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SUITABILITY OF GLASS FIBERS IN HIGH STRENGTH RECYCLED AGGREGATE CONCRETE-AN EXPERIMENTAL INVESTIGATION

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ABSTRACT

The use of Recycled Concrete Aggregate (RCA) is gaining importance throughout the globe due to the depleting sources of natural aggregate and disposal problem of demolished waste. The advancement in the prestressed concrete technology and multistoried structures has given impetus for making concrete of high strength. Also, it is well established that the fibers make concrete ductile. The aim of this research work is to determine the suitability of glass fibers for use in structural recycled aggregate concrete of high strength. The fresh and hardened state properties of partially replaced recycled aggregate concrete, with varying percentages of glass fibers, are compared with the corresponding conventional aggregate concrete. The compressive, split tensile and flexural strengths of M50 grade concrete with 0% RCA and 50% RCA have increased as the fiber content increased. The maximum values of all these strengths were obtained at 0.03% of fiber content for both the concretes of 0% RCA and 50% RCA. Large deflections of beams before failure indicated improved ductility with the addition of fibers.

Keywords: High strength concrete; recycled aggregate; natural aggregate; glass fibers; workability; mechanical properties

1. INTRODUCTION

The experimental investigations on the use of Building Demolished Waste (BDW) reveal that the behaviour of structural concrete with recycled aggregate are comparable to that of the concrete with conventional natural aggregate. The present day sustainable development demands the use of waste materials like BDW, Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), etc. The use of such materials solves the disposal problem, apart from reducing the cost of construction materials.

Concrete is a versatile material with numerous applications, but its low tensile strength and brittle behavior are the main drawbacks. These deficiencies can be overcome by adding

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fibers. Fiber reinforced concrete has become popular because of its crack arresting mechanism, high energy absorption properties, ductile behaviour and post-cracking tensile strength. The properties of Fiber Reinforced Concrete depend upon the efficient transfer of stress between the matrix and the fibers which in turn largely depend on the type of fiber, fiber geometry, fiber content, orientation and distribution of fibers, and size and shape of aggregate. The glass fiber which is originally used in conjunction with cement was found to be effected by alkaline condition of cement. Therefore in the present investigation, Cem-Fill AR glass fiber has been used to overcome the problem of alkali-glass reaction. High strength concrete is generally concrete with a specified compressive strength of 41Mpa or more. The changes in material properties or in production techniques generally take place for strengths more than 41 MPa and extend to high strength concretes as per ACI 363-R92(1).

Experimental investigations on RCA concrete [2-7] indicate that there is no effect on strength of concrete compared to that of Conventional aggregate concrete. Recycled aggregate concrete had 7 to 9% lower relative density and 2 times higher water absorption than that of natural aggregate concrete while there is no effect on strength of concrete for RCA replacements upto 30% [2]. The commonly accepted ACI relationships for the prediction of the modulus of rupture and split tensile strength for normal concrete was found to be adequate for the prediction of properties for RCA concrete also but the relationship to determine the modulus of elasticity of normal concrete is not valid for recycled aggregate concrete [3]. Ajdukiewicz et al. [4] considered different grades of concrete ranging from M40 to M70 in their study and found that there is a marginal difference in the tensile strength of recycled aggregate concrete and natural aggregate concrete. They also found that the RCA concrete possesses better durability characteristics compared to conventional concrete though the tensile strength is slightly lesser for the former. A marginal decrease was observed in the compressive strength of RCA concrete [5]. Flexural studies on RCA concrete beams established the use of RCA concrete as structural concrete [6]. Cracks were found to appear in low reinforced RCA concrete beams first compared to natural aggregate concrete beams [7]. A significant increase in various strengths and ductility of concrete with glass fibers compared to conventional concrete without fibers was noticed and optimum fiber content was found to be strength dependent [8]. Swami et al [9] reported improvement in the mechanical properties of natural aggregate concrete at higher volume of glass fibers. An improvement in split tensile strength and flexural strength was reported with the addition of glass fibers in recycled aggregate concrete [10].

2. SIGNIFICANCE OF THE PRESENT WORK

It is known from the literature that proper introduction of fibers in conventional concrete improves both mechanical properties and durability. Therefore an attempt has been made, in the present study to assess the mechanical properties of high strength recycled aggregate concrete mixes containing glass fibers and to arrive at the optimum dosage of glass fibers. Three different fiber contents were used to study the effect of addition of fibers on the properties of high strength recycled aggregate concrete. The results of the present work are encouraging and substantiate the use of the recycled aggregates and glass fibers in the construction.

3. EXPERIMENTAL INVESTIGATIONS

3.1 Materials Used

The details of materials used in the present experimental investigation are given below:

Cement

Ordinary Portland cement of 43 grade having specific gravity of 3.1 was used. The properties of cement are shown in Table 1(a).

Table 1(a). Physical properties of cement

Sample No.	Property	Test method IS 4031 [17]	Test result
1.	Normal consistency	Vicat apparatus	30%
2.	Specific gravity	Specific gravity bottle	3.10
3.	Initial setting time	Vicat apparatus	55 min
4.	Final setting time	Vicat apparatus	175 min
5.	Fineness	Sieve test on sieve no.9	7%

Fine and Coarse Aggregate

River sand locally available with specific gravity of 2.55 was used. Locally available machine crushed well graded angular granite of normal size 20mm was used. Recycled aggregate from demolished waste was crushed and classified before use. The specific gravities of natural and recycled coarse aggregates used in this investigation were 2.8 and 2.67 respectively. The properties of natural coarse aggregate and natural coarse aggregate with 50% RCA are given in Table 1(b).

Table 1(b). Properties of coarse aggregates

Type of mix	Fineness modulus	Specific gravity	% of water absorption	Bulk density (kg/m^3)	% voids
0% RCA	6.84	2.8	0.5	1567	44.03
50% RCA	6.83	2.67	1.94	1434	46.2

Glass fibers

The properties of Cem-Fill anti crack HD glass fibers are given in Table 1c.

Table 1c. Properties of Cem-Fill anti crack HD glass fibers

Fiber	Density in kg/m^3	Elastic modulus Gpa	Tensile strength in Mpa	Diameter in icrons	Length in mm	Number of fibers (million/kg)
Anti crack HD glass fiber	2600	72	1700	14	12	212

Water
Locally available potable water is used.

3.2 Test Programme
The concrete mix of M50 grade was designed using Erntroy and Shaklock's method [11]. The mix proportion for M50 grade concrete was arrived as 1:1.08: 2.52 with a water/cement ratio of 0.36 and the quantities are shown in Table 2. There were a total of eight batches of concrete mixes, divided into two groups; four batches with 0% RCA in the first group and remaining four with 50% RCA in the second group. In each batch, concrete cubes, cylinders, and prisms were cast to determine the compressive strength, split tensile strength, and flexural strength respectively. In each of these batches, four different percentages of fiber content from 0% to 0.03% with an increment of 0.01% were used.

Table 2. Various quantities of concrete mix M50 per cubic metre

Mix identification	Cement (kgs)	Fine aggregates (kgs)	Conventional coarse aggregate (kgs)	Recycled coarse aggregate (kgs)	Water (lts)	Glass fibers (gms)
Batch I	500	540	1260	0	180	0
Batch II	500	540	1260	0	180	38.8
Batch III	500	540	1260	0	180	58.2
Batch IV	500	540	1260	0	180	77
Batch V	500	540	630	630	206	0
Batch VI	500	540	630	630	206	38.8
Batch VII	500	540	630	630	206	58.2
Batch VIII	500	540	630	630	206	77

4. RESULTS AND DISCUSSIONS

4.1 Workability
Slump and compaction factor values for different mixes were plotted in Figures 1 and 2. The slump and compaction values indicate decreasing trend of workability when the percentage

of glass fiber is increased. Also, the workability of concrete decreased as 50% of the natural coarse aggregate is replaced with RCA. The low workability of recycled aggregate concrete is due to the high water absorption capacity of recycled aggregate.

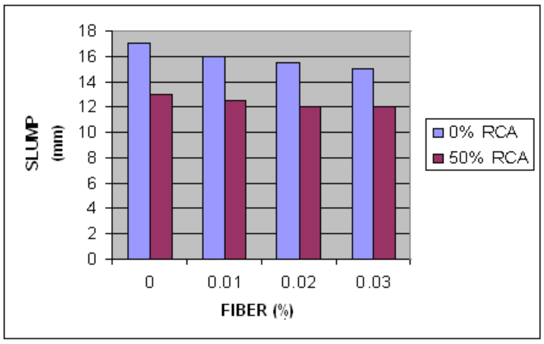

Figure 1. Relationship between slump and percentage of fiber for 0% RCA 50% RCA

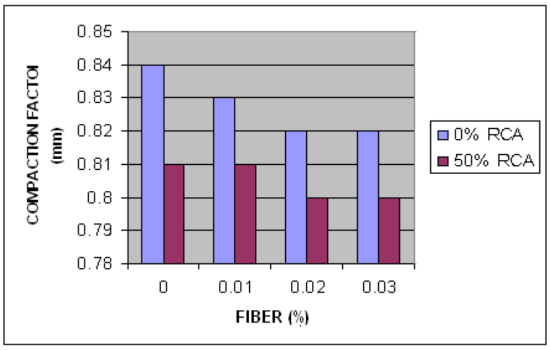

Figure 2. Relationship between compaction factor and percentage of fiber for 0% RCA & 50% RCA

4.2 Compressive Strength

The increase in compressive strength of M50 grade concrete with 0% RCA with the addition of 0.01%, 0.02% and 0.03% glass fibers was observed to be 2.22%, 3.46% and 6.08% respectively (Table 3) when compared with plain concrete. For M50 grade concrete with 50% RCA, the increase in strength with the addition of glass fibers was observed to be 4.55%, 6.66% and 8.73% respectively (Table 4) when compared to plain concrete. The maximum increase in the compressive strength at 0.03% of glass fibers was 6.08% and 8.73% for the grades of concrete M50 with 0% RCA & 50% RCA respectively. The strength variation in both the batches of concrete is marginal.

Table 3. Strength results of M50 Grade with 0% RCA

S. No	% of glass fiber	Compressive strength (MPa)		Split tensile strength (MPa)		Flexural strength (MPa)	
		7 days	28 days	7 days	28 days	7 days	28 days
1	0.00	41.24	41.24	3.66	4.82	5.44	6.08
2	0.01	44.08	44.08	3.73	5.11	5.51	6.16
3	0.02	48.53	48.53	3.87	5.31	5.98	6.68
4	0.03	49.02	49.02	4.02	5.62	6.08	6.80

4.3 Splitting Tensile Strength and Flexural Strength

There is a considerable increase in the split tensile strength and flexural strength of concrete as the fiber content increased from 0% to 0.03%. For M50grade concrete with 0% RCA and 50% RCA, the maximum increase in the splitting tensile strength at 0.03% of glass fibers was 16.75% and 12.32% respectively (Tables 3 and 4) when compared to plain concrete.

The increase in flexural strength of M50 grade concrete with 0% RCA with the addition of 0.01%, 0.02%and 0.03% glass fiber was observed to be 1.31%, 9.86% and 11.84% respectively (Table 3) when compared to plain concrete; the percentage increases for different fiber contents being 9.59%, 13.03% and 16.43% for concrete with 50% RCA. The maximum increase in the flexural strength at 0.03% of glass fiber was 11.84% and 16.43% respectively for the grades of concrete M50 with 0% RCA & 50% RCA.

Table 4. Strength results of M50 Grade with 50% RCA

S. No	% of glass fiber	Compressive strength (MPa)		Split tensile strength (MPa)		Flexural strength (MPa)	
		7 days	28 days	7 days	28 days	7 days	28 days
1	0.00	37.27	53.13	3.32	4.30	5.12	5.84
2	0.01	40.08	55.55	3.45	4.47	5.61	6.40
3	0.02	42.50	56.67	3.55	4.60	5.79	6.60
4	0.03	43.34	57.77	3.67	4.83	5.96	6.80

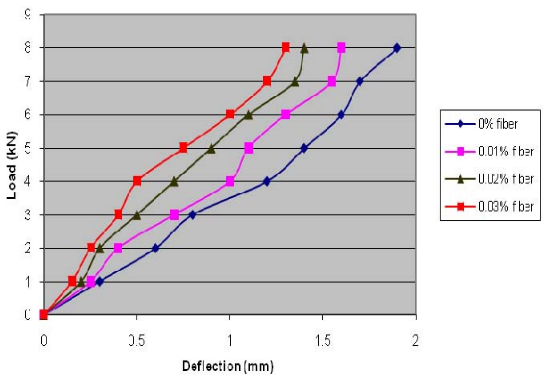

Figure 3. Variation of deflection with load for 0% RCA

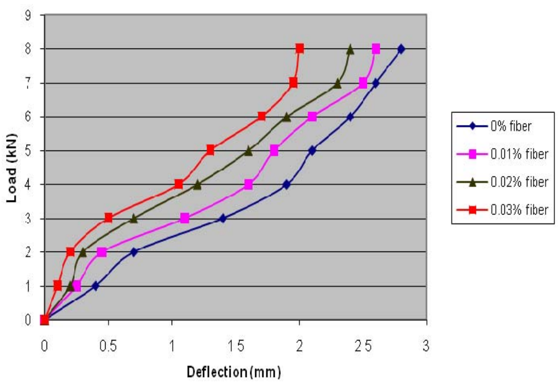

Figure 4. Variation of deflection with load for 50% RCA

4.4 Cracking characteristics

It was observed that the failure of concrete cubes, cylinders and prisms was gradual for both the groups of M50 mix with 0% RCA and with 50% RCA when fibers were used in the concrete. In case of plain concrete specimens, the failures were sudden and brittle. Also, the specimens with plain concrete broke into pieces at failure. The presence of glass fibers in the mix contributed towards arresting sudden crack formation and brittle failure. The failure of the specimens with fibers was gradual with large number of cracks (Figures 7, 8, 9) unlike conventional concrete specimens which failed by a single crack, Figure 10.

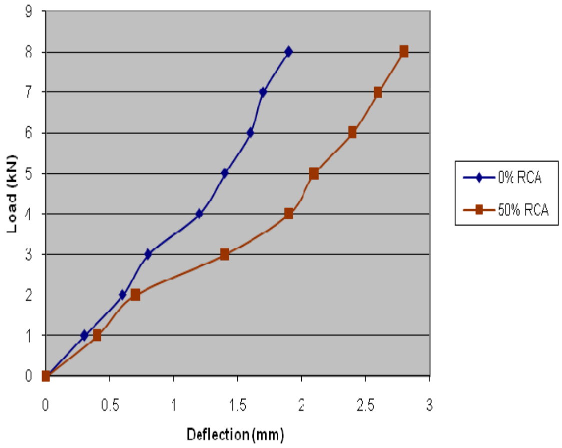

Figure 5. Variation of deflection with load for 0% RCA and 50% RCA with 0% fiber

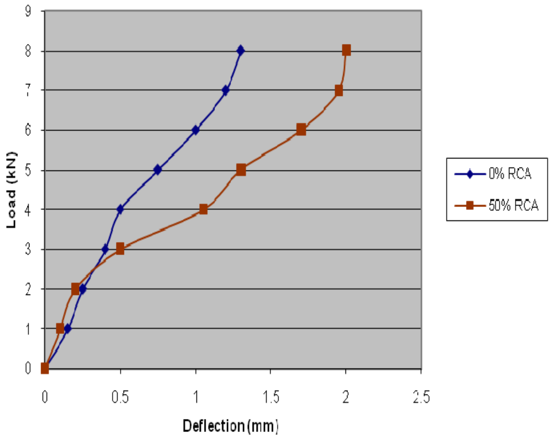

Figure 6 Variation of deflection with load for 0% RCA and 50 % RCA with 0.03% fiber

Figure 7. Failure pattern of fiber reinforced concrete cylinder

Figure 8. Failure pattern of fiber reinforced concrete cube

4.5 Ductility Characteristics

Prism specimens of M50 mix with various percentages of glass fibers with 0% RCA and 50% RCA were tested for flexural strength under two point loading as per Indian Standard Specifications. The flexural specimens have undergone large deflections showing high ductility characteristics. At the failure load, a diagonal crack appeared in between the loading points and the specimens did not fail suddenly. The failures were not brittle and a curvilinear deflected shape of the prisms was clearly seen.

It was also observed that with the percentage increase in glass fiber content from 0%-0.03%, there was a decrease in deflections for the same load. The load-deflection curves (Figures 3,4) indicate the improved flexural stiffness of the fiber reinforced concrete beams.

Figure 9. Failure pattern of fiber reinforced concrete prism

Figure 10. Failure pattern of plain concrete cylinder

CONCLUSIONS

Based on the limited experimental investigations carried out on high strength glass fiber reinforced concrete (HSGFRC) with conventional coarse aggregate and with partial replacement of conventional coarse aggregate by recycled coarse aggregate, the following conclusions are drawn:

1. With an increase in glass fibers content from 0.00% to 0.03% by volume of concrete, the ompressive strength, splitting tensile strength and flexural strength were enhanced.
2. The maximum values of strengths at the age of 28 days for M50 grade concrete were obtained for fiber content of 0.03% for both the concretes containing 0%RCA and 50% RCA.
3. The maximum percentage increase in compressive, tensile and flexural strengths of concrete with 0% RCA were 6.08, 16.67 and 11.84 respectively while the maximum percentage increase in these strengths for concrete with 50% RCA were 8.73, 12.32 and 16.43 respectively.
4. The large deflections at collapse of glass fiber reinforced concrete beams compared to plain concrete beams, physically noted while experimentation, indicate an improved ductility and energy absorption capacity of glass fiber reinforced RCA concrete.
5. The strengths of RCA concrete at all fiber contents are comparable to those of concrete with conventional aggregate. This clearly supports the use of glass fibers in high strength RCA concrete.

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