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Effect of Treated Recycled Aggregate on the Mechanical Properties of Polypropylene Fibre Reinforced Concrete

Nazrin Nazar, A. Nizad

Abstract: ***The non-availability of materials is one of the major factors affecting the progress of construction. Natural resources are becoming insufficient to meet the increasing demand in construction. As a solution to the above problems, recycled aggregates from the demolished waste are now being used as replacement of natural aggregates. But the use of recycled aggregates drastically decreases the strength of concrete. This is mainly due to old mortar on the surface of aggregate which render the surface porous and makes it of inferior quality. Recent literatures suggests surface treatment to improve the strength. Therefore in this study, recycled aggregate that is treated in dil. HCl to remove the loose mortar is used instead of recycled aggregate. Also fibre reinforced concrete is now being widely used in industry due to its abrasion resistance, shrinkage control and impact resistance. The objective of this study is to find out the combined effect of treated recycled aggregate with polypropylene fibres and the strength properties are compared with that of conventional concrete. Mix proportion is done for M25 concrete. Natural coarse aggregate is replaced by treated recycled coarse aggregate in proportions of 0, 20, 40, 60, 80 and 100%. In all mixes the proportion of polypropylene fibre is kept constant at 0.2% by volume of concrete. From the test results it is inferred that the use of concrete, containing up to 60% replacement of natural coarse aggregate with treated recycled coarse aggregate can be economically and judiciously encouraged for structural applications.***

Index Terms: ***Fibre reinforced concrete, polypropylene fibre, recycled aggregate, treated recycled aggregate.***

I. INTRODUCTION

A sustainable construction has become a great concern over the years. This is due to the fact that the construction industry is a massive consumer of natural resources and a huge waste producer as well. The resources such as coarse aggregate, sand and cement will be at a disadvantaged position, as these resources are not able to cope with the high demand in the construction industry. Therefore, utilizing the recycled aggregate may be one of the significant efforts in achieving a sustainable construction: it reduces the quantity of concrete waste that otherwise would have been disposed in landfills, decreases the dependence of the construction industry on natural aggregates, thereby preserving natural resources.

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***** Correspondence Author (s)

Nazrin Nazar, PG Scholar, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala, India, E-mail: nazrinnazar89@gamil.com

A. Nizad, Professor, Department of Civil Engineering, TKM College of Engineering, Kollam, Kerala, India, E-mail: anitkmce@gmail.com

The reuse of recycled aggregate can ease the aggregate shortage problem and reduce environment pollution. But despite the various environmental benefits and cost savings in using recycled aggregates as a substitute for natural aggregates, Recycled coarse aggregate (RCA) does not gain wide acceptance among practitioners due to the adhered mortar on the surface which poses deleterious effects on the concrete. Numerous studies performed on recycled aggregate (RA) indicated that RA had poor characteristic of porous structure, high water absorption, low crush resistance and low compressive strength attributed to the presence of porous mortar as well as the tiny seams derived from crushing process, which resulted in a decline of workability, strength and durability of recycled concrete. In addition, the high porosity and water absorption characteristics of RCA would lead to lowering the effective water content for the hydration process because the adhered mortar on the aggregate particle tends to absorb a large amount of water during the initial mixing stage. This creates a loose interfacial zone in the hardened concrete. Thus the compressive strength of recycled aggregate concrete (RAC) becomes unsatisfactory when a high percentage of RCA is used to replace natural aggregate. The poor quality of RCA, which affects the performance of concrete, imposes limitation on the widespread commercial use of RCA especially in production of structural concrete. Hence, several researchers have investigated various techniques and method that can enhance the physical properties of RCA. These involve the maximum removal of loose particles and old mortars attached to the original aggregate of RCA to attain quality comparable with that of natural aggregate. Some beneficial methods proposed include thermal or heating method, microwave heating method, heating then rubbing methods, and ultrasonic bath method. These methods minimise or totally remove mortars attached to the original aggregate of RCA. All these methods could improve the interfacial bond between RCA and new cement paste in new concrete, thus improving concrete performance. These methods, however, require complicated mechanical equipment and high energy consumption. Therefore, another potential treatment for RCA involves acid use. In this method, low-concentration acid is used to remove the loose attached mortar of RCA from the original aggregate. This method has great potential because it is inexpensive and could significantly improve RCA properties, thus increasing concrete performance.

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Meanwhile, benefits from using low-concentration acid is that it may not totally remove the adhered mortar of RCA but simply removes the loose adhered mortar on its surface and the strong bulk mortar remains, which can maximize the utilization of this waste as a part of the aggregate particle for concrete. In addition,

The reduction of loose mortar that covers RCA particles can significantly improves surface contact between the new cement paste and the aggregate which subsequently may result in a significant improvement in the strength of concrete.

Concrete is strong in compression, but weak in tension. Therefore, in recent years, many studies have been conducted in the mechanical characteristics of reinforced fibre concrete. Addition of fibres have improved the mechanical and durability properties of concrete. Advantages of polypropylene fibres are that they are non-magnetic, rust free, alkali resistant, safe and easy to use. Polypropylene twine is cheap, abundantly available and is of consistent quality. Polypropylene fibres are also compatible with all concrete chemical admixtures and can be handled with ease. They are chemically inert and hence, any chemical that will not attack the concrete constituents will not have any effect on the fibre also.

It was found that only limited studies were conducted on treated recycled aggregate and none on fibre reinforced treated recycled aggregate concrete. Thus an experimental programme was planned to study the effect of polypropylene fibre on a treated recycled aggregate concrete and the study would encourage the popularity of usage of the same.

II. OBJECTIVES

Objectives of the present investigations may be outlined as follows:

- To study the fresh stage properties of treated recycled aggregate on polypropylene fibre reinforced concrete.
- To investigate the development of strength characteristics of treated recycled aggregate on polypropylene fibre reinforced concrete and compare with normal concrete.
- To find the optimum percentage replacement of treated recycled aggregate in concrete by studying the mechanical properties.

III. EXPERIMENTAL PROGRAMME

A. Materials

The constituents used for the mixes were ordinary Portland cement (OPC) 53 grade, water, fine aggregate, natural coarse aggregate, treated recycled coarse aggregate and polypropylene fibres. The fine aggregate used was M – sand conforming to IS: 383 – 1970 specification for Zone II gradation, 20 mm nominal size crushed and washed aggregates was used as coarse aggregate and the recycled aggregate is got from a demolition site as shown in fig. 1 and the concrete structure is broken to small desirable sizes manually.

Fig. 1. Source of Recycled Aggregate

Treated recycled aggregate is prepared by immersing these recycled aggregate in 0.1M HCl for one day. It is then thoroughly washed and dried before use as shown in fig. 2.

Fig. 2. Treatment of Recycled Aggregate

The properties of RCA were observed to improve after immersion in acid. This shows that acid treatment effectively removes a great portion of weak cement mortar from the surface of RCA, thus improving their quality. Marked improvements in water absorption and specific gravity of RCA after acid treatments compared with untreated RCA are recorded in Table 1. The specific gravity of the recycled aggregate is found to increase after the treatment and the water absorption is found to decrease by nearly 8%, which suggests improvement in properties after treatment. Fig. 3 shows the pictures of natural aggregate, recycled aggregate and treated recycled aggregate.

Table 1. Comparison of Recycled Aggregate and Treated Recycled Aggregate

Properties	Recycled Aggregate	Treated Recycled Aggregate (in dil. HCl)
Specific gravity	2.45	2.48
Water absorption (%)	2.40	2.20

Fig. 3. Natural Aggregate, Recycled Aggregate and Treated Recycled Aggregate

B. Mix Proportioning

The grade of concrete prepared for the experimental study was M25. The study is limited to the preparation of seven different types of mixes.

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Control sample consists of 100% natural coarse aggregates and 0% treated recycled coarse aggregates with 0% polypropylene fibres. Other mixes were developed by varying the treated recycled coarse aggregate content in a systematic manner- 0, 20, 40, 60, 80 and 100%. In all these mixes polypropylene fibre content was kept constant at 0.2% by volume. Table 2 shows the mix designation of control mix.

Table 2. Concrete Mix Proportion

Grade of Concrete	Concrete Mix Proportion			
	Cement *(kg/m^3)*	*Fine aggregate* *(kg/m^3)*	*Coarse aggregate* *(kg/m^3)*	*w/c ratio*
M25	360	690.270	1235.660	0.48

The seven mixes vary in their percentage of natural coarse aggregate and treated recycled coarse aggregate content. The specific gravities of the same are also different. Therefore all the seven mixes were designed separately as per IS: 10262-2009 to find out the quantity of materials to be used for the mix. The mix designation and their mix proportions are given in Table 3.

Table 3. Concrete Mix Designations and Detailed Mix Proportions

Mix designation	Polypropylene (%)	Mix proportion (Cement: FA: NCA, TRCA)
C	0.0	1: 1.917: 3.432, 0
TRA0	0.2	1: 1.917: 3.432, 0
TRA20	0.2	1: 1.917: 2.746, 0.615
TRA40	0.2	1: 1.917: 2.059, 1.229
TRA60	0.2	1: 1.917 : 1.373, 1.844
TRA80	0.2	1: 1.917: 0.686, 2.458
TRA100	0.2	1: 1.917: 0, 3.073

C. Details of Specimen

The concrete mixtures were prepared in a pan mixer. Standard moulds made of cast iron were used for casting 150 mm cube specimens, 150 mm diameter and 300 mm height cylinders, 150 mm diameter and 50mm height discs and 500 mm × 100 mm × 100 mm beam specimens. A total of 147 specimens were cast for finding the mechanical properties of concrete.

IV. RESULTS AND DISCUSSIONS

A. Workability of Fresh Concrete

The relative quantities of various ingredients in concrete affect the workability of the concrete. The compacting factor value was obtained for all mixes to determine the workability and it was assessed as per the IS: 1199-1959.

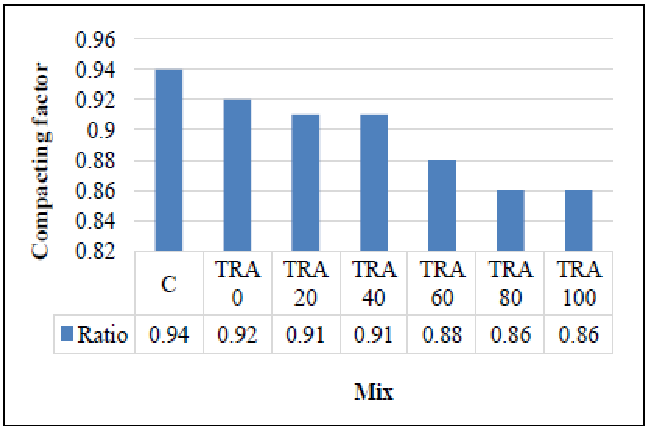

Fig. 4. Compacting Factor for Various Mixes

From fig. 4 it was observed that the compacting factor (CF) varied from 0.94 to 0.86. The highest value was observed for the control mix and lowest for TRA80 and TRA100 mix. This shows that as the amount of treated recycled aggregate is increased, the compacting factor decreased and thus the workability. In all the mixes the water cement ratio is kept constant, this is one of the reasons for decreased workability because treated recycled aggregates absorb more water than natural aggregates which is clear from the preliminary investigation.

B. Compressive Strength of Concrete

Concrete cubes of size 150 mm were tested at 3rd, 7th and 28th day (as per IS: 516-1959) and the values of compressive strength are given in fig. 5. The use of treated recycled coarse aggregate (TRCA) shows similar profile of strength development as the normal concrete where the compressive strength increases over the age. However, the TRCA content in concrete has greatly affected the compressive strength of the concrete. Among all of the specimens, the normal concrete achieves the highest strength, followed by 20%, 40%, 60%, 80% and 100% levels of TRCA replacement. The results indicate a decreasing trend in the compressive strength towards the high level of the TRCA content.

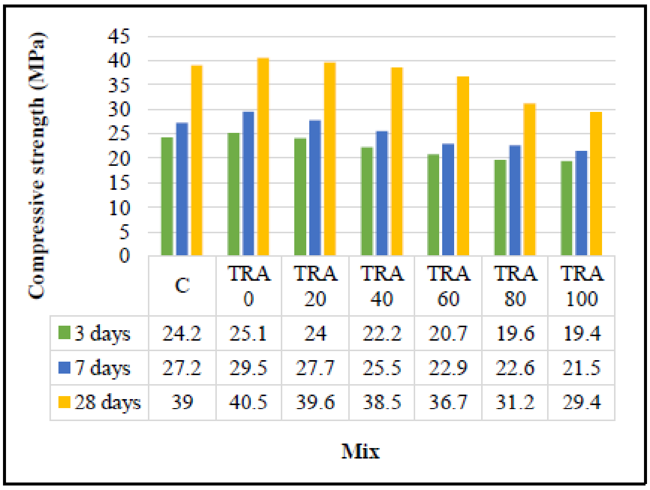

Fig. 5. Compressive Strength for Various Mixes

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The inverse relationship between the TRCA content and compressive strength is due to the poor quality of the aggregate which is a result of the crushing process and which has created the zones of weakness in the concrete. Table 4 shows the percentage decrease in 28th day compressive strength for different mixes.

Table 4. Percentage Decrease in Compressive Strength

Mix Designation	28th day Compressive strength (MPa)	Decrease in Compressive Strength Compared to TRA0 (%)
C	39.0	-
TRA0	40.5	-
TRA20	39.6	2.2
TRA40	38.5	4.9
TRA60	36.7	9.4
TRA80	31.2	22.9
TRA100	29.4	27.4

Thus the TRCA content in concrete is found to have an inverse relationship with its compressive strength but at low level of replacement, this effect is negligible. It is found that the compressive strength of concrete containing 20% treated recycled aggregate with polypropylene fibres are more than that of normal concrete. The percentage increase in compressive strength of concrete on addition of fibres is found to be 3.7%. The percentage decrease in compressive strength for 20%, 40%, 60%, 80% and 100% replacement of normal coarse aggregate with TRCA as compared to that with 0 % TRCA are 2.2%, 4.9%, 9.4%, 22.9% and 27.4%. Replacement up to 40% shows that the decrease in compressive strength is less than 5% which is very negligible. The target strength of the designed concrete is 31.6 MPa, and this is achieved for a replacement of up to 60% and the percentage decrease is also less than 10%. Therefore from the compressive strength test it can be concluded that 60% could be taken as optimum percentage of replacement of normal aggregate with TRA for structural purposes. The percentage decrease of TRA100 mix as compared to the optimum mix is 19.9% which is also high.

C. Flexural Strength of Concrete

Concrete beams of size 500 mm × 100 mm × 100 mm were tested at 28th day (as per IS: 516-1959) and the values of flexural strength are given in Table 5.

Table 5. Flexural Strength for Various Mixes

Mix Designation	Flexural strength (MPa)	Decrease in flexural strength compared to TRA0 (%)
C	4.8	-
TRA0	5.0	-
TRA20	4.8	4
TRA40	4.8	4
TRA60	4.6	8
TRA80	3.8	20
TRA100	3.6	28

Flexural strength is also found to decrease with percentage increase of treated recycled coarse aggregate (TRCA). Flexural strength of concrete containing 40% treated recycled aggregate with polypropylene fibres is equal to that of normal concrete. The percentage increase in flexural strength on addition of fibres to control mix is found to be 4%. The percentage decrease in flexural strength for 20%, 40%, 60%, 80% and 100% replacement of normal coarse aggregate with TRCA as compared to that with 0% TRCA are 4%, 4%, 8%, 20% and 28%. Replacement up to 40% shows that the decrease in flexural strength is less than 5% which is very negligible. The percentage decrease is less than 10% for TRA60 mix, therefore from the flexural strength test it can be concluded that 60% could be taken as optimum percentage of replacement of normal aggregate with treated recycled aggregates for structural purposes. The percentage decrease of TRA100 mix as compared to the optimum mix is 21.7% which is high. Fig. 6 shows the variation of flexural strength for the different mixes

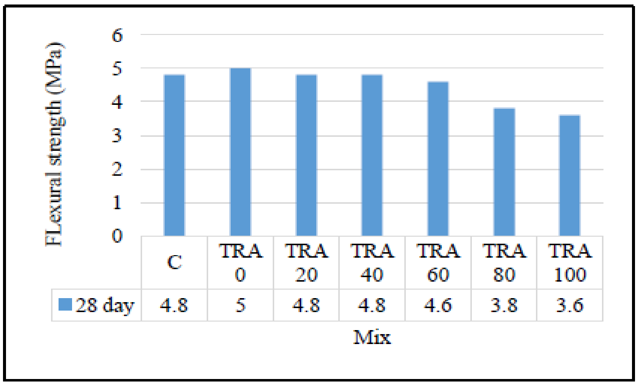

Fig. 6. Flexural Strength for Various Mixes

D. Split Tensile Strength

Concrete cylinders of 300 mm height and 150 mm diameter were tested at 28th day (as per IS: 5816-1999) and the values of split tensile strength are given in Table 6. Split tensile strength is also found to decrease with percentage increase of treated recycled coarse aggregate (TRCA). Split tensile strength initially increases on the addition of fibres and then decreases as percentage of TRCA increases. For replacement of coarse aggregate by TRCA up to 40%, the split tensile strength of fibre reinforced concrete is found to be more than control mix, similar to as obtained for flexural strength. The percentage increase in flexural strength on addition of fibres to control mix is found to be 4.04%. The percentage decrease in flexural strength for 20%, 40%, 60%, 80% and 100% replacement of normal coarse aggregate with TRCA as compared to that with 0% TRCA are 1.8%, 3.5%, 9.1%, 17.9% and 21.7%. Replacement up to 40% shows that the decrease in split tensile strength is less than 5% which is very negligible. The percentage decrease is less than 10% for TRA60 mix. Also when comparing the theoretical value of split tensile strength of concrete (0.7√fck), which come to around 3.5 N/mm2, the value of split tensile strength of TRA60 mix is 3.6 N/mm2, which is more, therefore from the split tensile strength test it can be concluded that 60% could be taken as optimum percentage of replacement of normal aggregate with treated recycled aggregates.

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The percentage decrease of TRA100 mix as compared to the optimum mix is 13.9%.Fig. 7 shows the variation of split tensile strength for the seven mixes.

Table 6. Split Tensile Strength for Various Mixes

Mix Designation	Split Tensile Strength (MPa)	Decrease in Split Tensile Strength Compared to TRA0 (%)
C	3.80	-
TRA0	3.96	-
TRA20	3.89	1.8
TRA40	3.82	3.5
TRA60	3.60	9.1
TRA80	3.25	17.9
TRA100	3.10	21.7

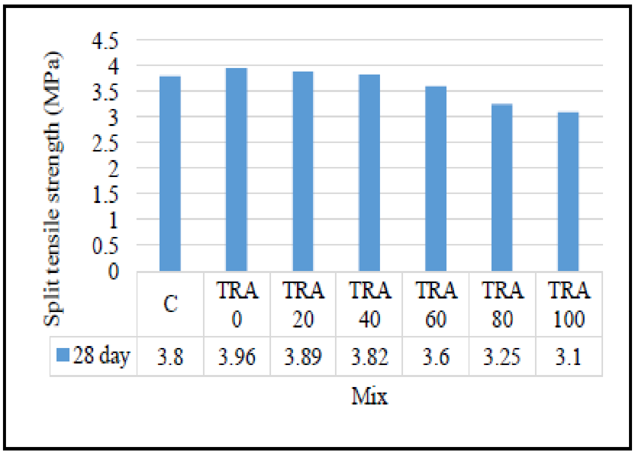

Fig. 7. Split Tensile Strength Variation

E. Modulus of Elasticity

Concrete cylinders of 300 mm height and 150 mm diameter were tested at 28th day (as per IS: 516-1959) and the values of modulus of elasticity are given in Table 7.

Table 7. Modulus of Elasticity for Various Mixes

Mix designation	Modulus of elasticity (MPa)	Decrease in modulus of elasticity compared to TRA0 (%)
C	27114.8	-
TRA0	28750.9	-
TRA20	27212.3	5.3
TRA40	26975.5	6.2
TRA60	25876.3	9.9
TRA80	22515.4	21.7
TRA100	21986.9	23.5

The percentage increase in strength of the mix on addition of fibres to control mix is found to be 5.69%. The modulus of elasticity of fibre reinforced concrete is found to be more than control mix for a replacement up to 20% with TRCA. The percentage decrease in strength for 20%, 40%, 60%, 80% and 100% replacement of normal coarse aggregate with TRCA as compared to that with 0% TRCA are 5.3%, 6.2%, 9.9%, 21.7% and 23.5%. For a replacement of NCA with TRCA up to 40 %, the decrease in strength is around 5% which is negligible. When comparing the theoretical value of modulus of elasticity of concrete (5000√fck), which come to around 2.5 GPa, the value of modulus of elasticity of TRA60 mix is more, also the percentage decrease is found to be less than 10% for TRA60 mix when compared to TRA0. Therefore from the modulus of elasticity test it can be concluded that 60% replacement of normal coarse aggregate with treated recycled coarse aggregates is acceptable. The percentage decrease of TRA100 mix as compared to the optimum mix is 15.03%. Fig. 8 shows the variation of modulus of elasticity at 28th day for polypropylene fibre reinforced concrete with various percentage of treated recycle coarse aggregate.

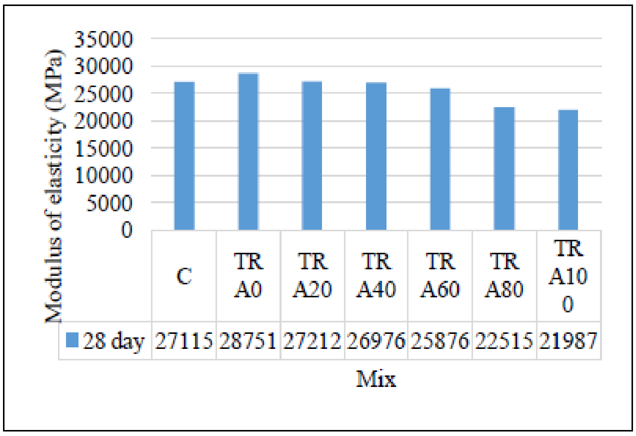

Fig. 8. Modulus of Elasticity Variation

F. Impact Resistance

Concrete discs of 150 mm diameter and 50 mm thickness were tested at 28th day (as per ACI: 544-2R-89) and the result of impact resistance obtained from the experimental investigation are given in fig. 9. Impact resistance is found to increase initially (for TRA0) compared to the control mix when polypropylene fibre is added, but gradually decreases as the percentage of TRCA. The TRA100 mix shows the least impact resistance and the highest value has been observed for TRA0 mix.

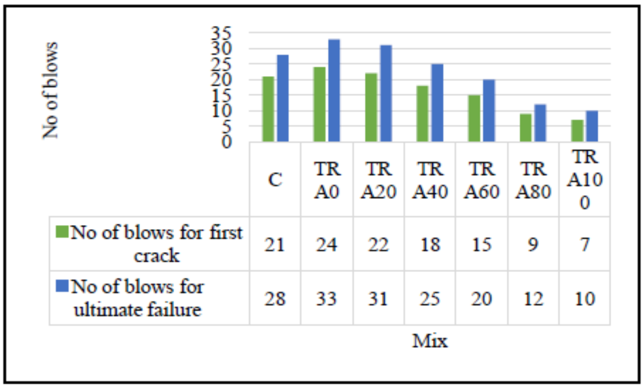

Fig. 9. Impact Resistance of Mixes

V. SUMMARY OF TEST RESULTS

In all the strength tests, the TRA0 mix has better strength compared to the control mix. This shows that the addition of fibre improves the properties of concrete.

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It can also be concluded that the optimum percentage for replacement of normal coarse aggregate with treated recycled coarse aggregate is 60%. Thus **Polypropylene fibre reinforced concrete containing treated recycled aggregate as 60 % partial replacement of natural coarse aggregate** (TRA60 mix) is selected for studying the durability characteristics by comparing with normal mix.

VI. CONCLUSION

With limited number of variables under study, the following conclusions can be drawn from the investigations.

1. The physical properties of recycled coarse aggregate (RCA) was observed to improve after immersion in acid. Thus treated recycle aggregate was found have a lower water absorption and higher specific gravity than untreated recycled aggregates.
2. The workability of concrete is lower for treated recycled aggregate concrete than that of conventional concrete and workability is also found to decrease with the addition of fibres.
3. The compressive strength, split tensile strength, flexural strength, modulus of elasticity and impact resistance of treated recycled aggregate concrete of conventional concrete increases by the addition of polypropylene fibres.
4. Maximum value of strength parameters was obtained when the amount of treated recycled coarse aggregate (TRCA) is zero and is found to decrease with percentage increase in TRCA.
5. The optimum percentage replacement of natural coarse aggregate with treated recycled coarse aggregate in polypropylene fibre reinforced concrete was found to be 60% for structural applications.
6. For 100% replacement of natural aggregates with treated recycled aggregates, the strength reduction is found to be marginal, therefore it can be suggested that concrete made with 100% treated recycled coarse aggregate can be used for structures with minor importance.

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AUTHOR PROFILE

Nazrin Nazar, P.G. Scholar, Department of Civil Engineering, T.K.M. College of Engineering, Kollam (affiliated to the University of Kerala). Graduated from College of Engineering Trivandrum (affiliated to the University of Kerala).

A.Nizad, Post graduate from T.K.M. College of Engineering, Kollam (affiliated to the University of Kerala), is working as a Professor at T.K.M. College of Engineering, Kollam. He has got more than 30years of teaching experience. He is a life member of Indian Society of Technical Education (ISTE), Quilon Management Association (QMA), Energy Conservation Society (ECS) and Indian Association of Structural Engineering (IASE).