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MODULUS OF ELASTICITY FOR STEEL FIBRE REINFORCED RECYCLE AGGREGATE CONCRETE

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Abstract

The paper presents the Modulus of Elasticity of recycle aggregate concrete reinforced with low strength steel fibers. In the experimental work the recycle aggregate is used in place of natural aggregate in the proportion of 0,25,50,75 and 100% with and without incorporation of steel fibers. The fibers were prepared by cutting the binding wire in required length of 50mm and the diameter was noticed as 1mm. These fibers were added to the recycle aggregate concrete mixes in the proportion of 0, 1, 1.5 and 2% by volume fraction of the cast specimens. The mixes without addition of fibers were taken as reference mixes and these are used for comparison purpose. Total 60 cubes and 60 cylinders were cast and tested to obtain compressive strength and modulus of elasticity's for various mixes. The obtained results are compared with IS code provision and earlier research works. Regression models are also deduced to suit the experimental data and checked its validity. The results found that the strengths are reducing as the percentage of recycle aggregate content increases and also observed that as the fiber content increases in the mixes the strengths are increasing.

Keywords:

Compressive strength;
Modulus of elasticity;
Natural aggregate concrete;
Recycle aggregate concrete;
Regression model.

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1. Introduction

Modulus of Elasticity is also known as the Young's modulus, it is a measure of the stiffness of a solid material. It is a mechanical property of linear elastic solid materials. It defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material. Young's modulus is named after the 19th-century British scientist Thomas Young. However, the concept was developed in 1727 by Leonhard Euler, and the first experiments that used the concept of Young's modulus in its current form were performed by the Italian scientist Giordano Riccati in 1782, pre-dating Young's work by 25 years. A solid material will deform when a load is applied to it. If it returns to its original shape after the load is removed, this is called elastic deformation. In the range where the ratio between load and deformation remains constant, the stress-strain curve is linear. Not many materials are linear and elastic beyond a small

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amount of deformation. A stiff material needs more force to deform compared to a soft material, and an infinite force would be needed to deform a perfectly rigid material, implying that it would have an infinite Young's modulus. Although such a material cannot exist, a material with a very high Young's modulus can be approximated as rigid. The Young's modulus enables the calculation of the change in the dimension of a bar made of an isotropic elastic material under tensile or compressive loads. For instance, it predicts how much a material sample extends under tension or shortens under compression. The Young's modulus directly applies to cases of uni-axial stress, that is tensile or compressive stress in one direction and no stress in the other directions. The present experimental work was focused to evaluate the young’s modulus of recycle aggregate concrete with and without addition of steel fibres. For this the cylinders were cast and tested in the laboratory by applying uni-axial stress. In addition to the cylinders, the cubes were cast and tested; the compressive strength results were used during deducing of the regression models. Before going to detailed experimental work a resent past literature is presented below to know the scenario.

Shen Dejian and LU Xilm [1] presented the relationship between compressive strength, modulus, peak strain and failure type of micro concrete under compression. V.S.Sethuraman and K.Suguna [2] conducted the experimental study to evaluate modulus of elasticity of M60 grade concrete using standard cylinder specimens, tested with compress meter under axial compression, in their study it is observed that the stress-strain behavior exhibits non-linear variation and from which the initial tangent modulus is plotted to arrive at modulus of elasticity values. IsamuYoshitake, Farshad Rajabipour, YoichiMimura and Andrew Scanlon [3] provided the results for Young smodulus of concrete and also gave the information of cracking due to restrained shrinkage and thermal construction. Byung Jae Lee, Seong-Hoon Kee, Taekeun Oh and Yun-Yong Kim [4] investigate the effect of cylinder size (150 by 300 mm and 100 by 200 mm) by using empirical equations that relate static elastic moduli and compressive strength and static and dynamic elastic moduli of concrete. Gupta Arundeb, Mandal Saroj and Gosh Somnath [5] studied the change in direct compressive strength and elastic modulus of recycled aggregate concrete in presence of fly ash (as replacement of cement). K.Krizova and R.Hela [6] studied the effect of dependencies of different composition concretes on elastic modulus values. N. Anusha and A V S Sai Kumar [7] studied the mechanical behavior of concrete in terms of modulus of elasticity with the change of aggregate size reinforced with steel fibers of different series for M30 and M50 grade concretes. U.Venkat Tilak and A.Narender Reddy [8] studied the effects of coarse aggregate on the modulus of elasticity of HPC concrete. Praful Vijay [9] studied the flexural and elastic modulus behavior of Lightweight aggregate in concrete with provision of steel fibers. The results revealed that, the concrete mix with steel fibres increases the tensile, flexural and elastic modulus properties. Dr.V.Bhaskar desai and A.Sathyam [10] studied the strength prosperities of light weight cinder aggregate cement concrete in different percentage proportions of 0, 25, 50, 75 and100 by volume of light weight aggregate concrete. The study was aimed to evaluate compressive strength, split tensile strength, modulus of elasticity, density and shear stress. K.Anbuvolan and Dr.K.Subramanian [11] presented the relationship between modulus of elasticity and modulus of rupture relationship for compressive strength of M60 concrete by incorporating the steel fibres. M.Ispir, K.D.Dalgic C.Sehgul, F.Kuran, Allki and M.A.Tasdemir [12] aimed to determine the modulus of elasticity of low strength concrete. From the literature it came to know that, no works has been carried out to estimate modulus of elasticity for recycle aggregate concrete by incorporation of low strengthsteel fibres with dosage of 1, 1.5 and 2% by volume fraction of cast specimen. In this direction an experimental study was planned to estimate modulus of elasticity for RAC mixes, the detailed test programme was presented below.

2. Test Programme

The experimental program consists of a total of 60 cubes and 60 cylinders. The standard cubes (60 cubes) were cast and tested in the compressive testing machine to know the compressive strengths for different mixes. Among 60 cylinders, 15cylinders are without fibres and remaining 45 cylinders were cast with steel fibres of 1, 1.5 and 2% volume of specimen respectively. For each mix three specimens were cast and tested, the average of three specimens was taken as strength of mix. Each cylinder was tested in compressive testing machine and for the cylinder the longitudinal extensometer was attached to find strains. The stress stain diagram was plotted for the mixes and young’s modulus was found from the graphs. For all the mixes the concrete was designed for M20 grade concrete as per ACI 211 code. The mix proportions are presented in Table 1. From the literature is is noticed that, various mix designs were proposed for the RAC from the researchers. But among them, the ACI 211 code methodology was found to be sastifactory and effective results for the recycle aggregate concerte. Hence here in also the ACI code provisions were taken to design the mix proportions. In the Table1, the nomenclature can understand as the first three letters indicated as type of concrete, next two/three numerical values are indicated as % of replacement of natural aggregate by the recycle aggregate. The NAC mix was taken as reference mix and this can also observed as conventional concrete. The RAC mixes were provided with incorporation of steel fibres. For this experimental work the low strength steel fibers (yield strength of wire is 390 MPa) are obtained from binding wire, which was cut by shear cutter with aspect ratio as 5 (the diameter of wire is 1.0mm and length is 50mm). The steel fibres were mixed in the concrete mixes and care was taken to avoid balling effect during mixing of concrete.

Table 1: Mix proportions of concrete (Kg/m3)

S.No	Nomenclature	Average compressive stress (MPa)			
		0% fibre	1% fibre	1.5% fibre	2% fibre
1	NAC-0-0	33.33	35.68	38.67	42.43
2	RAC-25-0	32.40	34.80	37.68	41.46
3	RAC-50-0	31.68	33.80	36.57	40.40
4	RAC-75-0	30.80	33.02	35.77	39.33
5	RAC-100-0	29.30	31.42	34.04	37.42

3. Casting

The standard cubes and cylinders were cast in steel moulds with inner dimensions of 150x150x150 for cubes and 150mm dia and 300mm height for cylinders. All the materials are weighed as per mix design and kept a side separately. The cement, sand, coarse aggregate, fibres and recycle aggregate were mixed thoroughly till to reach uniformity to the concrete mix. For all test specimens, moulds were kept on table vibrator and the concrete was poured into the moulds and the compaction was adopted by mechanical vibrator. The moulds were removed after twenty four hours and the specimens were de-moulded and were exposed to water bath for 28 days in curing pond. After curing the specimens in water for a period of 28 days, the specimens were taken out and allow drying under shade. Three cubes and cylinders were cast for each mix.

4. Testing

Compression test on cubes was conducted with 2000 kN capacity compression testing machine. The machine has a least count of 1kN. The cube was placed in the compression testing machine and the load on the cube is applied at a constant rate till to failure of the specimen and the corresponding load is noted as ultimate load. Then cube compressive strength of the concrete mix is computed by using standard formula and the obtained values are presented in next section. The cylinder specimens were tested in the laboratory to evaluate the young’s modulus for various mixes. The modulus of elasticity is determined using the longitudinal compression meter attached to the specimen as shown in figure 1. The modulus of elasticity is determined by subjecting the cylindrical specimen to axial compression and measuring the deformation by means of a dial gauge fixed to the longitudinal compression meter at regular intervals. The load on the cylinder is applied at a constant rate up to the failure of the specimen cylinder. Dial gauge reading divided by gauge length will give the strain and load applied divided by area of cross section will give the stress. A series of readings are taken and the stress-strain relationship is developed. Modulus of elasticity of steel fiber reinforced RAC is calculated as its initial tangent modulus. The various stress–strain responses obtained are presented in the next section.

Figure 1: Test set up for cylinder

5. Test Results and Discussion

5.1 Compressive Strength of Concrete

The results of cube compressive strength made with natural aggregate concrete and recycle aggregate concrete for 28 days curing are presented in Table 2. For RAC25 to RAC100 the compressive strengths are decreasing form 2.7 to 12% when compared with reference or natural aggregate concrete. Initially the concrete was designed for M20 grade concrete. The various mixes with RAC was shown from 33.33 to 29.3MPa, from this it is noticed that even the RAC100 mix showing design strength value. Hence it may conclude that the mix with RAC100 is also acceptable to concrete works. Etxeberria et al,[13] and Santos et al [14] has been reported that the 28 days compressive strength for RAC100 decreased about 20 to 25% , when compared with conventional concrete. In the present work the compressive strength for RAC100 was decreased by 12% only. The different % of decrease in strengths may be due to properties of aggregate and adhere of cement mortar variation for the surface of the aggregate. The RAC mixes with fibres (1, 1.5 and 2%) also showing the decreasing in compressive strengths about 2.3 to 12%. The strength is differing for various dosages of fibres, and from table 2 it is observed that as the % of fibre increases for the mix, the compressive strengths are increasing. As per the rule of mixtures the strengths may increase as% of steel fibres are increases for the mixes. The fibres are act as energy absorbers and also act as crack arresters. During the experimentation for 2% fibre cubes, the failure pattern is differ when compared to conventional concrete. Few thin cracks were noticed for the cube of containing fibres and this behaviour was not seen for cubes with no fibres. Dimensional stability was more for higher dosage fibres even at the stage of ultimate failure load. In the present experimental work the compressive strength results can be used to make the relation with modulus of elasticity, this can be discussed in the next section.

Table 2: Compressive strength of RAC concrete with and without fibres at 28 days

S.No	Nomenclature	Average compressive stress (MPa)			
		0% fibre	1% fibre	1.5% fibre	2% fibre
1	NAC-0-0	33.33	35.68	38.67	42.43
2	RAC-25-0	32.40	34.80	37.68	41.46
3	RAC-50-0	31.68	33.80	36.57	40.40
4	RAC-75-0	30.80	33.02	35.77	39.33
5	RAC-100-0	29.30	31.42	34.04	37.42

5.2 Modulus of Elasticity (ME)

The modulus of elasticity of a material in compression is a fundamental property that is needed for modelling its mechanical behaviour and for evaluation of stiffness criteria. Due to the high volume fraction of steel fibers, the concrete has not only very ductile compressive stress-strain behaviour, but also has ductile flexural, tensile and cyclic behaviour. There are a vast number of potential applications for such a composite particularly in earthquake and impact resistant structures. For safe and efficient use, the stress - strain response of the composite should be known, with the peak strength and the modulus of elasticity being two of the most important parameters of this response. The increasing application of damage mechanics to civil engineering composites calls for the knowledge of the modulus of elasticity and its deterioration or damage with loading history. Thus, there is need to generate experimental data related to the elastic modulus of steel reinforced RAC.

The stress strain curves for various mixes are presented in figure 2 to 5. From this curves the initial tangent modulus was drawn and corresponding slopes of the curve were taken as modulus of elasticity corresponding mixes. The obtained moduli of elasticity (ME) values are presented in Table 3. From this table it is observed that, mixes with 0% fibres for various replacements of recycle aggregates was varying about $2.53x10^4$ to $2.71x10^4$MPa. The percentage of decrease in ME is about 1.85 to 6.65% for RAC25 to RAC100, when compared with natural aggregate concrete respectively. This type of results are observed by the Kou and Poon [15], in their study the decrease is about 10% for RAC100 aggregate concrete over conventional concrete. But in the present experimental work the decrease for RAC100 noticed as 6.65% over reference mix. So in general it may conclude that, as percentage of recycle aggregate content increases the modulus of elasticity is decreasing. This may due to stiffness of mortar, concrete porosity and aggregate cement paste bonding. For mixes with addition of fibres of 1, 1.5 and 2% the ME values are varying 2.57 $x10^4$ to 3.08 $x10^4$, 2.61 $x10^4$ to 3.23 $x10^4$ and 2.72 $x10^4$ to 3.36 $x10^4$ MPa respectively. The % of decrease for 1% mix RAC25 to RAC100 is about 7 to 16%, when compared with reference mix of 1% fibre. In the similar way for 1.5% and 2% of RAC25 to RAC100 is about 6 to 10% and 5 to 10% respectively over corresponding mix of fibre reinforced natural aggregate concrete. In all the mixes as the % of RA content increases the ME values are decreasing. At the same time as the % of steel fibres content increases for the same mix the modulus of elasticity values are increasing (this can noticed from Table 3).

Table 3: Modulus of Elasticity for Various Mixes

Nomenclature	0% Fibre	1% Fibre	1.5% Fibre	2% Fibre
	10^4 MPa			
NAC	2.71	3.08	3.23	3.36
RAC25	2.66	2.86	3.03	3.17
RAC50	2.62	2.67	2.84	3.00
RAC75	2.58	2.62	2.68	2.85
RAC100	2.53	2.57	2.61	2.72

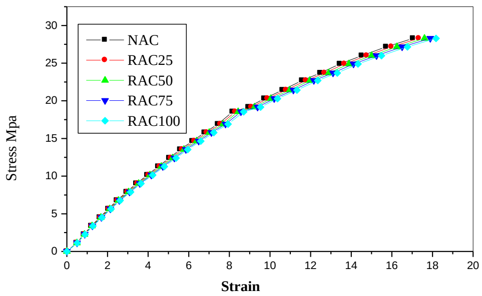

Figure 2: Stress – Strain response of 0% of Fibre

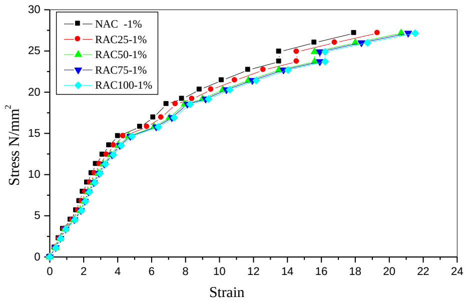

Figure 3: Stress – Strain response of 1% of Fibre

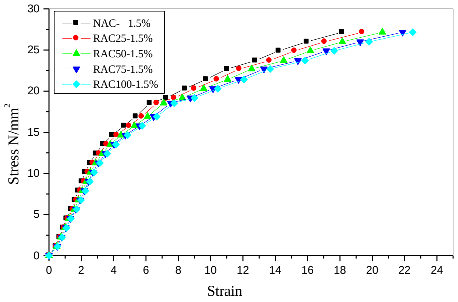

Figure 4: Stress – Strain response of 1.5% of Fibre

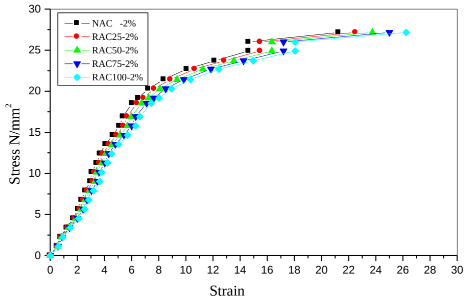

Figure 5: Stress – Strain response of 2% of Fibre

The authors would like test the modulus of elasticity values with the earlier research works and also with IS 456 code provision. Though the IS formula specified for conventional concrete, here in it is testing for the suitability of the experimental results. Earlier researchers Ravindrarajah and Tam [16], Dhir et.al [17], Corinaldesi et.al [18] and Xiao et.al [19] has been provided formulas to find Youngs modulus for RAC concrete. At present, those are tested in Table 4 as suitability of equation for steel fibre reinforced recycle aggregate concrete. In addition to the table for better understanding the behaviour of RAC, graphs are also drawn and are depicted in figure 6 to 9. For 0% fibre mix the modulus of elasticity values are over estimated by the IS code and underestimated by the earlier researchers (figure 6). For RAC with 1, 1.5 and 2% fibres the Modulus of elasticity is more for natural aggregate concrete but for 25 to 100% RA, the values are overestimate by The IS Code and underestimated by the earlier works (figure 7, 8 and 9). In order to estimate reasonably the authors are planned to develop regression model as the model be a function of compressive strength of mix, %RAC and % of Steel fibres.

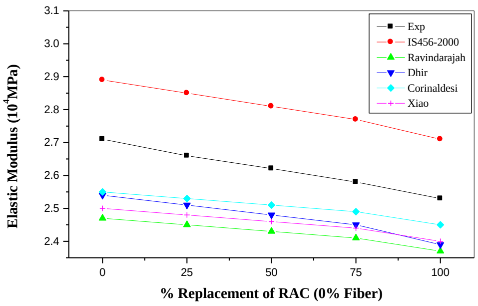

Fig 6:Elastic modulus vs % of RAC (0.0% fibre)

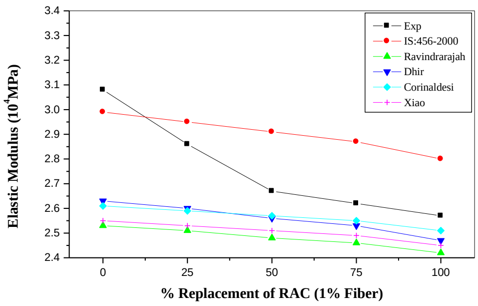

Fig 7:Elastic modulus vs % of RAC (1.0% fibre)

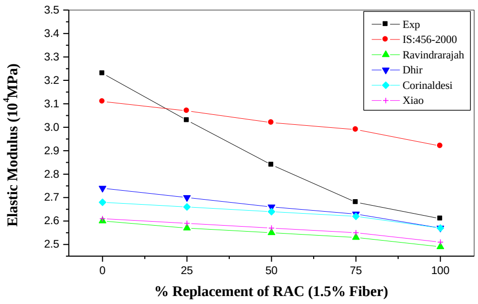

Fig 8:Elastic modulus vs % of RAC (1.5% fibre

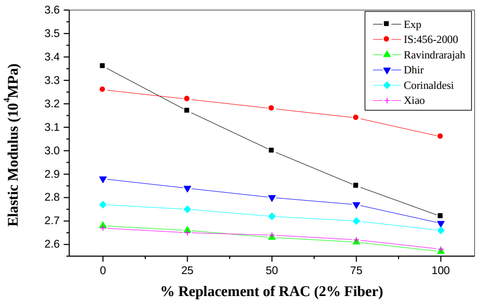

Fig 9:Elastic modulus vs % of RAC (2.0% fibre)

Table 4: Modulus of elasticity for RAC concrete

Sl. No	Nomenclature	Experimental	As per IS code E=5000√fcu	Ravindrarajah and Tam(1985) E=7770x $(fcu)^{0.33}$	Dhir et al.(1999) E=370x fcu+13100	Corinaldesi et al.(2011) E=18.2[$((0.83*fcu)/10)^{(1/3)}$]	Xiao et al.(2006), $E=10^5/(2.8+(40.1/fcu))$
		10^4 N/mm^2					
0% of Fibres							
1	NAC0	2.71	2.89	2.47	2.54	25.55	2.50
2	RAC25	2.66	2.85	2.45	2.51	25.31	2.48
3	RAC50	2.62	2.81	2.43	2.48	25.12	2.46
4	RAC75	2.58	2.77	2.41	2.45	24.89	2.44
5	RAC100	2.53	2.71	2.37	2.39	24.47	2.40
1.0% of Fibres							
6	NAC0	3.08	2.99	2.53	2.63	26.14	2.55
7	RAC25	2.88	2.95	2.51	2.60	25.92	2.53
8	RAC50	2.67	2.91	2.48	2.56	25.67	2.51
9	RAC75	2.62	2.87	2.46	2.53	25.47	2.49
10	RAC100	2.57	2.80	2.42	2.47	25.05	2.45
1.5% of Fibres							
11	NAC0	3.23	3.11	2.60	2.74	26.85	2.61
12	RAC25	3.03	3.07	2.57	2.70	26.62	2.59
13	RAC50	2.84	3.02	2.55	2.66	26.35	2.57
14	RAC75	2.68	2.99	2.53	2.63	26.16	2.55
15	RAC100	2.61	2.92	2.49	2.57	25.73	2.51
2.0% of Fibres							
16	NAC0	3.36	3.26	2.68	2.88	27.69	2.67
17	RAC25	3.17	3.22	2.66	2.84	27.48	2.65
18	RAC50	3.00	3.18	2.63	2.80	27.24	2.64
19	RAC75	2.85	3.14	2.61	2.77	27.00	2.62
20	RAC100	2.72	3.06	2.57	2.69	26.55	2.58

5.3 Regression Model for Modulus of Elasticity of RAC

The Indian standard code IS 456 – 2000 provided a square root function to estimate the modulus of elasticity of concrete as $E = 5000\sqrt{f_{ck}}$,

Where,

E is the modulus of elasticity in N/mm^2 and

f_{ck} is cube compressive strength of 28 days in MPa .

In similar manner, regression model has been developed as square root function of characteristic compressive strength along with other variables of %of RAC & % of fibre.

Based on regression analysis of the results of present investigation, the following model is recommended.

$E = 0.38181+0.43753(\sqrt{f_{ck}}) - 0.03441(\sqrt{RAC}) + 0.04066(\%\ of\ fibre)$

Where,

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

RAC= Recycle Aggregate Concrete.

E= Youngs modulus in MPa

The validity of the equation is depicted in Table 5 and in Figure 10. In general for most of the cases the regression models are able to predict the modulus of elasticity reasonably well. Here also the maximum difference observed is about 10%. Hence it is recommended that the above model can be used for predicting the modulus of elasticity approximately for various mixes of RAC (with and without fibres).

Table 5: Performance of Regression Model (RM)

Nomiclature	0%Fibre	1%Fibre	1.5%Fibre	2%Fibre

	10^4 N/mm^2							
	EXP	RM	EXP	RM	EXP	RM	EXP	RM
NAC	2.71	2.91	3.08	3.04	3.23	3.16	3.36	3.31
RAC25	2.66	2.70	2.88	2.83	3.03	2.96	3.17	3.11
RAC50	2.62	2.60	2.67	2.72	2.84	2.85	3.00	3.00
RAC75	2.58	2.51	2.62	2.64	2.68	2.76	2.85	2.91
RAC100	2.53	2.41	2.57	2.53	2.61	2.65	2.74	2.80

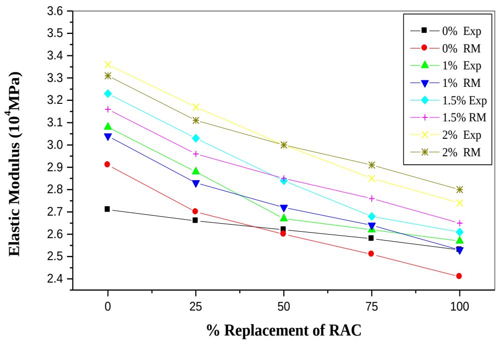

Fig 10: Performance of Regression model

6. Conclusions

The following conclusions were drawn from the experimental work.

1. The compressive strength is decreasing for the RAC mixes as the % of recycle aggregate increased in the mixes. The compressive strength is varying about 2.3 to 12% for RAC mixes when compared to conventional concrete.
2. The moduli of elasticity also decreasing as the % of recycle aggregate content increases in the mixes. The modulus of elasticity for RAC concrete (with out fibres) is is decreased by 1.85 to 6.65% when compared with reference mix. The modulus of elasticity for RAC with fibres (1 to 2%) was decreased from 5 to 10% over reference concrete containing corresponding dosage of fibres.
3. As the %of steel fibres increases for the RAC mixes the compressive strength and modulus of elasticity is increasing.
4. The validity of the equation proposed by the earlier researchers are checked and found as those are under estimating the experimental results.
5. A regression model has been developed to evaluate the modulus of elasticity with the functions of compressive strength, % of RAC and % of steel fibres.
6. Load deflection curves for various mixes are plotted from those it is observed that the stiffness is marginally varying.

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