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RESEARCH ARTICLE

FLEXURAL STRENGTH OF BASALT FIBRE REINFORCED RECYCLED AGGREGATE CONCRETE

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ABSTRACT

This article presents the flexural behaviour of basalt fibre reinforced recycle aggregate concrete. The natural aggregate is replaced by the recycle aggregate in the proportion of 0,25,50,75 and 100%. The basalt fibres used for the concrete with dosage of 4kg/m^3. Total ten mixes are taken for experimental work among them, 5 mixes with basalt fibres and other 5 mixes without basalt fibres. In addition to flexure, cube and split tensile strengths are evaluated for concrete mixes. For obtained flexural strength results, regression models are developed to estimate the flexural strength as function of cube compressive strength and % of basalt fibres. The results showed that the flexure strength is increased up to 50% RAC and for later replacements (75 and 100%) the flexural strengths are decreased. By adding the basalt fibres for various mixes, the strengths are increased and more effectiveness observed for 50% RAC.

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INTRODUCTION

Recycling of concrete is needed with concern of environmental preservation and effective utilization of resources. At present, utilization of recycling aggregate is limited mainly to sub-bases of roads and backfill works. A large portion of concrete waste is transported to disposal sites. It is anticipated that, there will be an increase in the amount of concrete waste, a shortage of disposal sites and depletion in natural resources especially in India. These lead to the use of recycling aggregate in new concrete production, which is deemed to be more effective utilization of concrete waste. However, information on concrete using recycling aggregate is still insufficient, and it will be advisable to get more detailed information about the characteristics of concrete using recycling aggregate. In this connection review is presenting herein related to recycled aggregate concrete and basalt fiber. Ivan S. Ignjatovic *et al*. (2012) studied the flexural behavior of RAC beams when compared to NAC beams under short term loading. The results reported that the flexural behavior RAC beams is satisfactory comparing to the behavior of NAC beams, for both the service and ultimate loadings. Katrina McNeil *et al*. (2013) reported the replacing Natural aggregate (NA) in concrete with RCA decreases the compressive strength, but yields comparable splitting tensile strength and beams with RCA experiences greater mid span deflections under a service load. Li *et al*. (2013) studied the cube compressive strength and other properties of RAC in the same curing age. The cube compressive strength of RAC cured 7days increases rapidly. Compared with 28 days compressive strength, the 360 days compressive strength increases 34.4% to 47.8 %. Prasad *et al*. (2007) studied about the Glass Fiber Reinforced Recycled Aggregate Concrete (GFRRAC). In their itt was observed that there was 10-17% increase in split tensile strength and about 10-14% improvement in flexural strength with fiber addition in recycled aggregate concrete. The increased energy absorption capacity in GFRRAC indicates higher toughness. Bairagi *et al*. (1993) investigates the quality of concrete with maximum utilization of recycled aggregate in place of natural aggregate. They introduced the term replacement ratio is defined as ratio of recycled aggregate to total coarse aggregate in a concrete mix and higher replacement ratio values suggested for getting good quality of concrete. Saravenakumar *et al*. (2012) studied the strength characteristics of high volume fly ash based concrete with recycled aggregate of M50grade were studied. He is observed that 50% replacement of cement with FA and 50% replacement of NA with RA give satisfactory results by compromising strength of 40 to 50% and major reduction in cost. Ahmad Altalmas *et al*. (2015) studied the bond durability on sand-coated basalt fiber-reinforced polymer (BFRP) bars. Pull-out specimens were tested under direct tensile load after

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being exposed to accelerated conditioning environments. Cory High *et al*. (2015) investigated the use of basalt fiber bars as flexural reinforcement for concrete members and the use of chopped basalt fibers as an additive to enhance the mechanical properties of concrete. Chaohua Jiang *et al*. (2014) studied the effects of the volume fraction and length of basalt fiber (BF) on the mechanical properties of FRC. Coupling with the scanning electron microscope (SEM) and mercury intrusion porosimeter (MIP), the microstructure of BF concrete was also studied. Fathima Irine *et al*. (2014) investigated the mechanical properties of Basalt fiber concrete and compare the compressive, flexural and splitting tensile strength of basalt fiber reinforced concrete with plain M30 grade concrete. Jon sung Sim *et al*. (2005) investigated the applicability of the basalt fiber as a strengthening material for structural concrete members through various experimental work for durability, mechanical properties and flexural strengthening. Kunal Singha (2012) presented a short review on basalt fiber. Mehmet Emin Arslan (2016) investigated the fracture behaviour of basalt fiber reinforced concrete (BFRC) and glass fibre reinforced concrete (GFRC). In the experimental study three-point bending tests were carried out on notched beams produced using BFRC and GFRC.Gore Ketan *et al*. (2013) evaluated the performance of high strength concrete (HSC) containing supplementary cementations materials. Concrete had a good future and is unlikely to get replaced by any other material on account of its ease to produce, infinite variability, uniformity, durability and economy with using of basalt fiber in high strength concrete. Nasir Shafiq *et al*. (2016) presentenced the flexural test results of 21 fiber reinforced concrete (FRC) beams containing Poly vinyl alchol (PVA) and basalt fibers (1-3% by volume) Fiber reinforced concrete was made of three different binders. Experimental results showed that the addition of PVA fibers significantly improved the post-cracking flexural response compared to that of the basalt fibers. Amuthakkannan *et al*. (2013) focused on the effect of fibre length and fibre content of basalt fiber on mechanical properties of the fabricated composites. TianyuXie and Togay Ozbakkaloglu (2016) conducted experimental study on the axial compressive behavior of concrete filled FRP tubes (CFFTs), prepared using different amounts of recycled concrete aggregate (RCA). Xiaochun Fan and Mingzhong Zhang (2016) conducted the experimental study on basalt reinforced inorganic polymer concrete (IPC) beam which combines the specific characteristics of IPC and basalt reinforcement. Venkata Ramana (2017) presented a review on basalt fiber reinforced concrete. From the presented literature review, it is noticed that no has been carried out on basalt fiber by using recycle aggregate concrete at various proportions. Hence herein an experimental work has been planned to evaluate the flexural strength of basalt fiber reinforced concrete and the detailed experimental program is furnishing below.

Experimental program

The following variables were considered for the experimental programme and same were presented in Table 1.

Material used

The following material were used for the present experimental work

Cement: Ordinary Portland cement conforming to IS 8112: 1989 was used. The specific gravity of the cement was noticed as 3.12.

Fine Aggregate: Locally available river sand passing through 4.75 mm I.S. Sieve is used. The specific gravity of the sand is found to be 2.75 and it was conformed to zone II.

Natural Coarse Aggregate: Crushed granite aggregate available from local sources has been used. To obtain a reasonably good grading, 60% of the aggregate passing through 20 mm I.S. sieve and retained on 12.5mm I.S. Sieve and 40% of the aggregate passing through 12.5mm I.S. Sieve and retained on 10 mm I.S. Sieve is used in preparation of NAC and RA. The specific gravity of the combined aggregate is 2.70.

Recycled concrete aggregate: The raw material of Recycled concrete aggregate was obtained from demolished cement concrete pavement. The generated waste material was is not able to use as it is, as coarse aggregate in the concrete. So there is a need to develop as graded aggregate to use in concrete. To convert the waste as coarse aggregate the waste material was transported to crusher unit and made as 20 and 12.5 mm aggregate. Two different sizes were obtained from the waste material, so as to use the material effectively. 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 of combined aggregate was observed as2.56.

Table 1. Variables for Experimental work

S.No.	Factors for the experimental work			
1	% of Recycle Aggregate Variation	0,25,50,75 and 100%		
2	Dosage of Basalt fibre	4 Kg/m^3		
3	Total number of mixes	10		
4	Mix Ratio as per ACI 211.1-91code	1:2.64:2.96	for 0% NAC mix	Water cement ratio for all mixes is 0.57
		1:2.69:2.91	for 25%RAC mix	
		1:2.76:2.84	for 50%RAC mix	
		1:2.80:2.80	for 75%RAC mix	
		1:2.81:2.79	for100%RAC mix	
5	Strengths are to be examined	Compression, Split tensile and Flexure strengths		
6	Type of specimens cast	Cubes (30Nos)	150 x150x150 mm	
		Cylinders (30Nos)	150 mm dia and300mm height	
		Beams (30Nos)	150 x150 x750mm	
7	Strength evaluation day for all mixes	28^{th} day from the date of casting		

Water: Potable fresh water available from local sources was used for mixing and curing.

Basalt Fibers: The used basalt fiber can be viewed in below Figure 1. The properties are presented in the below Table 2, which were obtained from the supplier.

Figure 1. Basalt Fiber

Table 2. Physical properties of Basalt Fibers

S. No.	Property	Units	Value
1	Equivalent length	Mm	50
2	Filament diameter	Micro meter	9-15
3	Specific gravity	No units	2.8
4	Tensile strength	MPa	3000-4840
5	Young's modulus	GPa	79.3-93
6	Ultimate elongation	%	3.1

Casting and curing

The cubes were cast in steel moulds with inner dimensions of 150 x 150 x 150mm, the cylinders were cast in steel moulds with inner dimensions as 150mm diameter & 300mm height and the beams are cast in steel moulds with inner dimensions as 150 x150 x750mm. All the materials are weighed as per mix design and kept aside separately. The cement, sand, coarse aggregate and recycled concrete aggregate were mixed thoroughly till to reach uniformity to the concrete mix. The fibers are added to concrete ingredients in dry state. After achieving uniform mix then the water is added to the mix and mixed with hand operation till to get homogenous 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 specimens are de-moulded after twenty four hours 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 allowed to dry under shade later they have gone to testing. Three cubes, three cylinders and three beams were cast for each mix.

Testiing

Compaction Factor Test

The compaction factor test apparatus consists of two hoppers, each in the shape of frustum of a cone and one cylinder. The upper hopper is filled with concrete this being placed gently so that no work is done on the concrete at this stage to produce compaction. The second hopper is smaller than the upper one and is therefore filled to overflowing. The concrete is allowed to fall in to the lower hopper by opening the trap door and then into the cylindrical mould placed at the bottom. Excess concrete across the top of the cylindrical mould is cut and the net weight of the concrete in cylinder is determined. This gives the weight of partially compacted concrete. Then the cylindrical mould is filled with concrete and compaction was done by tamping rod. The fully compacted weight is then determined and compaction factor (C.F) is calculated by using the standard formula (refer any standard text book of Concrete Technology).

Cube Compressive Strength Test

Compression test on cubes is conducted with 2000kN 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 then computed by using stand formula (this test has been carried out on cube specimens at 28 days).

Split Tensile Strength

The cylinder is placed on the bottom compression plate of the testing machine and is aligned such that the center lines marked on the ends of the specimen are vertical. Then the top compression plate is brought into contact at the top of the cylinder. The load is applied at uniform rate, until the cylinder fails and same load is taken in to account as ultimate load. From this load, the splitting tensile strength is calculated for each specimen by stand formula.

Flexure test

The beam is simply supported on two rollers with 12mm diameter over a span of 650 mm (the overall length of beam is 750mm). The element is checked for its alignment longitudinally and adjusted if necessary. Required packing is provided using rubber material and care was taken to ensure that the two loading points were at same level. The flexure test was conducted on beams using universal testing machine. The load is transmitted to the beam element through the I-section and two 16mm diameter rods spaced at a distance of 216mm (Figure 2(a) and (b)).

Fig 2(a). Test setup for flexure

Fig 2(b). Tested beam in flexure

For each increment of loading, the deflections at the centre of span were recorded using dial gauges. Continuous observations were made and the cracks were identified with the help of magnifying glass. Well before the ultimate stage, the deflect meters were removed and the process of load application was continued till to continued total failure and at this stage the load is recorded as ultimate load. The test set up can be observed in Figure 2(a) and 2(b). The flexural strength of the beam specimens for each mix is computed and the same values are presented in next section

results are presented in figure 3.From these it is observed that the compaction factor decreases with increase in the % of recycled concrete aggregate in the concrete mix. The decreases of workability may be due to higher water absorption of recycled concrete aggregate than the normal aggregate. The effect of workability in recycled concrete aggregate with fibers can also observed in figure 3 .From this it can be noticed that as the % of fibers increase the workability is decreases when compared to concrete without fibers. In the presence of the basalt fibers in recycled concrete aggregate concrete the workability is decreases. This may be due to effect fibers, generally the fibres gives dimensional stablity to the mixes, same may be expected in the mixes made with fibres.

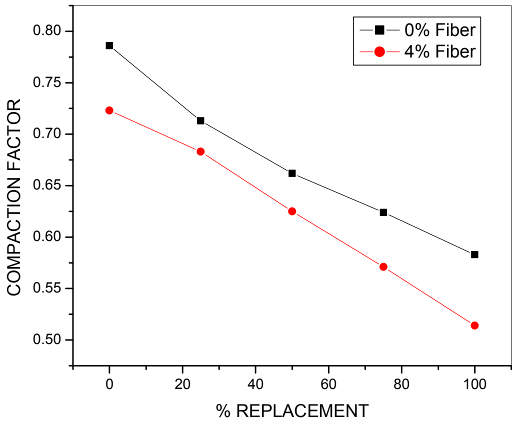

Fig. 3. Compaction factor vs % of replacement

Table 3. Compressive Strength

Nomenclature	First Crack Load (kN)	First Crack Compressive Stress (N/mm^2)	Average Stress (N/mm^2)	Ultimate Load (kN)	Ultimate Compressive Stress (N/mm^2)	Average Stress (N/mm^2)
NAC-0	524.30	23.31	21.85	821.20	36.50	33.30
	452.30	20.10		706.50	31.40	
	498.70	22.16		720.00	32.00	
RAC-25	532.30	23.79	22.26	877.50	39.20	34.83
	432.00	19.20		675.00	30.30	
	535.50	23.80		787.50	35.00	
RAC-50	500.90	22.26	22.31	821.25	36.50	37.03
	590.40	26.24		920.50	41.60	
	504.00	22.44		742.50	33.00	
RAC-75	532.30	23.79	21.45	877.50	39.30	33.60
	446.40	19.84		697.50	31.00	
	466.70	20.74		686.25	30.50	
RAC-100	425.50	18.91	20.45	697.90	31.20	31.90
	518.50	23.04		810.00	36.50	
	428.50	19.04		630.00	28.00	
FNAC4-0	555.80	24.70	22.94	911.50	40.80	36.77
	495.00	22.00		765.00	34.00	
	543.20	24.14		798.75	35.50	
FRAC4-25	562.70	25.01	23.93	922.50	41.00	37.33
	517.50	23.00		810.00	36.00	
	535.50	23.80		787.50	35.00	
FRAC4-50	540.00	24.10	24.55	911.25	40.50	38.33
	510.70	22.70		785.00	35.00	
	604.30	26.86		888.75	39.50	
FRAC4-75	549.00	24.40	22.89	900.00	40.00	36.00
	522.00	23.20		832.50	37.00	
	474.30	21.08		697.50	31.00	
FRAC4-100	507.80	22.57	22.09	832.50	37.00	32.50
	540.00	24.00		708.57	31.50	
	443.70	19.72		652.50	29.00	

RESULTS AND DISCUSSION

Workability

The workability of different mixes has been measured by Compaction factor test. The values of compaction factors

Compressive strength

The compressive strengths results are presented in Table 3, from this; it can be observed that the 28 days compressive strength increases with the increase in the percentage of recycled up to 50%. For 25, 50 recycled concrete aggregate there is an increase in compressive strength about 4.59%, 11.2% and for 75,100% recycled aggregate there is a decrease in compressive strength about 0.9, 4.2% respectively over reference concrete. From the same table it also observed that, for fiber added mixes, the compressive strength increases at every % of recycled concrete aggregate. From a law of rule of mixture the strength enhancement is expected for the mixes of natural and recycled aggregate concrete.

Spilt Tensile Strength

The 28 days split tensile strength of recycled aggregate concrete mixes are presented in Table 4. From this it is observed that, the split tensile strength increases with the increase in the percentage of recycled aggregate up to 50% and for other mixes the strengths are decreased. For 25, 50% of recycled there is increase in split tensile strength by 4%, 7.4% over the reference concrete. For 75% and 100%, the split tensile strength has decreased by 7.74% and 9.04 %respectively over reference concrete (NAC-0). From the Table 4, it is also observed that as the % of volume fraction of fibres increases the split tensile strength increases at every % of recycled concrete aggregate. The fibres are act as crack arresters and those may take more time to failure and also takes more loads to failure.

flexure strength has decreased by 6.6% and 4.8% respectively over natural aggregate concrete (NAC-0). From the same table, for fibre mixed mixes same trend has observed as in case of mixes without fibres. With addition of basalt fibers, the strengths are enhanced for all mixes, but the more effectiveness can be observed for 50% RAC mix (Figure 4). The fibres are the source to enhance the strengths and they may act as crack arresters and also required more energy to fail.

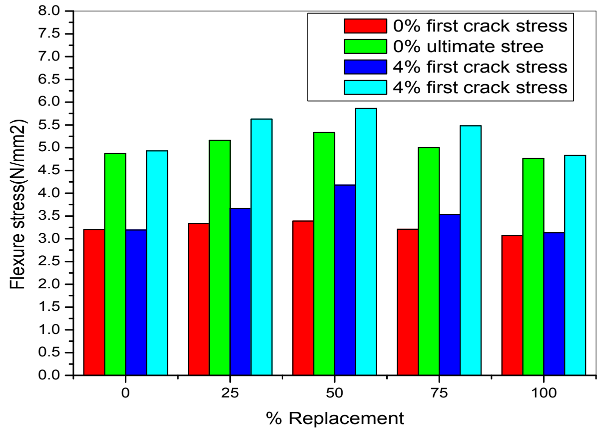

Fig. 4. Flexural stress vs % replacement

Table 4. Split Tensile Strength

S. No.	Nomenclature	First Crack Load (kN)	First Crack Split Tensile Stress (N/mm^2)	Average Stress (N/mm^2)	Ultimate Load (kN)	Ultimate Tensile Stress (N/mm^2)	Average Stress (N/mm^2)
1	NAC-0	86.73	1.23	1.51	139.80	1.98	2.29
		96.43	1.37		148.40	2.10	
		136.40	1.93		197.80	2.80	
2	RAC-25	87.60	1.24	1.70	141.30	2.00	2.38
		101.10	1.43		155.40	2.20	
		143.80	2.44		208.40	2.95	
3	RAC-50	92.00	1.30	1.61	148.30	2.10	2.46
		133.10	1.89		204.80	2.90	
		117.00	1.66		169.56	2.40	
4	RAC-75	91.10	1.29	1.39	146.90	2.08	2.12
		110.20	1.56		169.50	2.40	
		93.00	1.31		134.20	1.90	
5	RAC-100	92.00	1.31	1.37	148.30	2.10	2.10
		112.00	1.57		170.00	2.40	
		87.80	1.24		127.17	1.80	
6	FNAC4-0	113.90	1.61	1.65	183.69	2.60	2.38
		101.20	1.43		155.43	2.20	
		134.10	1.90		194.28	2.35	
7	FRAC4-25	122.60	1.74	1.55	197.82	2.80	2.40
		96.50	1.37		148.36	2.10	
		112.10	1.56		162.49	2.30	
8	FRAC4-50	127.10	1.80	1.61	204.88	2.90	2.47
		97.00	1.37		149.00	2.10	
		118.00	1.67		170.97	2.42	
9	FRAC4-75	113.90	1.61	1.54	183.69	2.60	2.35
		112.60	1.60		173.10	2.45	
		97.50	1.40		141.30	2.00	
10	FRAC4-100	96.40	1.36	1.47	155.40	2.20	2.25
		119.40	1.70		183.70	2.60	
		95.40	1.35		137.70	1.95	

Flexure Strength

The 28 days flexure strength results are presented in Table 5 and in Figure 4. From these it is observed that the flexure strength increases with the increase in the percentage of recycled aggregate up to 50% and for later replacements (75 and 100%) the flexure strengths are decreased. For 25, 50% of recycled there is increase in flexure strength by 6.2% and 3.3% over the natural aggregate concrete. For 75% and 100%, the

Load-Deflection response

Load vs deflection relationships of the recycled aggregate concrete and natural aggregate concrete with and without fibers can be observed in Figure 5(a) and (b). Form those it is noticed that, the stiffness of the beam are varying form point to point. At very initial stages the load deflection response for all mixes more or less equal but at subsequent stages their behaviour is varying.

Table 5. Flexural strength

Nomenclature	First Crack Load (kN)	First Crack Flexure Stress (N/mm^2)	Average Stress (N/mm^2)	Ultimate Load (kN)	Ultimate Flexure Stress (N/mm^2)	Average Stress (N/mm^2)
NAC-0	15.40	2.98	3.20	25.44	4.90	4.86
	15.50	2.99		23.80	4.60	
	17.60	3.40		26.40	5.10	
RAC-25	17.42	3.35	3.33	28.55	5.50	5.16
	16.53	3.18		25.44	4.90	
	18.00	3.46		26.48	5.10	
RAC-50	18.30	3.53	3.39	30.11	5.80	5.33
	16.80	3.25		26.00	5.00	
	17.60	3.40		27.00	5.20	
RAC-75	17.70	3.41	3.21	29.00	5.60	5.00
	16.10	3.12		25.00	4.80	
	16.10	3.10		23.90	4.60	
RAC-100	17.10	3.29	3.07	28.10	5.40	4.76
	15.20	2.92		23.40	4.50	
	15.50	3.00		22.84	4.40	
FNAC4-0	16.40	3.20	3.19	27.00	5.20	4.93
	15.80	3.05		24.40	4.70	
	17.30	3.33		25.40	4.90	
FRAC4-25	18.60	3.60	3.65	30.60	5.90	5.63
	17.90	3.44		27.50	5.30	
	19.70	3.80		29.60	5.70	
FRAC4-50	21.50	4.14	4.18	35.30	6.80	5.86
	22.90	4.42		30.11	5.80	
	20.60	3.97		25.96	5.00	
FRAC4-75	17.70	3.41	3.53	29.10	5.60	5.48
	20.58	3.96		31.60	6.10	
	16.70	3.23		24.60	4.75	
FRAC4-100	17.65	3.40	3.13	28.50	5.50	4.83
	13.83	2.66		21.30	4.10	
	17.30	3.33		25.40	4.90	

Table 6. Performance of Regression Model

S.No.	Nomenclature	Experimental value(EXP) (N/mm^2)	Based on regression model(RM)(N/mm^2)	EXP/ RM
1	NAC-0	4.86	4.84	1.00
2	RAC-25	5.16	5.10	1.00
3	RAC-50	5.33	5.34	1.00
4	RAC-75	5.00	4.88	1.03
5	RAC-100	4.76	4.53	1.03
6	FNAC4-0	4.93	5.45	0.92
7	FRAC4-25	5.63	5.49	1.02
8	FRAC4-50	5.86	5.68	1.02
9	FRAC4-75	5.48	5.26	1.03
10	FRAC-100	4.83	4.64	1.03

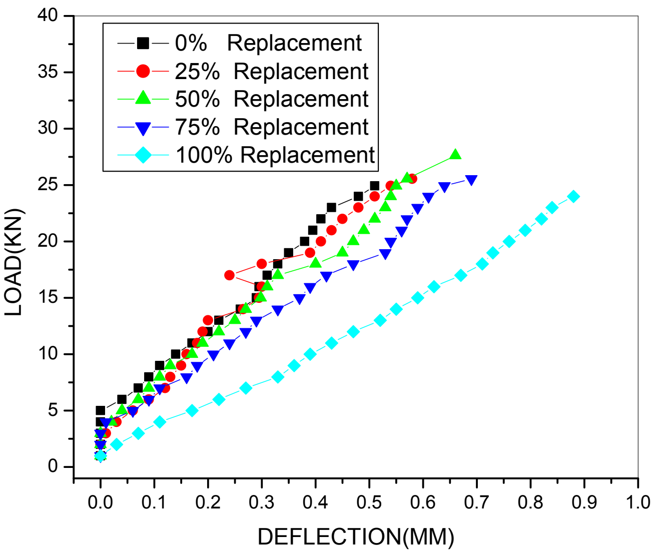

Fig 5(a). Load- displacement curves (Mixes without fibres)

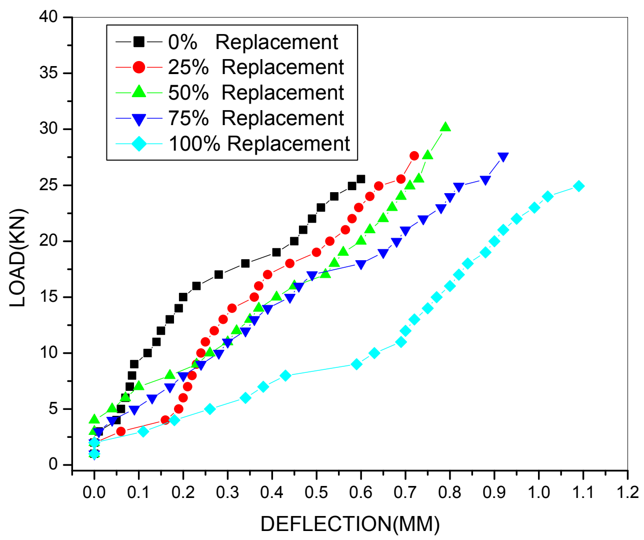

Fig 5(b). Load- displacement curves (Mixes with fibres)

Basalt fibers have ability to reduce cracking nature in the beam and have more stiffness while using these fibers compared to without addition of fibers (NAC-0). The ultimate load carrying capacity of recycled aggregate concrete without addition fibers are increase along with more deflections. This inference the incorporation fibres show the ductility property to the concrete. The fibres should act as crack arresters and post crack behaviour is varying when compared with plane mixes. Among all mixes the mix with 50% RAC showed effective carrying capacity both in load and deflection. The mix with 25% RAC shown a clink at one point in the Figure 4(a), this may due to some experimental error during experimentation.

Regression Model to estimate the flexure strength

The following regression models were established to estimate the flexure strength of concrete and the models are tested with experimental results. In general concrete properties (bearing, shear, split tensile strength etc) are related to cube compressive strength. Hence here in also, the authors would like to develop regression models to estimate the flexure strength as function of cube compressive strength. From this intension the models are developed and furnished below. The performance of regression models are presented in Table 6. From this table it is noticed that, the experimental values are varying about ±5%. From the results it is noticed that the proposed models are made good agreement with the experimental results.

f_{ck}= 33.3+0.013(R) +0.57(BF) ---------Eq (1)

Where

f_{ck}=compressive strength in MPa,
R=% replacement of recycled concrete aggregate
BF= Basalt fibre in kg/m^3.

f_{cr}= 0.17(f_{ck})-0.794 ……………………… Eq (2)

Wheref_{cr}=flexure stress MPa.
The above equations are subjected to constraints of
$0 \leq R \leq 100$
$0 \leq BF \leq 4$

Conclusion

The following conclusions may be drawn from the present experimental work

1. The workability for recycled concrete aggregate is decreases with compared with normal aggregate concrete.
2. The compressive, split tensile and bearing strengths were increases with the increase of recycled concrete aggregate up to 50% and for dosage of RAC (75 and 100%) decreases in the concrete mix. The same behavior was observed for all mixes with incorporation of basalt fibers.
3. For 25, 50% of recycled there is an increase in flexural strength by 6.2% and 3.3% respectively, over the natural aggregate concrete (NAC-0)
4. For 75% and 100%, the flexure strength has decreased by 6.6% and 4.8% respectively over granite aggregate concrete (NAC-0)
5. The % of increase for 25 and 50% FRAC mixes (with addition fibres) is about 7 to 10% respectively when compared with FNAC-0 mix.
6. To estimate the flexural strength, a regression model was proposed in the present article and this model shown good compatibility with experimental results

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