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Research Article

FLEXURAL BEHAVIOUR OF POLYETHYLENE TEREPHTHALATE (PET) FIBRE REINFORCED RECYCLE AGGREGATE CONCRETE

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ABSTRACT
This paper presents the compressive and flexural strength of PET fibre reinforced recycles aggregate concrete. The Natural Aggregate (NC) was replaced by recycle aggregate (RA) in the proportion of 25, 50, 75 and 100%. PET fibres are added to the Recycle Aggregate Concrete (RAC) by 1 and 2% volume. Total 45 cubes and 45 beams are cast and tested. The results showed that as the % of RA and volume fraction of PET fibre content increases the strength was decreased. For obtained experimental results Regression Model (RM) is developed to predict the flexural strength by knowing the compressive strength of concrete.

Keywords: *RAC, PET fibres, Compressive strength, Cube, flexural strength, beam, Regression Model*

INTRODUCTION
For design grade of concrete the aggregate (coarse and fine) occupies about three fourth of the volume of specimen and play a significant role in concrete properties such as fresh and harden concrete properties, dimensional stability and durability. Conventional concrete consists of sand as fine aggregate and gravel (granite in various sizes and shapes) as coarse aggregate. There is a growing interest in using waste materials as alternative aggregate materials. In this context Demolished Waste Material (DWM) of building or any structure (after completing of its life span) or during modernization, waste is generated. This can be utilized in the concrete as recycle aggregate (RA). Many research works have been carried out on Recycle aggregate concrete (RAC). Now days the plastic is also is a waste and this waste is using for many works as recycle products. Among the different type of plastics groups, Polyethylene Terephthalate (PET) is one of the major products using by the society in the form of various articles. In this connection a review is presenting below related to PET fibres and RAC. Marzouk *et al.,* (2007) conducted the experimentation on concrete with plastic waste. The plastic material was used as sand substitution in the concrete. The results showed that the use of plastic bottle waste was effective and it attracts as low cost material. Siddique *et al.*, (2008) investigated the effective utilization of waste products (tires, plastic, glass etc) in concrete. The study showed that the use of waste product in concrete not only makes it economical but also helps in reducing disposal problem. Kou *et al.*, (2009) reported that splitting tensile strength of PVC concrete. From their study it is noticed that as PVC content increases the strength was decreased. Akcaozoglu *et al.*, (2010) investigated the use of shredded waste polyethylene using two types of binders. The authors found that the compressive strengths of mortar with PET aggregate is higher with combination of binders. Kandasamy and Mrugesan (2011) reported the behavior of composite material consisting of cement based matrix with an ordered or random distribution of fibre of steel, nylon, polythene. The results showed that the addition of fibres increases the properties of concrete. Baboo Rai *et al.*, (2012) reported the concrete properties produced with waste plastic with and without plasticizer. The study showed that reduction in workability and compressive strength with inclusion of plastic. But they also specified that with addition of Plasticizer the strengths were increased marginally. Bhogayata *et al.*, (2012) presents a comparative study of compressive strength of concrete made by mixing of plastic bags as concrete constituent. The results showed that as increase of plastic the compaction factor and

compressive strength decreases. Jianz huang Xial *et al.*, (2012) has given a overview of study on recycle aggregate concrete. In this paper different property of RAC and its behaviour was described. Xiao.J.Zh. *et al.*, (2006) has shown relationships between mechanical properties of RAC. From literature it is observed that there is a little work has been focused on PET fibres with combination of RA. So the authors had planned to evaluate compressive strength (CS) and flexural strength (FS) of PET fibre recycle aggregate concrete and also to establish the relation between the two strengths. To find CS and FS of PET fibre reinforced recycle aggregate concrete, 45 cubes and 45 beams were cast and tested in the laboratory.

MATERIALS AND METHODS

***1) Cement*:** Ordinary Portland cement–53 grade was used. The specific gravity of cement was found as 3.15 and it satisfies the requirements of IS: 12269–1987 specifications.

***2) Super Plasticizer**:* To impart the additional desired properties, a super plasticizer (Conplast SP-430) was used. The dosage of super plasticizer adopted in the investigation was 0.85% (by weight of cement).

***3) Sand**:* Locally available sand collected from river bed was used as fine aggregate. The sand used was having fineness modulus 2.96 and confirmed to grading zone-III as per IS: 383-1970 specification.

***4) Coarse Aggregates**:* The crushed stone aggregates were collected from the local quarry. The coarse aggregates used in the experimentation were 20mm and down size aggregate and tested as per IS: 383-1970 and 2386-1963 (I, II and III) specifications. The specific gravity was observed as 2.65.

***5) Recycle Aggregate Concrete**:* The Recycled coarse aggregate obtained by crushing demolished concrete mass and the same was used as recycled coarse aggregate in the present investigation. To obtain a reasonably good grading, 50% of the aggregate passing through 20 mm I.S. sieve and retained on 12.5mm I.S. Sieve and 50% of the aggregate passing through 12.5mm I.S. Sieve and retained on 10 mm I.S. Sieve is used. The specific gravity was found as 2.48.

***6) Water**:* Ordinary potable water, free from organic content, turbidity and salts was used for mixing and for curing throughout the investigation.

***7) PET Fibres**:* The waste PET fibres were obtained by cutting of unused drinking water bottles. The fibres were cut from steel wire cutter and it is labour oriented. The PET fibres were sieved and found that 10mm size are more in fibber content and the thickness was observed as 1mm. (Figure: 1)

Figure 1: PET Fibres

Casting and Curing

Concrete was prepared by a design mix proportion of 1:1.90:3.09 with a W/C ratio of 0.45 which correspond to M20 grade of concrete. The entire mix was homogeneously mixed with calculated quantity of required materials. The standard cubes and beams were (cube size is 150 x 150 x 150mm and beam size is 150 x 150 x750 mm (Figure 2) cast and tested after 28 days of curing as per IS specifications. A total 15 mixes (45cubes and 45 beams) were consider in the investigation and for each mix three cubes and three beams are tested. The average value of ultimate load and stress of three cube and beam specimens are presented in Table 1. In the table.1, RAC indicates recycle aggregate concrete , F1 and F2 indicates PET fibre volume fraction of 1 and 2% by volume of cast specimen and the number 0, 25, 50, 75 and 100 indicates the % of replacement of granite aggregate with recycle aggregate. The RAC-0 considered as reference mix (M20) or Natural aggregate concrete (NAC), in this forth coming text, the other mixes were compared with reference mix or NAC.

Figure 2: Testing of Beam for Flexure

RESULTS AND DISCUSSION

Compressive Strength

The compressive strength results are presented in Table.1. From this table it is observed that as % of RA content increases the compressive strength decreases. For 25 to 75% replacement of RA in conventional mix the strength decrement is about 2 to 14%. The reason may be the bond between recycle aggregate concrete and new cement mortar forms weak links, but it is vice versa for NA. The Compressive strength of RAC with fibres is in the range of 30 to 19 MPa. As the % fibre increase the compressive strength decreases. The design compressive strength of concrete is 20MPa, for PET fibre RAC this value touches at 2% of PET fibre and 75% RA. This indicated that, RAC with 1% fibre volume and upto 100% replacement of RA is effectively utilized, but the RAC with 2% fibre upto 75% replacement of RA is permitted for the designer/engineer in charge at site. The decrease in compressive strengths for RAC with PET fibres may be due to low bond strength between the surface of plastic waste and cement paste as well as the hydrophobic nature of plastic waste, which can inhibit cement hydration reaction by restricting water improvement and another reason may be particle size and shape between natural and plastic fibre. Frigione (2010) was reported this type of trend for natural aggregate concrete with plastic waste. Venkata Ramana *et al.*, (2013) developed some regression models to predict the compressive strengths for 0, 1 and 2% of PET fibres for recycle aggregate concrete.

Table.1: Compressive Strength

Sl.No.	Nomenclature	Average Ultimate compressive Load(KN)	Average Ultimate Compressive Strength (N/mm2)	% of Decrease or increase of compressive strength
1	RAC-0	750	33.33	-
2	RAC-25	723	32.13	-2.89
3	RAC-50	696	30.93	-7.2
4	RAC-75	673	29.19	-12.42
5	RAC-100	645	28.6	-13.98
6	RACF1-0	680	30.22	-9.33
7	RACF1-25	647	28.75	-13.74
8	RACF1-50	619	27.51	-17.46
9	RACF1-75	596	26.54	-20.55
10	RACF1-100	577	25.64	-23.07
11	RACF2-0	506	22.48	-32.55
12	RACF2-25	485	21.55	-35.34
13	RACF2-50	467	20.75	-37.74
14	RACF2-75	452	20.08	-39.97
15	RACF2-100	436	19.37	-41.88

Flexural Strength

The flexural results were presented in Table 2 and Figure 3. From the results it observed that as the % of RA content increases the flexural strength decreased. The % of decrease is about 3 to 13% for 25 to 100% replacement of RA. Malhotra (1976) also reported that the RAC exhibited lower flexural strengths compared with conventional concrete.

The decrement in strength may be due to interfacial transition zone (ITZ), the smooth surface of PET fibres causes weaker links between the plastic and concrete mass. Bataayneh *et al.*, (2007) reported a decreasing trend of flexural strength with increase plastic waste in concrete. Saikia and de Brito (2010) found low flexural strength values for concrete with PET waste than for concrete with natural aggregate.

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Hannawi *et al.*, (2010) reported decrease of flexural strength is about 9.5 to 17.9 % for PET waste concrete when compared with conventional concrete. During the experimental work the author noticed that for conventional concrete beams the rupture occurred in the ITZ, because of the poor properties of this zone. But for the RAC beam specimens, with PET fibres show, elastic nature or non brittle characteristic, under flexural loading. The PET fibres were act as bridge between the two separated pieces.

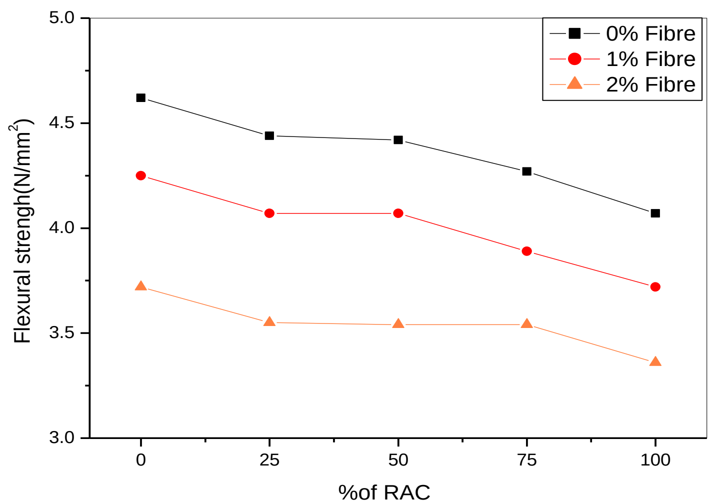

Figure 3: Flexural Strength vs % of RAC

Table 2: Flexural Strength

S.No.	Nomenclature	Average Ultimate Compressive Strength (N/mm2)	% of Decrease in compressive strength
1	RAC-0	4.62	-
2	RAC-25	4.44	-3.89
3	RAC-50	4.42	-4.32
4	RAC-75	4.27	-7.54
5	RAC-100	4.07	-11.90
6	RACF1-0	4.23	-8.44
7	RACF1-25	4.07	-11.90
8	RACF1-50	4.07	-11.90
9	RACF1-75	3.89	-15.80
10	RACF1-100	3.72	-19.40
11	RACF2-0	3.72	-19.40
12	RACF2-25	3.55	-23.16
13	RACF2-50	3.54	-23.37
14	RACF2-75	3.54	-23.37
15	RACF2-100	3.36	-27.27

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Relation Between Flexural and Compressive Strength

The flexural strength of concrete is most important mechanical quantity during the design of flexural elements. Earlier investigator of Xio *et al.,* (2006) have been proposed a relation between flexural and compressive strength as $f_f = 0.75\ \sqrt{f_{ck}}$. The equation is valid for RAC concrete only. For normal concrete the IS 456-2000, ACI 318M-11 and CEB codes recommended the following equations.

$f_f = 0.7\sqrt{f_{ck}}$--------------------------IS 456-2000

$f_f = 0.54\sqrt{f_{ck}}$------------------------ACI318M-11

$f_f = 0.81\sqrt{f_{ck}}$------------------------CEB

f_f = flexural strength in N/mm^2

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

The validities of the above equations are demonstrated in Table 3. From this table it is observed that the IS and ACI codes are underestimate the strength. But CEB code over estimates the strength. Hence the author is felt that there is a necessity to develop a regression model (RM) to suit the experimental values for RAC with and without PET fibres. The author developed a regression modal with a correlation coefficient R^2=0.947.

$f_f = 0.82\sqrt{fck}-027$

The performance of the proposed model is checked and the results are presented in Table 4 and Figure 4. From those table and figure it is observed that the ration between EXP and RM is about 0.98 to 1.04. The ration inferences the proposed model is best suited to the experimental values and also may concluded that it is better than IS, ACI and CEB code formulae.

Table.3: Comparison of Experimental strengths with different codes

S.No	Nomenclature	EXP flexural strength	Xio et.al.	IS Code	ACI code	CEB code	EXP/Xio	EXP/IS	EXP/ACI	EXP/CEB
1	RAC-0	4.62	4.33	4.04	3.12	2.29	1.07	1.14	1.48	2.02
2	RAC-25	4.44	4.25	3.97	3.06	2.25	1.04	1.12	1.45	1.97
3	RAC-50	4.42	4.17	3.89	3.00	2.21	1.06	1.14	1.47	2.00
4	RAC-75	4.27	4.05	3.78	2.92	2.14	1.05	1.13	1.46	1.99
5	RAC-100	4.07	4.02	3.75	2.89	2.13	1.01	1.09	1.41	1.92
6	RACF1-0	4.23	4.12	3.85	2.97	2.18	1.03	1.1	1.43	1.95
7	RACF1-25	4.07	4.02	3.75	2.9	2.13	1.01	1.08	1.41	1.91
8	RACF1-50	4.07	3.93	3.67	2.83	2.08	1.03	1.11	1.44	1.96
9	RACF1-75	3.89	3.86	3.60	2.78	2.04	1.01	1.08	1.4	1.90
10	RACF1-100	3.72	3.80	3.54	2.73	2.01	0.98	1.04	1.36	1.85
11	RACF2-0	3.72	3.56	3.32	2.56	1.88	1.05	1.12	1.45	1.98
12	RACF2-25	3.55	3.48	3.25	2.51	1.84	1.02	1.09	1.42	1.93
13	RACF2-50	3.54	3.42	3.19	2.46	1.81	1.04	1.11	1.44	1.96
14	RACF2-75	3.54	3.36	3.14	2.42	1.78	1.05	1.13	1.46	1.99
15	RACF2-100	3.36	3.30	3.08	2.38	1.75	1.02	1.09	1.41	1.92

Table 4: Performance of Regression Model for Flexural Strength

S.No	Nomenclature	Experimental flexural strength (N/mm^2)	Regression Model flexural strength (N/mm2)	Exp flexural strength / Regression Model flexural strength
1	RAC-0	4.62	4.46	1.04
2	RAC-25	4.44	4.37	1.01
3	RAC-50	4.42	4.29	1.03
4	RAC-75	4.27	4.16	1.03
5	RAC-100	4.07	4.12	0.98
6	RACF1-0	4.25	4.23	1.00
7	RACF1-25	4.07	4.12	0.98
8	RACF1-50	4.07	4.03	1.00
9	RACF1-75	3.89	3.95	0.98
10	RACF1-100	3.72	3.88	0.96
11	RACF2-0	3.72	3.61	1.03
12	RACF2-25	3.55	3.53	1.00
13	RACF2-50	3.54	3.46	1.02
14	RACF2-75	3.54	3.40	1.04
15	RACF2-100	3.36	3.33	1.01

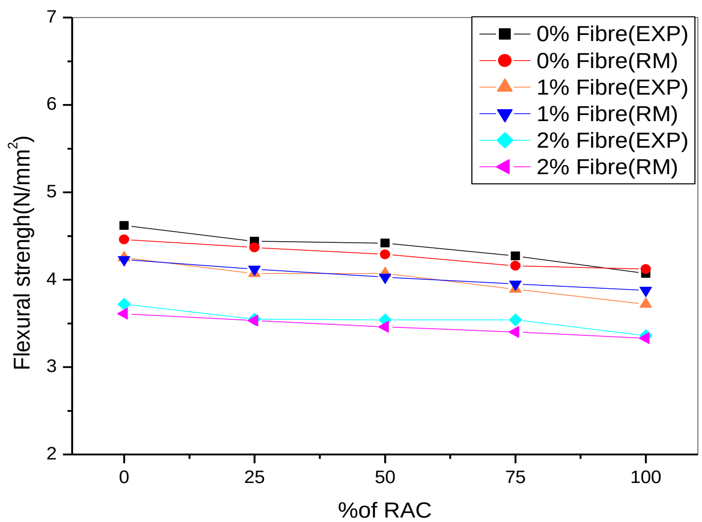

Figure 4: Performance of Regression Modal

Conclusions

1. The compressive and flexural strengths decreases as the RA content increase in the concrete mix.
2. The compressive strengths decreased about 2 to 14% with RA content of 25 to 100% respectively
3. As PET fibre volume increases in the RAC the compressive and flexural strengths are decreased.
4. The PET fibre volume with 1% can be used effectively without change in design mix.

5. The Maximum permissible limit for recycle aggregate content with 2% fibre volume is 75%.
6. For RAC with 1% PET fibre volume the compressive and flexural strengths decreased about 9 to 23% and 8 to 19% with RA content of 0 to 100% respectively when compared with reference mix.
7. For RAC with 2% PET fibre volume the compressive and flexural strengths decreased about 32 to 42% and 19 to 27% with RA content of 0 to 100% respectively when compared with reference mix.

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