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STRENGTH STUDIES ON GLASS FIBER REINFORCED RECYCLED AGGREGATE CONCRETE

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ABSTRACT

The transformation from a conventional consumption based society to a sustainable society is urgently required due to the pollution of the natural environment, the exhaustion of the natural resources and the decreasing capacity of the final waste disposal facilities. One of the ways to solve this problem is to use Building Demolished Waste (BDW) concrete as aggregates in structural concrete. The aggregates thus obtained can be called as Recycled Concrete Aggregate (RCA).Concrete is a versatile material with numerous applications, but the only problem with concrete is its brittle behaviour more so in recycled aggregate concrete. This brittleness in concrete can be overcome by dispersing fibers discretely in the material of concrete. In the present work, Glass Fiber Reinforced Recycled Aggregate Concrete (GFRRAC) was developed. The mechanical properties of GFRAC with M20 & M40 grade concretes, for different replacements of Recycled Concrete Aggregate (RCA) in Natural Aggregate (NA) are presented. It 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. There is an improvement in the modulus of elasticity of concrete. The values of split, flexure and modulus of elasticity obtained were also compared with the Indian Standard Codal Provisions. The increased energy absorption capacity in GFRRAC indicates higher toughness and better post elastic deformations in the event of seismic actions.

Keywords: Natural aggregate, recycled aggregate, sustainability, glass fiber, fly ash, strength studies

1. INTRODUCTION

Construction and Demolition (C&D) waste constitutes a major portion of total solid waste production in the world, and most of it is used in land fills. Research by concrete engineers has clearly suggested the possibility of appropriately treating and reusing such waste as aggregate in new concrete [1,2,3,4]. Recycling is the act of processing the used material for use in creating new product. The utilisation of waste material as secondary raw material is

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the solution to the problem of an excess of waste material, not forgetting the parallel trend of improvement of final product quality. The technology today has advanced so far that it is forcing us to think of new concept called sustainability [5,6]. Preservation of the environment and conservation of the rapidly diminishing natural resources should be the essence of sustainable development [7].

Concrete is brittle under tensile loading and the mechanical properties of concrete may be improved by randomly oriented short discrete fibers which prevent or control initiation and propagation or coalescence of cracks. The character and performance of Fiber Reinforced Concrete (FRC) change depending on the properties of concrete and the fibers. The properties of fibers that are usually of interest are fiber concentration, fiber geometry, fiber orientation, and fiber distribution. Glass and Glass fibers have various applications in concrete like crack control, prevent coalescence of cracks, and to change the behaviour of the material by bridging of fibers across the cracks [8]. In other words, ductility is provided with fiber reinforced cementitious composites because fibers bridge crack surfaces and delay the onset of the extension of localized crack [9].

2. RESEARCH SIGNIFICANCE

In the present investigation the utility of recycled aggregate when used as a coarse aggregate for standard concrete mix proportions is being examined. The study examined the influence of physical properties of recycled aggregate on concrete strength, and the variation of structural properties, for percentage replacement of natural aggregate with recycled concrete aggregate and with and without fiber. An effort has been made in this present work to describe the salient properties of coarse aggregate when natural aggregate is replaced with recycled aggregate with 25%, 50%, 75% and 100% and the mechanical properties of concrete with replacement of Recycled Concrete Aggregate in Natural Aggregate with 0%, 50% and 100% replacements for no fiber and Glass Fiber Reinforced Concrete (GFRC) is being examined. The fly ash available locally was used as a partial replacement for cement in optimum dosages for improving the strength and workability properties of recycled concrete. The present work provides very useful information for the practical use of recycled aggregate in new concrete production and appreciates the applications of glass fiber in natural and recycled aggregates.

3. EXPERIMENTAL STUDIES ON RECYCLED AGGREGATE

Aggregates occupy bulk of the volume of concrete. Their size, grading, shape and surface texture have significant influence on properties of concrete. Moreover, in the present study recycled aggregate from Building Demolished Waste (BDW) was crushed and classified before use. For qualifying the utility of recycled aggregate in concrete, the important parameters like bulk density, voids ratio, specific gravity, water absorption, crushing and impact value, angularity and IAPST were determined based on IS Codal provisions [10]. These properties were determined for different replacement of RCA in NA and the methods are detailed in the following paragraphs.

3.1 Aggregate sizes

The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which we call gradation. The grading pattern of a sample of natural and recycled aggregates and combinations thereof with an interval of 25% is assessed by sieving the sample as suggested by IS: 2386 [10]. In the sieve analysis the particle size distribution in a sample of aggregate was found out. Fineness modulus is an empirical factor and is an index of the coarseness or fineness of the material. From the data of the sieve analysis and the grading curve it was noticed that the grading of the natural and recycled aggregates was more or less same with a slightly coarser grading observed in the case of recycled aggregate.

3.2 IAPST & Angularity Number (A.N)

Aggregates occupy bulk of the volume of concrete. Their size, grading, shape and surface texture have significant influence on the properties of concrete, both in fresh and hardened state. Specifications in various codes, on concrete mix proportioning, regarding size and grading of the aggregate are much clear than their counterparts regarding shape and surface texture, which is broadly classified into angular/ crushed and rounded/uncrushed. The lack of quantitative definition of aggregate particle shape and surface texture often leads to inconsistent results, and requirement of number of trials for achieving desirable properties of concrete. Index of Aggregate Particle Shape and Texture (IAPST), Angularity Number (A.N) as per ASTM D-3398-97 [11], provides a quantitative measure of shape and surface texture of aggregate.

3.3 Determination of IAPST

The aggregate sample is compacted in three layers with 10 drops per layer of tamping rod. Each drop is applied from a height of 50 mm above the surface of aggregates. After the completion of tamping of the third layer, individual pieces of aggregate are added to make the surface level with the rim of the mould. The mould is then weighed and the weight of the aggregate sample (M_{10}) is determined to an accuracy of 1 g. The test is repeated twice and the average value of M_{10} is used for calculating percentage voids (V_{10}).

$V_{10}= 100\ [1- M_{10}/(S \times V)]$, where S - Specific Gravity of aggregate size fraction;

V - Volume of cylinder in m^3.

The following equation is used to obtain IAPST of each size fraction:

$$IAPST = 1.011 \times V_{10} - 32.$$

3.4 Angularity Number (A.N)

The aggregate sample is compacted in three layers with 100 drops per layer of tamping rod. Each drop is applied from a height of 50 mm above the surface of aggregates. After the completion of tamping of the third layer, individual pieces of aggregate are added to make the surface level with the rim of the mould. The mould is then weighed and the weight of the aggregate sample (M_{100}) is determined to an accuracy of 1 g. The test is repeated twice and the average value of M_{100} is used for calculating percentage voids (V_{100}).

$$V_{100} = 100\,[1 - M_{100}/(S \times V)],$$

Where, S - Specific Gravity of aggregate size fraction, V - Volume of cylinder in m^3.
The following equation is used to obtain IAPST of each size fraction:

$$\text{Angularity Number} = V_{100} - 33.$$

Table 1. IAPST and Angularity numbers of natural and recycled aggregate

Aggregate	Size Fraction in mm	% Weight Retained	Specific Gravity	IAPST	AN
NA	25-20	2.5	2.82	23.69	10.30
	20-16	17.5	2.80	23.82	11.19
	16-12.5	20	2.84	22.65	11.56
	12.5-10	20	2.76	15.21	9.29
	10-4.75	40	2.74	14.43	9.82
	Weighted Average		2.78	18.10	10.31
RA25	25-20	2.5	2.70	24.15	10.75
	20-16	17.5	2.69	24.21	11.59
	16-12.5	20	2.72	23.57	12.06
	12.5-10	20	2.73	15.86	9.91
	10-4.75	40	2.68	14.98	10.27
	Weighted Average		2.70	18.72	11.35
RA50	25-20	2.5	2.68	24.42	11.02
	20-16	17.5	2.65	24.57	11.98
	16-12.5	20	2.69	24.34	12.83
	12.5-10	20	2.66	16.28	10.33
	10-4.75	40	2.68	15.64	10.58

Aggregate	Size Fraction in mm	% Weight Retained	Specific Gravity	IAPST	AN
	Weighted Average		2.67	19.29	12.09
RA75	25-20	2.5	2.64	25.71	12.29
	20-16	17.5	2.52	25.62	12.96
	16-12.5	20	2.65	24.89	13.25
	12.5-10	20	2.61	16.86	10.83
	10-4.75	40	2.58	15.79	10.71
	Weighted Average		2.59	19.79	13.30
RA100	25-20	2.5	2.62	26.02	12.46
	20-16	17.5	2.60	26.11	13.21
	16-12.5	20	2.64	25.15	13.52
	12.5-10	20	2.58	17.26	11.24
	10-4.75	40	2.55	16.77	11.69
	Weighted Average		2.58	20.41	13.99

3.5 Specific Gravity and Water absorption

The specific gravity of coarse aggregate was determined as per IS: 2386 [10] and procedures differ with the sizes of aggregates. The specific gravity of independent sizes and for different replacements is presented in Table 2. It was noted that the specific gravity of demolished concrete aggregates is lower than that of natural aggregate. The average specific gravity of aggregate usually varies from 2.6 to 2.8

3.6 Elongation and Flakiness indices

The flakiness index of aggregates is the percentage of weight of particles in it whose least dimension is less than 3/5 of their mean dimension (IS 2386 [10]). The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of total weight of sample taken. Elongation index is the percentage by weight of aggregate particles whose greatest dimension is greater than 1.8 times the mean dimension (IS 2386 [10]). Elongation index is the total weight of the material retained on various length gauges expressed as percentage weight of sample gauges. In the present study, these parameters were evaluated for natural and different of replacements of recycled aggregate in natural aggregate**.**

3.7 Bulk Density and Voids Ratio

Bulk density is the weight of material in a given volume. Percentage voids is the ratio of volume of voids to the total volume. The value of Bulk Density showed a decreasing trend with increasing replacement of recycled aggregate in natural aggregate**,** while % voids increased with increase in replacements. This is shown in Table 2. The lower value of bulk density of recycled aggregate may be due to the increase in voids and decrease in the specific gravity.

Table 2. Properties of natural & recycled aggregate concretes

Properties	**100% Natural Aggregate**	**25% Recycled Aggregate**	**50% Recycled Aggregate**	**75% Recycled Aggregate**	**100 %Recycled Aggregate**
Bulk Density	1.46	1.44	1.39	1.35	1.28
% of Voids	44.26	44.95	45.21	46.18	48.26
Void Ratio	0.79	0.82	0.825	0.85	0.93
Specific Gravity	2.78	2.72	2.68	2.61	2.55
Fines Modulus	7.1	7.12	7.135	7.142	7.15
Water absorption	1.00	2.10	3.52	4.85	5.68
Flakiness Index	3.56	3.82	4.06	4.31	4.6
Elongation Index	7.13	7.43	7.75	8.05	8.4
Agg.Impact Value (%)	32.20	33.15	33.68	34.15	34.48
Agg.Crushing Value (%)	22.77	23.00	24.21	27.08	28.16
IAPST	18.10	18.72	19.29	19.79	20.41
Angularity Number	10.31	11.35	12.09	13.30	13.99

3.8 Crushing Value

The aggregate crushing value gives a relative measure of the resistance of an aggregate to crushing under gradually applied compressive load (IS: 2386 [10]). The standard aggregate crushing test is made on aggregate passing a 12.5 mm IS sieve and retained on 10 mm IS sieve. If required, or if the standard size is not available, other sizes up to 25mm may be tested. The recycled concrete aggregate is relatively weaker than the fresh granite aggregate against applied compressive load. As per IS code [10], the crushing value should not be more than 45% for aggregate used for concrete other than wearing surfaces and 30% for concrete used for wearing surfaces. From the experiments conducted on natural and recycled aggregate replacements it was noted in Table 2. That crushing value is with in the IS codal provisions [10]. It was also noticed that with the increase in the percentage replacement of recycled aggregate for natural aggregate, there is an increase in the crushing value suggesting that the weightage fraction passing the standard 2.36 sieve is increasing for the same weight of surface dry sample taken.

3.9 Impact Value

The aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact (IS: 2386 [10]). It can also be showed from Table 2**.** That the impact value of recycled aggregate increases with replacement in natural aggregate. But all the values were well with in the codal limits of 45% for concrete.

It was concluded from the above experimental study on recycled aggregates that these can be used in structural concrete.

4. GLASS FIBER REINFORCED RECYCLED AGGREGATE CONCRETE

A detailed experimental investigation carried on Recycled Aggregate Concrete obtained from crushed Building Demolished Waste (BDW) has confirmed the utility of this RCA in Structural Concrete. But, Recycled Aggregate Concrete being an inferior Concrete particularly in tension and flexure there is a need to enhance these properties by fiber additions. Hence, an experimental program is designed to compare the strength properties of recycled aggregate concrete with out with and fiber addition. Cubes, cylinders and prisms of standard dimensions were cast and tested to determine the compressive strength, Split tensile strength flexural strength and modulus of elasticity of Glass Fiber Reinforced Recycled Aggregate Concrete (GFRRAC).

4.1 Materials

Ordinary Portland cement of 53 grade (compressive strength not less than 53 N/mm^2) was used in the study. The cement was selected as per IS-12269 [12]. Fine aggregate was standard river sand procured locally and was confirming to zone-II as per IS-2386 [10]. Crushed granite was used as coarse aggregate. The recycled aggregate used was obtained by crushing and processing concrete cubes, cylinders and the corresponding reinforced concrete beams. The aggregate was passed through standard sieves of 20mm and retained on 4.75mm sieve. For both M20 and M40 grades the ACI mix design procedure [13] is adopted and the proportions are 1: 2.28: 2.61: 0.5 and 1: 1.46: 1.89: 0.36. The Glass fiber is Cem-Fil Anti Crack and its Specific gravity is 2.6, length of the fiber is close to 12 mm, aspect ratio 857:1, and Specific surface area being 105m^2 /kg.

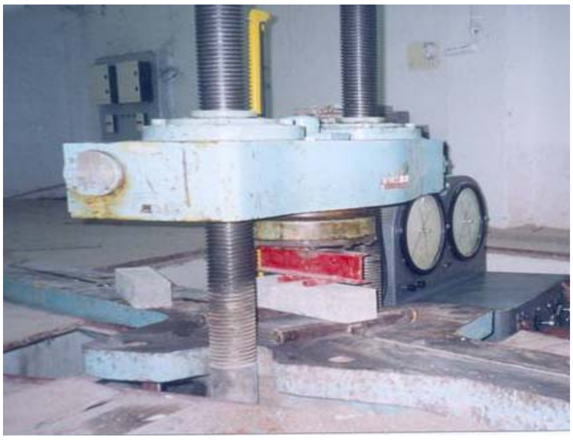
4.2 Casting of specimens

The scheme of casting the specimens was done in two stages. First, the percentage of recycled aggregate in concrete was replaced for natural aggregate and the second, the influence of replacements of Recycled Concrete Aggregate and Natural Aggregate in case of without and with Glass fiber on the behavior in compression, Split tension and Flexure is being investigated. For these studies, 150×150mm cubes for compressive strength, 150mm diameter and 300mm height cylinders for split tensile strength and 100×100×400mm prism specimens for studying the modulus of rupture were employed. The program consisted of casting and testing a total number of 36 cubes, 36 cylinders and 36 prisms cast in 6 batches. Of these 36cubes, 18 cubes correspond to each of M20 and M40 grades of concretes. Of these, 9 each correspond to no fiber (WF) and with Glass Fiber (GF) additions. Of these three each corresponds to 0%, 50%, 100% recycled aggregate replacements respectively for 28days strength. Additional 36 cylinders were cast for examining the stress-strain behavior of 0%, 50% and 100% RCA replacement in NA concrete specimens for two grades and with & without glass fiber. The mix was designed as per ACI method of mix design [13]. All the specimens were demoulded after 24 hrs and kept in water for curing for 28days.The specimens were capped using plaster of paris to ensure plane-testing surface.

4.3 Testing of Specimens

Tinius-Olsen testing machine (TOTM) of capacity 2000KN was used for testing the specimens under standard load rate control. While testing, precautions were taken to ensure axial loading. For flexural strength standard three point loading was adopted. The modulus of elasticity of concrete was determined using compressometer setup and tested under TOTM. The details of the specimens under test in compression, split, flexure and for modulus of elasticity are shown in Photographs 1, 2, 3 and 4, respectively.

Photograph 1. Test on Cube Specimen



Photograph 2. Flexure Test on Specimen

Photograph 3. Split tensile test on specimen

Photograph 4. Modulus of elasticity test

5. INTERPRETATION AND DISCUSSION OF TEST RESULTS

5.1 Compressive Strength of Glass Fiber Reinforced Recycled Aggregate Concrete (GFRRAC)

The mechanical properties of M20 and M40 grade concretes cast without and with RCA and without and with Glass Fiber (GF) additions shows in Tables 3 and 4. The dosage of GF in concrete was found based on experimental results. Two aspects can be determined here, one is the effect of different replacement of RCA in NA on no–fibrous (WF) concrete and the other one is in fibrous concrete (GF). One notable observation is that in both the grades of concrete the target compressive strength could be easily achieved. In control mixes that is without fiber and natural aggregate and with Glass Fiber (GF) and natural aggregate the compressive strength could be easily achieved. With replacement of RCA in NA the compressive strength has decreased but was always above the target strength. This gives a conclusion that recycled aggregate concretes are not inferior to normal concretes. Addition of fibers has definitively increased the compressive strength, though marginally. In case of M40 grade concrete, also the target strength could be achieved for 50 % replacement and was close to target mean strength for 100% replacements. The details of % increase in compressive strength of M20 and M40 grade concrete with GF addition for different replacement of RCA in NA is as shown in Figure 1. It can be noted that the percentage increase is marginal in the range of 2-3 %.

5.2 Influence of Glass Fiber on Split Tensile Strength of RAC

The tensile strength of concrete is relatively much lower than its compressive strength because it can be developed more quickly with crack propagation. The decrease is more so in case of recycled concrete aggregate. Hence, it is important to improve the tensile strength of such a recycled aggregate concrete. The split tensile strength of recycled aggregate concrete decreased with increase in the dosage of replacement of RCA in NA, while fibers improve the behaviour. This is as high as 22.58 % in normal concrete to 13.03 % in recycled aggregate concrete in M20 grade concrete, while this is 18.55 % and10.57 % in M40 grade concrete. The variation of split tensile strength with recycled aggregate replacement and with fiber additions for M20 and M40 grade concretes is plotted in Figure 2.

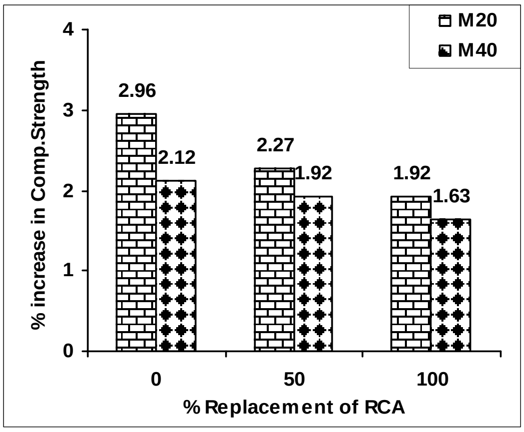


Figure 1. %Increase in Compression Strength Vs% replacement of RCA

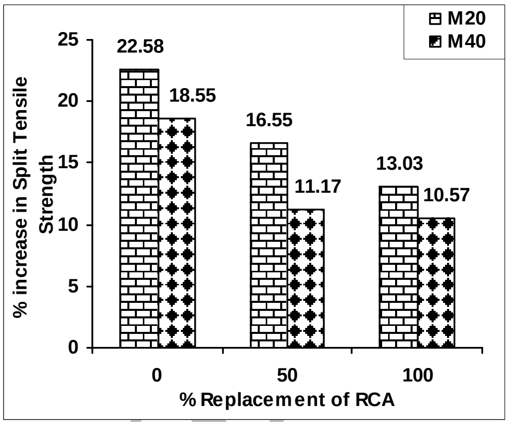


Figure 2. %Increase in Split Strength Vs% replacement of RCA

5.3 Effect of Glass Fiber addition on Flexural Strength of RAC

Tables 3 and 4 show the details of flexural strength for M20 and M40 grade concretes for different replacement of RCA in NA for no fiber (NF) and Glass Fiber (GF) additions. There is an increase in flexural strength of fibrous concretes at all percentage replacements of RCA in NA as compared to no fiber concretes. In case of no fibers and fibrous concretes the flexural strength is dropping with increase RCA in NA. It can be noted that there is a general decrease in the value with increasing in replacement of RCA in NA. This is true for both M20 and M40 grade concretes. The values are close to 0.7*sqrt (f_{ck}) as given by standard codes for the relationship between flexural strength sqrt (f_{ck}) for normal concrete. The value of flexural strength to sqrt(f_{ck}) is more for Glass Fiber concrete. It can be concluded from this study that the fibers improve the flexural strength as high as 17.43 % in fibrous normal concrete and 10.62 % for glass fibrous recycled concrete in M20 grade. There is also an increase noticed in M40 grade concrete as can be seen in Table 4 and Figure 3.

Table 3. 28 Days strength results of M20 grade concrete

% Repl. of RCA	Compressive Strength (Mpa)		Split Tensile Strength (MPa)		Flexural Strength (Mpa)		Split/sqrt (Comp)		Flexure/sqrt (fck)	
	WF	With GF	WF	With GF	WF	With GF	WF	With GF	WF	With GF
0	34.60	35.62	3.10	3.80	3.27	3.84	0.53	0.64	0.73	0.86
50	33.00	33.75	2.96	3.45	3.10	3.53	0.52	0.59	0.69	0.79
100	31.24	31.84	2.84	3.21	2.92	3.23	0.51	0.57	0.65	0.72

Table 4. 28 Days strength results of M40 grade concrete

%Repl. of RCA	Compressive Strength (Mpa)		Split Tensile Strength (MPa)		Flexural Strength (Mpa)		Split/sqrt (Comp)		flexure/sqrt (fck)	
	WF	With GF	WF	With GF	WF	With GF	WF	With GF	WF	With GF
0	54.96	56.12	4.15	4.92	4.32	4.94	0.56	0.66	0.68	0.78
50	51.98	52.98	3.94	4.38	4.09	4.50	0.55	0.60	0.65	0.71
100	47.87	48.65	3.69	4.08	3.78	4.08	0.53	0.58	0.60	0.65

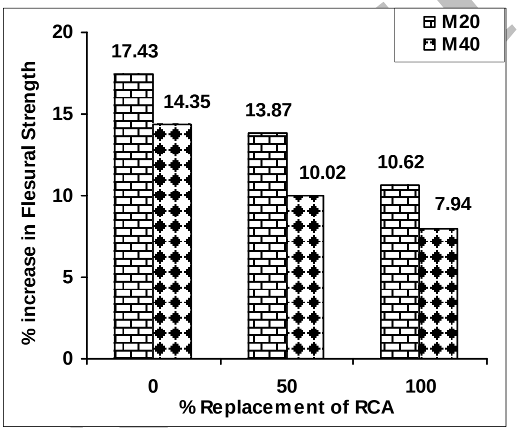


Figure 3. %Increase in flexural strength VS % replacement of RCA

5.4 Effect of Glass Fiber addition on Modulus of Elasticity of RAC

The brittle behavior of concrete in general and recycled aggregate concrete in particular is known. The fiber addition in such concretes may modify the stress-strain behaviour of concrete. Using a compressive meter setup and under compression the stress-strain curves are determined for the initial portions and Modulus of Elasticity (E) was evaluated, following the specifications as laid by IS Code 516-1999 [14]. Figures 4-6, and 7 shows the details of the stress – strain curves for natural and recycled aggregate concretes without and with fibers for different grades of concrete. Table 5 shows the details of the values of modulus of elasticity for M20 and M40 Grade concretes without and with Glass fiber respectively. A comparison shows that an increase in the % of recycled concrete aggregate in Natural Aggregate, there is a decrease in the value of Modulus of Elasticity. This trend is similar in the case of Glass fibrous concrete also. Similar observation could be noticed in M40 Grade concrete without and with glass fiber. A comparison of values shows an increase in the value of E with the addition of Glass fiber, in case of 50%, 100% replacement of RCA also. This trend is same for M40 grade concrete also. The E value is higher for M40 Grade as compared to M20 Grade concrete. It may be concluded that the addition of fiber in general increases the value of **E** of Recycled Concrete Aggregate (true for both M20 & M40grades of concrete). These values are close to 5000×√**fck** in case of no fiber concrete & higher in case of glass fibrous concretes.

Table 5. Modulus of elasticity values

% Repl. of RCA	**M20 Grade Concrete**		**M40 Grade Concrete**	
	WF	**With GF**	**WF**	**With GF**
0	26986	31401	33525	35894
50	26658	30894	31256	33421
100	23936	27815	26373	27812

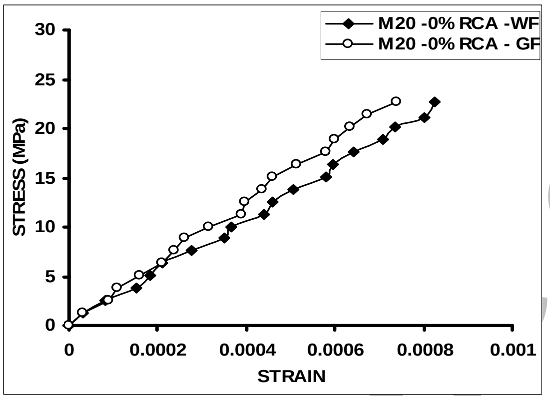


Figure 4. Stress-Strain curve for NA without and with GF (M20)

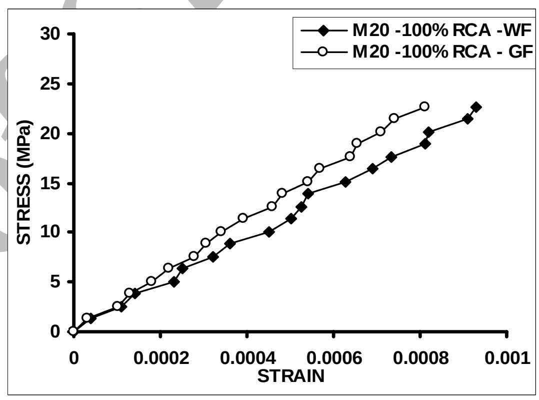


Figure 5. Stress-Strain curve for RA without and with GF (M20)

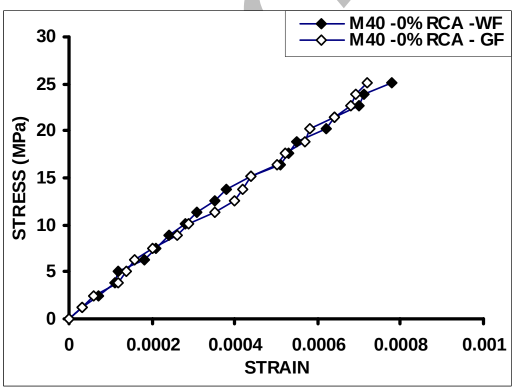


Figure 6. Stress-Strain curve for NA without and with GF (M40)

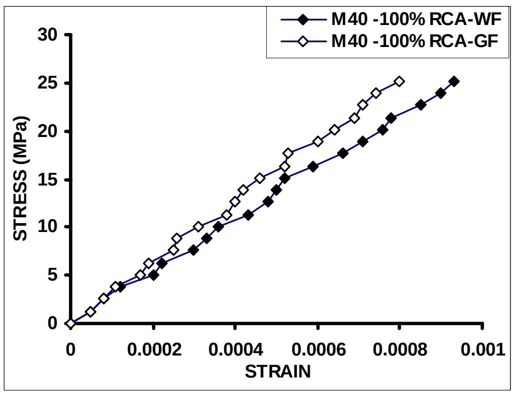


Figure 7. Stress-Strain curve for RA without and with GF (M40)

6. CONCLUSIONS

Based on experimental and analytical results of Glass Fiber Reinforced Recycled Aggregate Concrete (GFRAC) the following conclusions can be drawn.

1. From the structural properties of RCA it can be concluded that the coarse aggregate obtained from crushing BDW can be used for structural concrete works. This confirms the fact that RCA is in no way inferior to NA.
2. The addition of Glass Fiber in Recycled Aggregate Concrete has increased the Split Tensile Strength by 13.03 % and 10.57 % in M20 and M40 grade concretes.
3. There is an improved Flexural Strength with Glass Fiber additions in RAC and is 10.62 % and 7.94 % in M20 and M40 grade concretes. The fibrous specimens failed by splitting not by debonding.
4. A relationship between compressive strength and split tensile strength and flexural and characteristic compressive strength for different replacements of RCA in NA without and with glass fiber is suggested.
5. The Stress– Strain Curves for GFRRAC in the initial stages is drawn and hence the Modulus of Elasticity of Concrete is evaluated. There is an improvement in 'E' value with fibers addition in both normal and recycled aggregate concrete.
6. The increased strains at constant stress in fibrous concretes, physically noted while experimentation suggests an improved ductility and energy absorption capacity.

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