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Performance of Recycled Aggregate Concrete Reinforced with Discrete Polypropylene Fibres

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Abstract

This article presents the compressive and split tensile strengths of Recycle Aggregate Concrete (RAC) reinforced with discrete Polypropylene (PP) fibers. In the experimental work natural coarse aggregate was replaced by recycle aggregate in the proportion of 0, 25, 50, 75 and 100%. The Polypropylene fibres (PP) were used in the recycle aggregate concrete by 1 and 2% volume. After conduction of experiments on the cube and cylinder specimens, the results showed that, the incorporation of PP fibers increases the strengths of RAC. Few Regression Models were deduced to estimate the strengths for RAC and Finite Element Method (FEM) analysis was performed on cube and cylinder specimens to identity the stress variations in the specimens. The average result of Finite Element (FE) analysis for each specimen is checked with the experiments results and it is noticed that the variation is about 2%.

Key words: Recycled aggregate, Polypropylene fibres, Compressive strength, Split tensile strength, Regression models, FEA.

1. Introduction

To develop the infrastructures for society, various building or construction materials are required. Among the construction materials, cement concrete is most important material. Basically the concrete composed of cement, fine and coarse aggregates, these all mixed with the help of water and also with super plasticizers if it requires as per design requirements. In the present scenario for making concrete very acquit shortage of good quality aggregates. Hence, the concrete or industry people are looking towards

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alternative material for aggregates. Nowadays, the researchers are focusing on various other materials, in this view, many studies are focusing on recycle aggregate to establish as an alternative material for aggregates. In the past many works have been taken place in concrete area with the help of recycle aggregates. Still many research works are going to improve the properties of RAC with the help of fibre technology. In this concern a few recent past works are presenting herein. Nixon [1] has provided a review on RAC and from the article, it is observed that the compressive strength of RAC was decreased by 20% when compared to conventional concrete. Bairagi *et al.* [2] concluded that the average relative compressive strength varies from 98 to 94% when the replacement levels were varied from 25% to 50%. For 100% replacement of aggregate, there is decrease in compressive strength about 14%. Oliveira *et al.* [3] studied the effects of three different moisture conditions for the recycled aggregate (dry, saturated and semi-saturated) and concluded a slight decrease in the compressive strength of the concrete made from dry saturated recycled aggregates. Otsuki *et al.* [4] concluded that the improvements in strength of recycled aggregate concrete can be achieved by using the double mixing method in the case of higher water binder ratio concrete. Chakhradhararao *et al.* [5] observed that the concrete cured in air after 7 days of wet curing shows better strength, than concrete cured completely under water for 28 days for various replacements of recycle aggregate. Rosario Herrador *et al.* [6] conducted the studies on road works and focused the demolition waste aggregate for surface works. The study concluded that, the use of waste aggregate for road has shown remarkable load bearing capacity. Roland F [7] conducted the experimental studies on concrete with polypropylene fibers (19 mm long) and of acrylic material (10 mm long). The results showed as the concrete with fibres have less shrinkage and crack width. Ahsana Fathima K M and Shibi Varghese [8] conducted the experimental work on concrete with addition of PP fibres and their study revealed that, splitting tensile and flexural strengths were increased for 0.5 % of PP addition. Prasad and Rathish Kumar [9] conducted the research on concrete with addition of polypropylene fibre and they noticed that, the flexural strength was enhanced by 6.13% and elasticity values decreased with increase in replacements of recycled coarse aggregate. Shreyas *et al.* [10] obtained a marginal increase in split tensile strength at fibre dosage from 2 kg/m^3. From the literature, it is observed that no studies are conducted on RAC by using PP fibres at higher volume fractions. Hence, the present experimental study was planned to evaluate the strengths of RAC with PP fibres.

2. Experimental

The experimental program was planned to assess the compressive and split tensile strengths. The results are to compare with the previous work which are done in the area of recycle aggregate concrete and existing mathematical models are to be tested for the experimental results, if the models are not well perform, the authors were decided to generate the few regression models. The work is also focused to implement FEA analysis on cubes and cylinders by using ANSYS software. For experimental work, standard size of cubes and cylinders were cast to find compressive and split tensile strengths. Total 45 cubes and 45 cylinders were casted with M20 grade concrete and the mix was designed as per ACI211.1-91 (2002) code. In this study, five mixes were taken as RAC-0, RAC-25, RAC-50, RAC-75 and RAC-100, for each mix the PP fibres were added at 1 and 2% by volume of specimen. Few samples were (RAC-0 or NAC) taken as control specimens and these were considered for comparison purpose. For each mix, three samples were cast and tested. The average strength of three samples was taken as result for each mix. In the nomenclature of the mix, the RAC indicates Recycle Aggregate Concrete and immediate value indicates the % of replacement for natural aggregate with recycle aggregate. NAC can be read as Natural Aggregate Concrete, in further discussion, it may consider as control or reference mix. For experimental work the following materials were used.

2.1. Materials

2.1.1. Cement

Ordinary Portland cement of 43 grade confirming to IS 8112-1989 standards was used to cast the specimens. The specific gravity of cement was noticed as 3.1.

2.1.2. Fine aggregate

Nearby available sand from Bhadra River confirming to zone III conforming to IS 383-1970 has been used as fine aggregate. The specific gravity of sand was observed as 2.6.

2.1.3. Natural coarse aggregate

Crushed natural granite aggregate from local crusher has been used and which has maximum size of 20 mm. The specific gravity of coarse aggregate was observed as 2.69.

2.1.4. Recycled coarse aggregate

The recycled coarse aggregate was obtained from demolished building wastes. In order to use as graded aggregate, the waste material was crushed in crusher and made as 12.5 mm and 20 mm aggregate. The specific gravity of the combined aggregate was 2.53.

2.1.5. Water

Clean fresh water was used for mixing and curing the specimens.

2.1.6. Conplast SP-430

To obtain better workability Conplast SP-430, super plasticizing admixture used in the present work. For the present experimental design work, the dosage was varied from 0.6 to 0.9% by weight of cement.

2.1.7. Polypropylene (PP) fibres

In the present work Macro synthetic fibres were used as reinforcement material for concrete. The PP fibres were purchased from Bajaj Reinforcements, Nagpur. The physical properties for these fibres were presented in Table 1. The used material of natural coarse aggregate, recycle aggregate and fibres can be viewed in the figure 1.

Table 1. Physical properties of Polypropylene fibres.

Specification	Description
Specific Gravity	0.91
Tensile strength	550-640MPa
Young's modulus	6-10GPa
Melting point	159 to 179^{0}C
Bulk density	910 kg/m^3
Fibre cut length	47mm
Physical Form	Fibrillated

Figure 1. Materials, A. Natural coarse aggregate, B. Recycle aggregate, C. Polypropylene fibres.

2.2. Casting

The cubes of inner dimensions 150x150x150 mm were cast to find out the compression strength of mixes. To evaluate the split tensile strength, cylinders of 150 mm diameter with 300 mm height were cast. The proportions for various mixes were evaluated for 75 to 100 mm slump. The mixes are designed for M20 grade concrete. Soujendra Kumar Reddy [11] has made attempts to design the M20 concrete with various codes and he found that ACI code gave better results than other codes. Hence, herein the ACI code procedure was adopted with target strength as 26.56 N/mm^2. The Table 2 gives the mix proportions for various mixes. The proportions are varying for each mix due to variation of properties such as specific gravity, dry rod density etc.

All materials were weighed as per mix design separately. The cement, sand, natural coarse aggregate and recycled coarse aggregate were dry mixed in pan mixer thoroughly till uniform mix is achieved. Required quantity of water is added to the dry mix along with super plasticizer. The fresh concrete was placed in the mould and the compaction was adopted by mechanical vibrator. The specimens were removed from moulds after 24 h and placed in water tank for 28 days curing. After a period of 28 days the specimens were taken out and allowed to dry under shade, later the specimens are allowed for testing.

Table 2. Mix proportions per cubic meter of concrete.

Mix	Cement (Kg)	FA (kg)	NCA (kg)	RCA (kg)	Water (Litres)	SP (Litres)	Mix Proportion
RAC-0	363.64	838.27	915.37	---	200.00	0.000	1 : 2.31 : 2.52
RAC-25	357.14	842.10	225.00	675.00	197.56	0.091	1 : 2.36 : 2.52
RAC-50	333.33	917.50	417.06	417.06	197.33	0.098	1 : 2.75 : 2.50
RAC-75	333.33	924.15	613.45	204.48	197.00	0.111	1 : 2.77 : 2.45
RAC-100	333.33	962.28	---	777.08	196.67	0.123	1 : 2.89 : 2.33

2.3. Test Set Up and Testing

The cubes and cylinders were tested as per IS 516-1959 and IS 5816-1999 to obtain compressive and split tensile strengths respectively. The specimen was tested with manual operated compression testing machine of capacity 1000kN. The tested specimens can be viewed in figure 2.

Figure 2. Testing of specimens, A. Compression test, B. Split tensile test.

3. Results and Discussion

3.1. Test Results

3.1.1. Compressive Strength

The test results of the cube compressive strength are presented in Table 3. From the Table 3, it is observed that the compressive strength of RAC without PP fibres is in the range of 33 to 17N/mm^2. The compressive strength was increased at 25% replacement. At this stage, the compressive strength is more than the other mixes including natural aggregate concrete (NAC or RAC-0). In general, the natural aggregate concrete shows more results than the RAC. But here it showed lesser value, it may be due to super plasticizer effect. In this work for NAC super plasticizer is not used and also the water content is more. From 50 to 100% replacement of RA the strength decreases about 25 to 40%. The reason may be the bond between RAC and cement mortar (it may forms weak links). This type of observation was made by Rasheeduzzafar and Khan [12]. From the review paper of Torben C Hansen [13], it is observed that, there is strength decrement about 8-24% recycled aggregate concrete. The design strength of NAC mix is 20 N/mm^2. The replacement level of RA at 50% showed the 20.74MPa. Hence, it is viable to use RAC up to 50% replacement without affecting the required strength. The compressive strength of RAC with PP fibres is in the range of 18 to 37% for 1% and 2% volume of fibres. As the percentage of fibre increases, compressive strength increases. This value coincides for 0% and 1% of PP fibre RAC at 50 and 75% replacement respectively. But RAC with 2% fibre up to 100% replacement of RA is permitted. The increase in compressive strength of RAC with PP fibre may be due to good bond strength between the surfaces of fibre and cement paste. The PP fibres have tuff feature embossed surface, due to this, the bond may enhance for the matrix. Sudheer Jirobe *et al.* [14] reported that the same trend of increase in compressive strength from 10.75% to 33.79% with increase in PP fibre of 0.5% to 1.5% respectively for natural aggregate concrete.

3.1.2. Split Tensile Strength

The split tensile strength test results are presented in Table 3. From the results, it is observed that as the % of RA content increases, the tensile strength increases up to 25% then decreases. The % of decrease is about 7 to 33% for 50 to 100% replacement of RA. The split tensile strength of RAC with PP fibres is increases as % of PP fibre volume increases. The percentage of increment for 1% fibre is 35 to 60%, for 2% fibre is 66 to 125% when compared to reference mix. The increment in strength may be due to presence of PP fibres in the interfacial transition zone. The PP fibre rough surface produces good bond in the matrix of the mix. During application of load, the stress transfer may takes place in the matrix through the fibre and also the fibres have good adhesive nature with the concrete, so that it may not debond easily and also it takes more energy to failure. Shreyas MT *et al.* [10] also reported marginal increase in split tensile strength with increase of PP fibre from 2 kg/m^3 to 4 kg/m^3 for fly ash blended self compacting concrete. During the experimentation, it is observed that the concrete cylinders with PP fibres did not split into two pieces after attaining the failure load. This may be due to the PP fibres may act as bridge between the two fractions.

Table 3. Compressive and split tensile strengths.

Mix	Compressive Strength (N/mm^2)			Split Tensile Strength (N/mm^2)		
	0% PP Fibres	1% PP Fibres	2% PP Fibres	0% PP Fibres	1% PP Fibres	2% PP Fibres
RAC-0	27.85	28.59	30.52	1.51	2.41	3.40
RAC-25	32.88	36.89	37.33	1.98	2.69	3.58
RAC-50	20.74	25.03	30.07	1.84	2.31	3.06
RAC-75	17.33	18.96	23.41	1.65	2.26	2.88
RAC-100	17.03	19.70	23.11	1.32	1.78	2.45

3.2. Test results Comparison with Earlier Research Works

3.2.1. Compressive Strength

From Katrina McNeil and Thomas H K Kang [17] studies, it is observed that the compressive strength of RAC decreases with the increase in RA content. In the similar lines of present work, Venkata Ramana *et al.* [18] proposed the equations to estimate compressive strength in terms of % RAC for the varying percentages of Polyethylene Terephthalate (PET) fibres. Hanumesh BM *et al.* [19] has tested the present experimental results in the proposed equation of Venkataramana [18] and found that the results are varying about 40 to 50%. Hence, Hanumesh B M *et al.* have derived the regression models and presented in the reference paper of [19]. However for better understanding of the present work once again the equations are presenting below.

$$\mathbf{f_{ck} = 35.21 + 3.24\,(\%PP) - 0.211(\%RAC)}$$

f_{ck} = 28 days cube compressive Strength in MPa.

% RAC = percentage of recycle aggregate content in the mix.

% PP = percentage of Polypropylene Fibres.

3.2.2. Split Tensile Strength

In practical applications, many codes suggest that, the tensile strength of concrete is often estimated from the compressive strength. Here in ACI 318-M-11 code and Chinese codes (GB 50010-2002) are taken for estimating the split tensile strength in terms of compression. Though the codes specified equations are fit for conventional concrete. But the present work is pertaining to recycled aggregate concrete (RAC). However, it would like to test the equations for suitability of present results. In this view, Hanumesh BM *et al.* [19] has tested the split tensile strength results in the specified equations of various codes and they observed that the results are varying about 40%. Hence, they deduced the models for better estimate the results and presented in the reference paper of [19]. Herein for better understanding in the view of reader, once again the deduced equations are furnishing below. (The authors are suggesting, referring the research article of reference no [19] for more details)

$f_{sp} = 0.3643\sqrt{f_{ck}}$---------------- for 0% PP RAC

$f_{sp} = 0.4539\sqrt{f_{ck}}$---------------- for 1% PP RAC

$f_{sp} = 0.5650\sqrt{f_{ck}}$---------------- for 2% PP RAC

f_{ck} = 28 days cube compressive strength in N/mm^2

f_{sp} = 28 days split tensile strength in N/mm^2

3.3. Finite element (FE) analysis

In general during experimentation, it can be noticed that failure load and strains for the specimen. But the variation of stress in the specimens cannot be observed or seen by our naked eyes. Hence to know the variation of stresses for the specimen here FE analysis was carried out on each specimen by using ANSIS software. During the feeding of properties concrete for software, as per IS456-2000 code, the Young's modulus value taken as $5000\sqrt{fck}$ and poissions ratio (μ) was taken as 0.15. After performing analysis, the obtained results are presented in the Table 4. The actual experimental results and FE analysis results are presented in the Table 4 and also the ratio can be observed in the same table for compressive and split tensile strengths. The ratio results are varying marginally. The stress variation for cube and cylinder can be noticed in the Figure 3. From the analysis, it is concluded that the results (obtained from FE analysis) are made good compatibility of experimental results.

Table 4. FE analysis and experimental strengths.

Mix	Compressive strengths (N/mm^2)			Split tensile strength (N/mm^2)		
	Experimental value (N/mm^2) EXP	FE analysis (N/mm^2)	EXP/FE	Experimental value (N/mm^2) EXP	FE analysis (N/mm^2)	EXP/FE
0% Polypropylene Fibre						
RAC-0	27.85	28.43	0.98	1.51	1.38	1.09
RAC-25	32.88	33.56	0.98	1.98	1.82	1.09
RAC-50	20.74	21.17	0.98	1.84	1.69	1.09
RAC-75	17.33	17.68	0.98	1.65	1.51	1.09
RAC-100	17.03	17.38	0.98	1.32	1.21	1.09
1% Polypropylene Fibre						
RAC-0	28.59	29.17	0.98	2.41	2.21	1.09
RAC-25	36.89	37.64	0.98	2.69	2.47	1.09
RAC-50	25.03	25.54	0.98	2.31	2.12	1.09
RAC-75	18.96	19.35	0.98	2.26	2.07	1.09
RAC-100	19.70	20.10	0.98	1.78	1.63	1.09
2% Polypropylene Fibre						
RAC-0	30.52	31.43	0.98	3.40	3.12	1.09
RAC-25	37.33	38.09	0.98	3.58	3.28	1.09
RAC-50	30.07	30.68	0.98	3.06	3.81	1.09
RAC-75	23.41	23.89	0.98	2.88	2.64	1.09
RAC-100	23.11	23.58	0.98	2.45	2.25	1.09

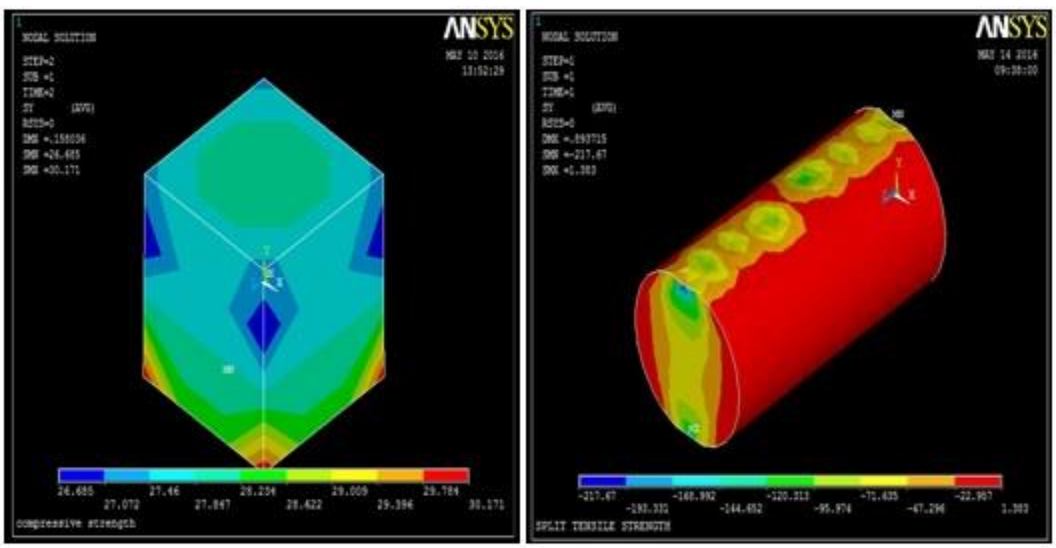

Figure 3. Stress variation for cube and cylinder specimens.

4. Conclusions

The following conclusions are made from the present experimental work.

- Use of recycle aggregates in the mix up to 50% is viable for construction works.
- Compressive split tensile and shear strengths are increased for RA content of 25%. Then it decreases till to 100% RA replacement.
- As PP fibres volume increases in RAC, the compressive strength, split tensile and shear strengths get increased.
- The maximum permissible limit for RA with 1% PP fibre is 50%.
- The PP fibres volume with 2% can be used

effectively without change in design mix.

- For 100% RAC with 1% PP fibre volume, compressive strength, split tensile strength and shear strength increases by 15.68%, 34.84% and 38.32% respectively when compared with reference mixes.
- For 100% RAC with 2% PP fibre volume, compressive strength, split tensile strength and shear strength increases by 35.7%, 85.6% and 38.32% respectively when compared with reference mixes.
- Proposed regression models presented herein are having good compatibility with the experimental results. The FE analysis results are made good agreement with experimental results.

5. Conflicts of Interests

The author(s) report(s) no conflict(s) of interest(s). The author along are responsible for content and writing of the paper.

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NA

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