Cracking	Up to 0.3% by volume
2	Tensile Strength	0.2–0.3% by volume
3	Flexural Strength & Toughness	1.5% by volume
4	Impact Resistance	0.2% by volume increases impact resistance by 250%
		0.3% by volume increases impact resistance by 900%
5	Permeability	0.1% fiber by volume
6	Durability	0.1% fiber by volume

3.2. Methodology

A total of 180 cube and cylinder specimens were cast keeping cement, fine aggregate and coarse aggregate ratio of 1:2:4 and 1:1.5:3 which are followed traditionally. Water cement (w/c) ratio was maintained as 0.6 for all the batches of fiberly reinforced concrete and 0.45 for plain concrete. Water to cement ratio of 0.6 was selected for concrete mix with fibers because the fibers in concrete were absorbing more water and eventually the mixture was becoming dry when the w/c ratio was 0.45, hence extra water was needed to put in the mix. However, 0.45 w/c ratio was selected according to ASTM standards and is used in conventional concrete mixture. Dimensions of Cube specimens were 150 mm by 150 mm and for cylinders 150mm diameter specimen with height of 300 mm. After making plain cement concrete specimens, aggregate and cement were replaced at different percentages. Apart from this a dosage of 6 grams of polypropylene fiber per one kilogram was added in concrete made with 1:2:4 ratio. Virgin aggregate was replaced by recycled road aggregate at 10%, 20% and 30%, for the curing period of 7, 14, 28 and 56 days. After curing cubes were tested for compressive strength and cylinders for both tensile and compressive strengths [14–18].

3.3. Experimental work & tests

The experimental work during this research activity was carried out in the structural engineering laboratory of civil engineering department at Quaid-e-Awam University College, of Engineering, Science &

Technology, Larkana, Sindh, Pakistan. Various tests regarding concrete and sand were conducted among which few are given as follows;

3.3.1. Slump Test

Slump test was conducted for all the batches of mix design and the results are given in Table 4.

Table 4.
Slump cone test results of different concrete mix

Batch	Concrete Type	Mix Design Ratio	W/c Ratio	Slump
1	Plain Concrete	1:2:4	0.6	25 mm
2	Plain Concrete	1:1.5:3	0.45	25 mm
3	10% Replacement with Recycled aggregate	1:2:4	0.6	20 mm
4	20% Replacement with Recycled aggregate	1:2:4	0.6	25 mm
5	30% Replacement with Recycled aggregate	1:2:4	0.6	20 mm

3.3.2. Fineness Modulus of Sand

The Fineness Modulus (FM) of sand was calculated in which an empirical figure is obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves, and dividing the sum by 100. In general, a lower FM results in more paste, making concrete easier to finish. For the high cement contents used in the production of high-strength concrete, coarse sand with an FM around 3.0 produces concrete with the best workability and highest compressive strength. One Kg of sand was used to perform the sieve analysis as per ASTM C33. The fineness modulus of sand was calculated by using the given equation;

$$\textit{Fineness Modulus (FM)} = \frac{\sum \textit{Cumulative Weight Percentage Retained on Each Sieve}}{100}$$

The results of sieve analysis and fineness modulus are given in Table 5.

Table 5.
Sieve analysis and Fineness Modulus of sand

Sieve #	Weight retained (grams)	Cumulative Weight Retained (grams)	Cumulative Weight Percentage Retained
8	15	15	1.5
16	35	50	5
30	80	130	13
50	130	260	26
100	540	800	80
Pan	200		

Result: Fineness Modulus (FM) = 1.25

4. ANALYSIS OF TEST RESULTS & DISCUSSION

At first concrete specimens of conventional concrete as bases for comparison were cast. The Cement concrete made by recycled coarse aggregate and by adding the dosage of Polypropylene fiber revealed positive result which almost reached the strength of traditional concrete. Marked strength results have been achieved in the concrete made with 1:2:4 ratio. With the addition of Polypropylene fiber this gave the same strength of concrete made with 1:1.5:3 ratio concrete thereby making it more economical. This gave almost the same results. The peak values and increase in strength after curing period of 7 days is demonstrated in the following figures.

4.1. Compressive strength results (with virgin aggregate)

4.1.1. Cubes of Plain Concrete with Ratio 1:1.5:3 and Fiberly Reinforced Concrete with Ratio 1:2:4

Initially compressive strength test results of cubes made with plain cement concrete of 1:1.5:3 mix ratio and cubes made with adding polypropylene fiber in 1:2:4 concrete mix ratio were tested. Fig. 1 shows increase in compressive strength of cubes for curing periods of 28 and 56 days. It is also observed that the strength is approximately the same as that of plain concrete for the curing period of 28 and 56 days. Peak values are obtained for both 28 and 56 days of curing. It was observed that the compressive strength after 56 days decreased and could be due to the recycled aggregates which had minimum quantity of bitumen attached and lost its strength when remained in contact with water for longer time.

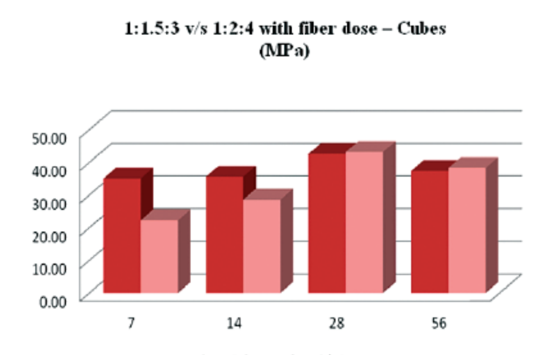

Figure 1.
Compressive strength test results of cubes for different curing periods

4.1.2. Cylinders of Plain Concrete with Ratio 1:1.5:3 and Fiberly Reinforced Concrete with Ratio 1:2:4

Fig. 2 shows increase in compressive strength of cylinders for 14, 28 and 56 days of curing. It also shows that the strength is almost the same as that of plain concrete. Peak values are obtained for both 28 and 56 days of curing. Addition of Polypropylene fiber has shown marked increase in strength.

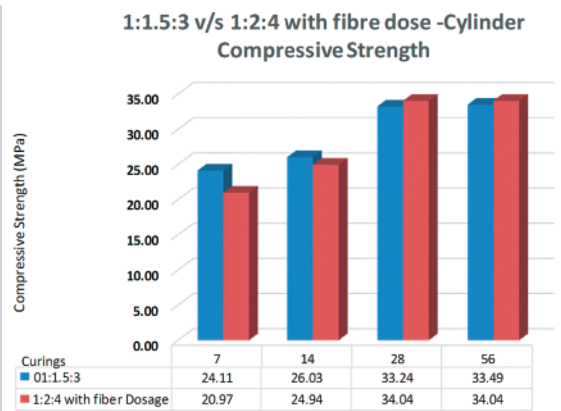

Figure 2.
Compressive strength test results of cylinders for different curing periods

4.1.3. Tensile strength results of cylinders

Fig. 3 presents the tensile strength test results of cylinders made for curing period of 7, 14, 28 and 56 days. It may be observed from the results that curing period of 28 and 56 days give the maximum tensile strength. Peak values are obtained for both 28 and 56 days of curing.

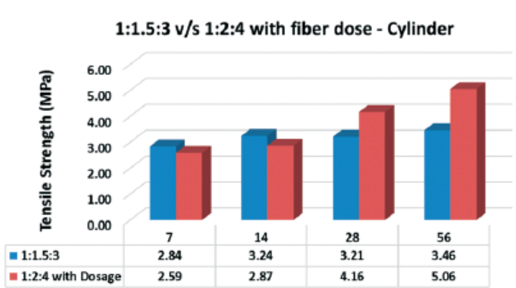

Figure 3.
Tensile strength test results of cylinders for different curing periods

4.2. Compressive strength results (recycled concrete)

4.2.1. Cubes of Recycled Concrete with Ratio 1:1.5:3 and Fiberly Reinforced Concrete with Ratio 1:2:4

Fig. 4 shows compressive strength results for cube of plain concrete with ratio 1:1.5:3 and Fiberly reinforced concrete with ratio 1:2:4 along with replacement of coarse aggregate with recycled aggregate. It can be observed that with 10% replacement of aggregate and by adding fiber dose, the strength obtained is more than that of plain concrete of 1:1.5:3. Peak values are obtained at curing periods of 14 and 28 days.

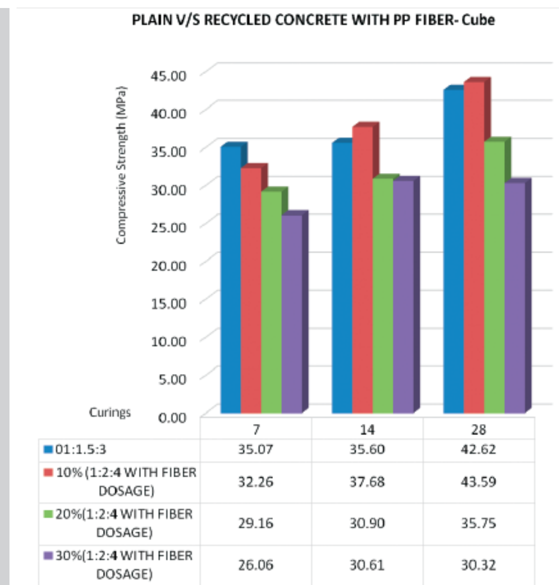

Figure 4.
Compressive strength test results of cubes both for plain and recycled concrete

4.2.2. Cylinders of Recycled Concrete with Ratio 1:1.5:3 and Fiberly Reinforced Concrete with Ratio 1:2:4

Fig. 5 shows the comparison of compressive strength results for cylinders of both plain concrete with ratio 1:1.5:3 and fiberly reinforced concrete with ratio 1:2:4 along with replacement by recycled road aggregate. It can be observed that the coarse aggregate replaced with 10% and by adding fiber dosage the strength attained is more than that of plain concrete of 1:1.5:3. Peak values are obtained at 7 and 14 days curing period.

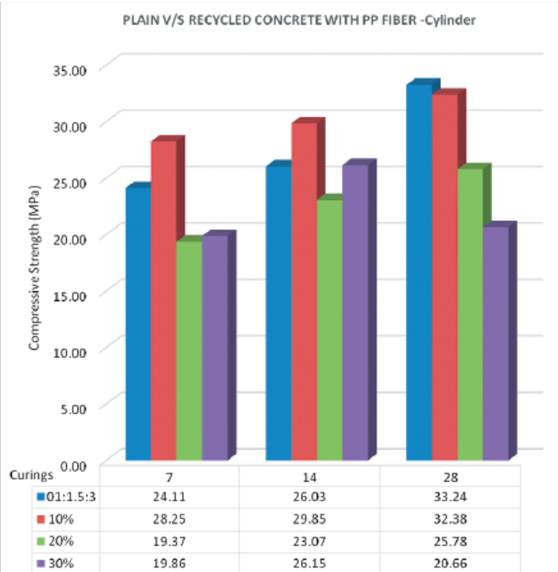

Figure 5.
Compressive strength test results of cylinders both for plain and recycled concrete

4.2.3. Tensile strength results of cylinders

Fig. 6 shows tensile strength test results of cylinders made of both virgin and recycled aggregate. The aggregate replaced at 10% gave the highest tensile strength for cylinders for all curing periods of 7, 14 and 28 days. So the tensile strength attained is more than the strength of plain concrete. It is because of the addition of polypropylene dosage in concrete. Peak value is obtained at curing period of 28 days.

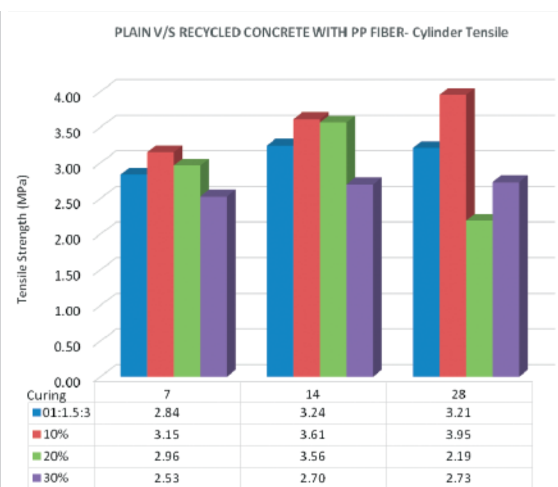

Figure 6.
Tensile strength test results of cylinders both for plain and recycled concrete

5. OBSERVATIONS & RECOMMENDATIONS

In this experimental study, it has been observed that addition of fiber reinforced concrete is much better than the plain concrete alone in many aspects. It is obvious that the mix design ratios play very vital role on the properties of concrete particularly on the strength. Therefore, by observing the test results, mix design ratio of 1:1.5:3 is recommended to be stronger and gives more strength as compared to mix design ratio of 1:2:4. It is clear that concrete mix made with 1:2:4 does not give the same strength as that of 1:1.5:3. To achieve the same strength of 1:1.5:3 in the mix design of 1:2:4 is nearly impossible. However, this strength has been achieved in this experimental work and became possible in the way when a secondary material like polypropylene fiber is added. And it has been proved in this experimental work that cement concrete of 1:2:4 mix gave almost the same strength as that of 1:1.5:3 concrete mix. It was also observed after testing concrete specimens that, cubes and cylinders made by adding fibers show post crack ductility which is nearly impossible in plain concrete specimens. It can be observed in fig. 7, the specimens tested having fibers are still strong enough since the fibers are holding the whole concrete mix together. The cube and specimens on right side of the figure, 7 are with fiber content. This is a better solution to provide ductility in concrete which will also help concrete to undergo more deflection before getting to its ultimate failure.

During our experimental work concrete specimens, have not been cured and tested for 90 days. It is suggested and hoped that this approach will surely work for more strength if it is cured up to 90 days or even more. Based on result obtained, it is also suggested that polypropylene fiber reinforced concrete should also be used where high strength is desired eventually saving cost and producing an economical solution.

6. CONCLUSIONS

The following conclusions can be drawn:

- It is found from experimental investigations that the use of Polypropylene (PP) fiber in mix design of 1:2:4 gave the same strength as obtained by cement concrete of 1:1.5:3 mix. In this way an economical concrete could be made by adding polypropylene fiber and getting higher strength.
- Dosage of 6 grams of PP fiber per one kilogram of cement in concrete mix design of 1:2:4 ratio gave

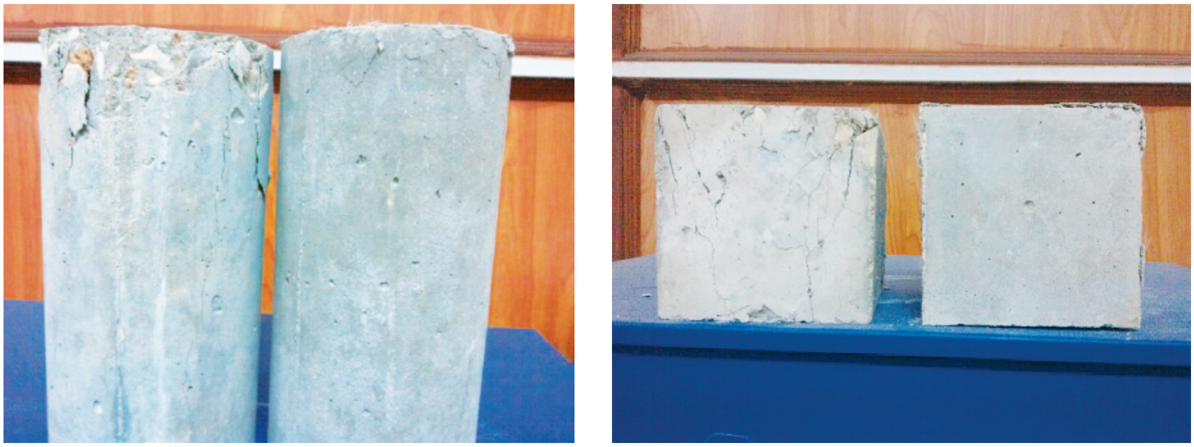

Figure 7.
Post crack ductility shown both in cylinder and cube specimens

incredible results. Typically, after 14 days curing fiberly reinforced concrete revealed excellent results at 28 and 56 days of curing.

- Furthermore, in mix design of 1:2:4 the replacement of virgin aggregate by recycled road aggregate in percentages of 10, 20 and 30% gave noticeable increase in the strength of concrete when compared with the test results of mix design of both 1:1.5 :3 and 1:2:4.
- The strength results obtained by testing the specimens of recycled concrete along with the addition of PP fiber revealed suitable results as mentioned in the graphs.
- By using polypropylene fiber, properties of concrete like permeability and shrinkage cracks could be controlled.
- Polypropylene fibers provide better post crack ductility in concrete, helping in taking much longer before getting to fail completely which is apparent in Figure 7.

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