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Studies on Flexural Behavior of Natural and Recycled Aggregate Concrete Beams Using Glass Fibre

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Abstract – The present investigation outlines the use of glass fibre with structural concrete. Glass fibre of length 12mm, diameter 14 micron, having an aspect ratio of 857 was employed in percentages and properties of this Glass Fibre Reinforced Concrete like compressive strength and flexural behaviour were studied.

In the present work, an attempt is made to investigate the influence of the glass fibre on the natural and recycled aggregate concrete. Specimens were cast in the form of Cubes and Beams for testing. 30Nos of standard cubes of size 150x150x150mm and 10 beams of size 1500x150x230mm were cast and curing were done for 28days.The flexural behaviour of beams is studied in the present work with glass fibre for recycled aggregate concrete. There was total of five batches of concrete mixes for the grade M30 for natural and recycled Aggregate. The glass fibres were added in proportion by 0.50%, 1%, 1.5% and 2% by weight of cement. The effect of glass fibres on concrete improve the flexural strength as well as the compressive strength of concrete, the most contributions glass fibres behaves as reinforcement of steel in the concrete.

The first batch consists of six cubes and two beams with natural aggregate, the second batch consists of six cubes and two beams with recycled aggregate and 0.5% glass fibre by weight of cement, the third batch consists of six cubes and two beams with recycled aggregate and 1% of glass fibre by weight of cement, the fourth batch consists of six cubes and two beams with recycled aggregate and 1.5% of glass fibre, the fifth batch consists of six cubes and two beams with recycled aggregate and 2% of glass fibre. The workability of the concrete considerably reduced as the amount of fibre increased. For strength characteristics, the results showed that a compressive strength, flexural strengths gradually increases as the percentage of glass fibres used in the specimen increase. The load carrying capacity of specimens with 100 %(RCA) with 2% fibre content is increased by 11% compared to that of 100% (RCA) with 0.5% fibre content. Compared to beam A (NCA) 0%fibre, the moment of beam E (RCA) at 2%Fibre is increased by 56%.

Keywords: Recycled Coarse Aggregate, Natural Aggregates, Glass Fibre, and Compressive strength, Load-Deflection, Moment-Curvature.

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INTRODUCTION

1.1 General

In recent years certain countries have considered the reutilization of construction and demolition waste as a new construction material as being one of the main objectives with respect to sustainable construction activities. This thesis focuses on recycling of concrete waste as an aggregate in structural concrete. From the mid 70's many researchers have dedicated their work to describe the properties of these kinds of aggregates, the minimum requirements for their utilization in concrete and the properties of concretes made with recycled aggregates.

The concepts of recycling are waste material and using it again in some form or the other as gathered momentum. As recycling not only solves the waste disposable problem, but are also reduces the cost and conserves the non-renewable natural resources an urgent need is being increasingly felt to evolve a suitable and variable technology for recycling. One such area where this technology has made considerable headway is in the recycling of demolished concrete. The quantities of such concrete discarded every year have reached staggering figures of about 60 million tonnes in the United States of America; 50 million tonnes is in the European Economic Community's and 10 to 12 million tonnes in Japan. It is estimated that these figures will increase nearly three –fold by the year 2000 A.D., thus necessitating urgent steps to recycle this waste materials.

1.2 Recycled Concrete Aggregates

Aggregates produced by the crushing of original concrete; such aggregates can be fine or coarse recycled aggregate. Fine recycled aggregate is sometimes referred to as crushed concrete fines. When no misunderstanding is possible, recycled concrete aggregate may be referred to as recycled aggregates. This is the case in the present state of the art report. it is suggested to use the notation RS for recycled fine aggregate and RC for recycled coarse aggregate . R stands for 'recycled' and s stands for 'sand' while c stand for 'coarse aggregate'.

1.3 Sources of Recycled Aggregate

According to recycling of Portland cement concrete, recycled aggregate are mainly produced from the crushing of Portland concrete payment and structures building. It stated that the isolated areas of 1 inch of asphalt concrete could be used to produce the recycled aggregate. The main reason that choosing the structural building as this source for recycled aggregate is because there is a huge amount of crushed demolition Portland cement concrete can be produced.

1.4 Applications of Recycled Aggregate

Traditionally, the application of recycled aggregate is used as landfill. Nowadays, the applications of recycled aggregate in construction areas are wide. The applications are different from country to country.

- Embankment Fill Materials
- Backfill Materials
- Granular Base Coarse Materials
- Concrete Kerb and Gutter Mix
- Paving Blocks

1.5 Introduction to Glass Fibres

The development of alkali-resistant glass fibre (by trade name 'CEM-FIL') by the U.K. Building Research Establishment and Pilkington glass. U.K leads to wide ranging applications of fibrous concrete in several areas of building construction. Glass fibre is a recent introduction in producing fibrous concrete. It has very high tensile strength of order 1020-4080 N/mm2. Early conventional borosilicate glass caused reduction in strength due to alkali reactivity with the cement paste. Alkali resistant glass fibres (AR glass type) were then produced resulting in long term durability, but other strength loss trends were observed. Better durability result was observed when AR glass is used with developed low alkaline cement.

1.5.1 Advantages of Glass Fibres

1. Enhances mechanical properties of concrete.
2. Fibers are light weight that minimizes the load added to structures.
3. Improved chemical resistance.
4. Improved shrinkage properties.
5. Low permeability.

1.5.2 Applications of Glass Fibres

1. Noise barriers.
2. Tunnel lining and table ducts.
3. Embankment drainage channels.
4. Road side drainage channel.
5. Bridge deck formwork.
6. Façade cladding.

1.6 Introduction to Glass Fibre Reinforced Concrete (GFRC)

Glass fibre is a material consisting of numerous extremely fine fibres of glass. Glass fibre is commonly used as an insulating material Normal or E-glass fibre is affected in the presence of alkalinity whereas alkali-resistant glass fibre by trade name "CEM-FIL" has been developed and used.. Cem-FIL® AR glass fibres are unique as a concrete reinforcement. Cem-FIL® fibres have the same specific gravity as the aggregates, so assured fibre dispersion is easier to achieve than with other fibres. Cem-FIL® fibre contributes efficiently to the tensile strength before the concrete is able to crack thanks its high Elastic Modulus, its affinity and its efficient bonding with the concrete. In this experimental study the contribution of CEM-FIL is analyze for compressive strength, spilt tensile strength and flexural strength of mortar.

1.7 Scope of Present Work

1. M30 grade of concrete mix is used in present experimental work.

2. 30cubes (150mmx150mmx150mm)and10 beams(1500mmx150mmx230mm) were cast by using recycled and natural aggregate with partial replacement of cement by fibre with different percentages (0.5%,1%, 1.5%, 2%) by weight of cement.

3. Five batches of concrete were cast. In which first batch was with natural aggregate without glass fibre and remaining four batches are with recycled aggregate along with different percentage of glass fibre.

4. Investigation and Laboratory testing on concrete with natural and recycled aggregate.

5. Analysis the results and recommendation for further research work.

2. EXPERIMENTAL PROGRAMME

2.1 General

The experimental programme was carried out to evaluate the mechanical properties i.e., compressive strength, flexural behavior of concrete with 100% NCA with no fibre and 100%RCA of M30 grade using glass fibre. The programme involved casting and testing of total 40 specimens. The specimens of standard cubes of 150mm X 150mm X 150mm, and standard beams of 1500mm X 150mm X 230mm, with and without glass fibres. Universal testing machine was used to test all the specimens. In first batch the specimens were cast with 0%RCA and 0% fibre content and remaining four batch were cast by using 100% recycled coarse aggregate with increase in percent of fibre varying with 0.5% ,1%,1.5%,and 2% by the weight of cement.

2.2 Study of Materials

2.2.1 Cement

In the experimental investigations ordinary Portland cement of 53 grade was used .The cement procured was tested for physical properties in accordance with IS: 4031-1988.

S. NO.	Property	Test Result
1.	Normal Consistency	32%
2.	Specific Gravity	3.15
3.	Initial Setting Time	40min
4.	Final Setting Time	178 min
5.	Fineness	7%Residue

Table No 2.1 Property of Cement

2.2.2 Fine Aggregates

In the present investigations, fine aggregate obtained from local market was used. The physical properties of fine aggregate such as specific gravity, fineness modulus were tested in accordance with IS: 2386.

S. NO.	PROPERTY	VALUE
1.	Specific Gravity	2.68
2.	**Bulk Density** Loose Compacted	 1644 kg/m^3 1614 kg/m^3
3.	Water Absorption	0.5%
4.	Fineness Modulus	3.58
5.	Porisity	0.293
6.	Void Ratio	0.415
7.	Moisture Content	1%

Table No 2.2 Property of Fine Aggregate

2.2.3 Coarse Aggregates

Aggregates occupy bulk of the volume of concrete. Their size grading shape and surface texture have significance influence on the properties of concrete. In the present study recycled aggregate from demolished waste as crushed and classified before use for qualifying the utility of recycled aggregate in concrete the important parameters like bulk density, specific gravity, water absorption were determined. These properties were determined for different percentages of replacement of RA with NA. The properties of aggregate found out are as follows:

Property	Natural Aggregate Value	Recycled Aggregate Value
Specific Gravity	2.74	2.67
Fineness Modulus	7.07	7.04

Bulk Density Loose Compacted	1498 kg/m^3 1710 kg/m^3	1498 kg/m^3 1711 kg/m^3
Aggregate Impact Value	1710 kg/m^3	16.8%
Water Absorption	0.25%	0.826%
Crushing Strength	22	21

Table No 2.3 Property of NA & RA

2.2.4 Recycled Coarse Aggregate

In the present study, Recycled coarse aggregates of maximum size 20mm, 10mm coarse aggregate were used and its specific gravity, fineness modulus and water absorption were found to be 2.67, 7.456 and 0.826% respectively. The test results for different properties on recycled coarse aggregate are presented in Table above

Recycled aggregates are aggregates derived from the processing of materials previously used in a product and/or in construction. Examples include recycled concrete from construction and demolition waste material (C&D), reclaimed aggregate from tested cubes and cylinders from concrete lab.

2.2.5 Glass Fibres

In general fibres are the principal load-carrying members, while the surrounding matrix keeps them in the desired locations and orientation, acting as a load transfer medium between them, and protects them from environmental damage. In fact, the fibres provide reinforcement for the matrix and other useful functions in fibre-reinforced composite materials. This glass fibre is typically used at a low level of addition to prevent cracking & improve the performance of ready mix concrete, floor screeds, renders or other special mortar mixes.

2.2.5.1 Properties of Glass Fibre

Fibre	Glass Fibre
Density in g/cm^3	2.7
Elastic Modulus GPa	72
Tensile strength in MPa	1700
Density in micron	14
Length in mm	12
No. of fibers in million /kg	212
Electrical Conductivity	Very low
Chemical resistance	Very high
Aspect ratio	857

Table No 2.4 Property of Glass powder

2.3 Mixing of Concrete

The performance of concrete is influenced by mixing and a proper and good practice of mixing can lead to better performance and quality of the concrete. M30 grade of concrete was designed using IS: 10262-2009.

Once the mix design is done, the mixing of the concrete can be carried out. In the present study the mixing was done manually.

2.6 Casting of Specimens

The program consists of casting of 30 standard cubes of size 150mm x 150mm x150mmand 10 beams of size 1500mm x 150mm x 230mm. This has been done in five batches while varying the following parameters:

Mix	Batch		No. Of Cubes	No. Of Beams
M30	1	N.C.A + 0% Fibre	6	2
M30	2	R.C.A + 0.5% Fibre	6	2
M30	3	R.C.A + 1% Fibre	6	2
M30	4	R.C.A 1.5% Fibre	6	2
M30	5	R.C.A 2% Fibre	6	2

Table No 2.5 Mixing of batches

Glass Fibre was added with a volume fraction of 0%, 0.5%, 1.0%, 1.5%, and 2.0% by weight of the cement with grade of concrete (M30). The standard moulds were fitted such that there are no gaps between the plates of the moulds. If there are small gaps they were filled with plaster of Paris. The moulds were then oiled and kept ready for casting. The entire casting was carried out in five batches, each batch containing six cubes, two beams. The total number of specimens casted is 40. The concrete is checked for its slump values after mixing and before casting, the wet mortar is directly poured into the cube moulds, beams. At the end of casting the top surface was made plane using trowel and a hacksaw blade to ensure a top uniform surface.

2.7 Curing of Specimens

After the completion of casting all the specimens were kept to maintain the ambient conditions viz. temperature of 27±2^0 C and 90% relative humidity for 24 hours. The specimens were removed from the mould and submerged in clean fresh water until just prior to testing. The temperature of water in which the specimens were submerged was maintained at 27±2^0 C. The specimens were cured for 28 days.

2.8 Experimental Methodology

In this the workability test and hardened concrete specimen have been discussed.

2.8.1 Workability Test

The two tests used to measure the workability of concrete are

Slump Test: In the case of slump test, firstly the internal surface of the mould is cleaned and moistened with damp cloth. The mould is then filled with concrete in three layers where each layer is around one third height of the specimen and each layer is tamped 25 times with tamping rod during filling. The surface concrete is rolled off then the mould is removed immediately by raising it slowly in vertical direction. Measure the height if the slump which is the difference between the height of the mould and the average height of the mould and the average height of the top surface of concrete.

Compaction factor test: This test is more accurate form of measuring workability of concrete. This test works on the principle of determining the degree of compaction achieved by a standard amount of done by allowing the concrete to fall through a standard height. The degree of compaction, called the compaction factor is measured by the density ratio of the density actually achieved in the test to density of same concrete fully compacted. In this test firstly the internal surface of the mould is cleaned and moistened with damp cloth. Concrete is placed in upper hopper until the hopper is filled and the additional concrete is scrapped off. After that the trap door is opened to let the concrete fall into the lower hopper. The trap door of the lower hopper is opened to let the concrete fall into the cylinder. The excess concrete in the cylinder is struck off and the mass of the concrete the partially compacted cylinder is taken. The cylinder is emptied and filled again this time in three layers and each layer tapped 25 times with the help of tamping rod. The top surface is levelled and the weight of fully compacted concrete is determined. Then the compaction factor is determined using the formula.

Compaction Factor = weight of partially compacted concrete /weight of fully compacted concrete

2.8.2 Testing on Hardened Concrete Specimens

2.8.2.1 Compression Test

Compressive strength of concrete can be defined as maximum resistance of concrete to axial loading. The specimens used for compression test were cubes of size 150x150x150mm size. Compressive strength for various percentages of glass fibres used in concrete was determined for 28 days. The test was conducted in the laboratory on the compression testing machine of 2000kN capacity and the reading at the time of failure of specimen was taken.

2.8.2.2 Flexure Test

It can be defined as the resistance of concrete specimen to bending. Normally the flexure strength of concrete is about 10 to 20% of the compressive strength.

2.8.2.3 Deflection

Readings on dial gauges were recorded for deflections at one third span mid span for each set of beams respectively. Readings were recorded to a minimum of 0.01 mm with dial gauges with least count of 0.01 mm.

One Third Span Section

Dial gauges was fixed at one – third and two – third points along the span and readings were recorded for every increment load of 2 kN initially up to 10 kN and 5 kN subsequently.

Mid Span Section

Dial gauges were fixed at the mid span and readings were recorded for deflections for every increment in load 2 kN initially up to 10 kN and 5 kN subsequently. The test results are presented in Tables.

2.8.2.4 Strains

Readings on dial gauges were recorded for strains at one third span and mid span for beams. Readings were observed to a minimum of 0.01 mm using a least count of 0.01 mm on dial gauges.

One Third Span Section

Dial gauges were fixed both at top and bottom along the span at one-third and two-third point. Readings were recorded for strains at one third span and two third span for each increment in load 2 kN initially up to 10 kN subsequently. The test results are presented in Tables.

Mid Span Section

Dial gauges were fixed both at top and bottom at mid span and readings on dial gauges were recorded for each increment in load 2 kN initially up to 10 kN and

5 kN subsequently. The test results are presented in Tables.

2.9.2.5 Moment – Curvature Relations

Moment – Curvature relations were developed with variations of load at one – third span and mid span. Both Compressive and tensile were measured at top and bottom for every increment in load 2 kN initially up to 10 kN and 5kN subsequently.

One Third Span Section

Curvatures at top and bottom fibres of beam were calculate and mean curvatures at one third span section at the level of neutral axis were found.

Mid Span Section

Curvatures at top and bottom fibres of beam were calculated and mean curvatures at mid span section at the level of neutral axis were found.

2.9 Reinforcing Bars

In this only one size of high yield stress deformed steel bars of Fe 415 were used as the longitudinal and transverse reinforcement..

2.10 Geometry and Reinforced Configuration

All beams were 150mm wide by 230 mm deep in cross section, they were 1500mm in length and simply supported over a span of 1200mm. the beams were designed to fail in flexural mode. The clear cover to reinforcement was 25mm on all faces. The geometry and reinforcement details of beams are shown in figure, specimen details are given in Tables 2.6 and 2.7.

All beams were casted horizontally in steel moulds in two layers. The moulds were cleaned and oiled and the reinforcement was inserted into the moulds providing a nominal cover of 25mm at the top and bottom. Steel of Fe 415 grade using 16mm diameter bars in 2 numbers Were provided at bottom and 2 numbers 8mm at top designed as per balanced section. The nominal shear reinforcement with 8mm diameter bars, 2-legged stirrups were provided at 230 mm c/c in overall span for beams.

Each layer was compacted using a stick internal compaction and simultaneously vibrator was used for compaction with each beam a three number of cubes (150mm x 150mm x 150mm) were cast. The slump of every batch of fresh concrete was also measured in order to observe the consistency of the mixtures.

Cubes were then filled to the top and vibration started again, each mould being topped up as the vibration caused the elimination of any air voids. Upon completion of the concrete placement, cubes were moved from the table to an area in the labs for setting under ambient conditions

Diameter (mm)	**Properties of Reinforced Steel**		**Percentage Elongation, mm**
	Proof Stress N/mm^2	**Ultimate Stress,N /mm^2**	
8	430	455	28
12	440	458	24
16	442	459	24

Table No 2.6 Properties of Reinforced Steel

Beam Designation	**No. of Beams**	**Reinforcing Bars**	**Spacing**
A(NAC)	2	2-8mm+2 -16mm	2L-8mm stirrups @ 230 mm c/c
B(RAC)	2	2-8mm+2 -16mm	2L-8mm stirrups @ 230 mm c/c
C(RAC)	2	2-8mm+2 -16mm	2L-8mm stirrups @ 230 mm c/c
D(RAC)	2	2-8mm+2 -16mm	2L-8mm stirrups @ 230 mm c/c
E(RAC)	2	2-8mm+2 -16mm	2L-8mm stirrups @ 230 mm c/c

Table No 2.7 Reinforcement Details of Beam Specimens

3. RESULTS AND DISCUSSIONS

3.1 General

Series of tests were carried out on the concrete specimens to obtain the strength characteristics for different percentages of fibre concrete beams of recycled and natural aggregate. This chapter discusses on the results that obtained from the testing. The results such as workability, Compressive test; Deflection pattern of beams and Crack pattern compared to that of the conventional beams are discussed and tabulate.

3.2 DISCUSSIONS ON TEST RESULTS

3.2.1 Slump Test

The test results of concrete grade M30 with N.A.C (0%fibre) and R.A.C with volume of fibre viz, 0.5%, 1%, 1.5%, 2% by weight of cement are tabulated in the table below. For all the batches the workability observed was very low. This low workability is because of high water absorption capacity of recycled aggregate. From the results obtained, it is observed that there is marginal change in the workability with R.A.C and with the introduction of fibres. However, there is a decrease in the workability as fibres are introduced. At 2% fibre the mix was hard; at higher percentages more than 2% fibres may require super plasticizers to maintain workability.

3.2.2 Compaction Factor Test

The compaction factor test values of concrete grade M30 with N.A.C (0%fibre) and R.A.C with volume of fibre viz, 0.5%, 1%, 1.5%, 2% by weight of cement are tabulated in the Table 3.12,respectively. The compaction factor value gradually decreased with the increase in percentages of glass fibres.

Mix	Fibre (%)	Slump (mm)	Compaction Factor
M30(NAC)	0	60	0.9
M30(RAC)	0.5	50	0.85
M30(RAC)	1	45	0.83
M30(RAC)	1.5	43	0.82
M30(RAC)	2	40	0.8

3.2.3 Compressive Strength

Compressive strength of the concrete is the key property of concrete .Compressive strength of concrete is taken as a basis for evaluating various other properties of the concrete. Thus cube compressive strength of concrete mixes was determined at 28days age is carried out to verify target strength. It is observed that with increase in fibre percentage, the compressive strength also increases with age.

Cube specimens were tested for compression and the ultimate compression strength was determined from failure load measured using the compression testing machine (Plate 11). The average values of six specimens for each category at the age of 28 days are tabulated in the Table, the compressive strength of glass fibre concrete is found to be maximum at 2% of fibre. With this percentage there is an increase of 11% of strength as compared to 0.5 % of fibre for M30 grade mix for 100% RCA at 28 days. The compressive strength of 100% RCA at 2% fibre content decreased by 10% as compared to natural aggregate concrete with 0% fibre.

Mix	Fibre (%)	Compressive Strength (N/mm^2)
M30(NAC)	0	50
M30(RAC)	0.5	40
M30(RAC)	1	41
M30(RAC)	1.5	43
M30(RAC)	2	45

3.2.4 Flexural Behaviour of Reinforced Concrete Beams

The experimental programme on reinforced concrete beams shows the behaviour, the crack patterns, the failure modes, and the load-deflection characteristics are described. The effects of different parameters on the strength of beams are also presented. It is found that with increase in fibre percentage, the flexural strength also increases with age.

Beam specimens were tested for flexural behaviour. The specimens are tested under two point loading (Plate 20) the average values of two specimens for each category at the age of 28 days

3.2.5 Load-Deflection

The experimental programme on reinforced concrete beams shows the load-deflection variation. In this method the beam of size 1500x150x230 mm size were firstly placed on the supports. Then two point loading was applied and the corresponding deflections were noted using dial gauge attached at the centre of the specimen. The reading at the time of failure of the specimen was noted. In which with addition of fibres the load increases and deflection value decreases. It was observed that the failure took place gradually with formation of cracks with addition of glass fibres in mix. The specimens with 0% fibre for M30(NAC) the deflection is more compared to specimens with (0.5%,1%,1.5%,2%)glass fibre of M30(RAC). It was observed that at 2%fibre of M30(RAC) the deflection decreased by 67% compared to M30(NAC) with 0% fibre.

3.2.6 Moment Curvature

In this experimental programme the beams specimens were tested by two point loading method and the results were tabulated. It was observed that with the increase in glass fibre percentages the moment and curvature values increases gradually. Compared to moment of beam A 0%fibre (NAC) it showed increased in moment by 56% of beam E 2%Fibre(RAC).The moment and curvature gradually increase with increase in fibre percentages from 0.5% to 2% for M30 mix (RAC) concrete. It was observed that curvature of beam E 100% (RAC) with 2% fibre content was increased by 9.7% compared to that of natural aggregate concrete with no fibre content.

3.2.7 General Behaviour of Beams

The specimens were tested under monotonically increasing load until failure. As the load increased, beam started to deflect and flexural cracks developed along the span of the beam. Eventually, all beams failed in a typical flexure mode an analysed load deflection curve at mid span of beam. The progressive increases of deflection curve indicate distinct events that were taking place during the test. These events are identified as first cracking, yield of the tensile reinforcement, Crushing of the concrete at the compression face associated with spalling of concrete cover, a slight drop in the load following the ultimate load and disintegration of the compression zone concrete as a consequence of buckling of the longitudinal steel in the compression zone, these features are typical of flexure behaviour of reinforced concrete beams.

3.2.8 Crack Patterns and Failure Mode

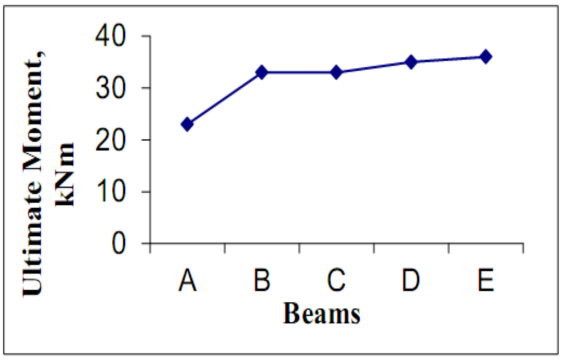
As expected, flexure crack initiated in the pure bending zone. As the load increased, existing cracks propagated and new cracks developed along the span. In the case of beams with large tensile reinforcement ratio some of the flexural cracks in the shear span turned into inclined cracks due to the effect of shear force. The width and the spacing of cracks varied along the span. In all the crack patterns observed for reinforced glass fibre concrete beams were similar to those reported in the literature for reinforced Portland cement concrete beams.

The cracks at the mid-span open widely near failure near peak load, the beams deflected significantly, thus indicating that the tensile steel must have yielded at failure. The final failure of the beams occurred when the concrete is in the compression zone, crushed, accompanied by buckling of the compressive steel bars. The failure mode was typical of that of an under-reinforced concrete beam. The crack patterns and failure mode of test beams are shown in plates.

In this experimental programme concrete cubes and beams were being tested for compressive strengths, load deflection, respectively, it was observed that the failures took place gradually with the formation of cracks for specimens with fibre content. But in case of plain concrete with no fibre content specimens, the failures were sudden and brittle. The cracks were observed diagonally at the point of loading in all the cases. In case of plain concrete with no fibre the first crack was found at 90 KN, whereas for 2% fibre content the concrete (100%RAC), the first crack was observed at 120 KN. The load carrying capacity was increased by 25%.

3.2.9 Flexural Capacity

The ultimate moment and the corresponding mid-span deflection of test beams are given in Tables show the effect of tensile reinforcement on the flexural capacity of each series of beams. These test trends show that, as expected, the flexural capacity of beams increased significantly with the recycled aggregate ratio because all beams are under reinforced, the observed increased flexural strength is approximately proportional to the increase in the tensile reinforcement ratio.



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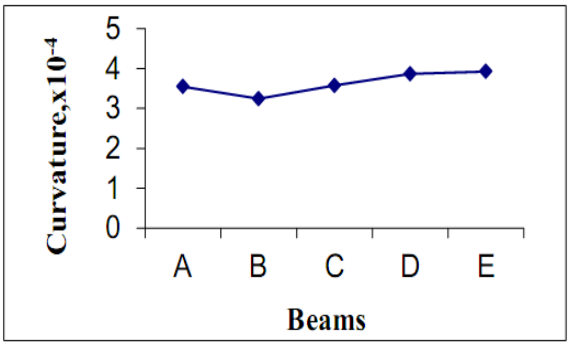


The flexural capacity of beams is also influenced by the concrete compressive strength, as shown by the test data plotted in Figures below. Because the beams are under-reinforced, the effect of concrete compressive strength on the flexural capacity is only marginal

4. CONCLUSIONS

4.1 Summary

Studies have been carried out on Glass Fibre Reinforced Concrete (GFRC) with conventional coarse aggregate and with replacement of conventional coarse aggregate by recycled coarse aggregate. The results show that there is a slight decrease in workability with the use of recycled coarse aggregate and also with the addition of fibres. There is a marginal decrease in the strength of concrete as conventional coarse aggregate is replaced with recycled coarse aggregate.

4.2 Conclusions

Based on the experimental results the following conclusions were drawn.

1. The workability of concrete for M30 grade mix is decreased gradually with increase in glass fibre percentage.

2. The flexural strength and compressive strength are enhanced with increase in glass fibre content from 0.5% to 2%.

3. The compressive strength of glass fibre concrete is found to be maximum at 2% of fibre. At 2% there is a increase of 11% of strength as compared to 0.5 % of fibre for M30 grade mix for 100% RCA at 28 days.

4. The compressive strength of 100% RAC at 2% fibre content decreased by 10% as compared to NAC with 0% fibre.

5. The first crack was found at 90 kN for NCA with no fibres and for 100%RCA at 2% fibre was found at 120 kN. The first crack of 100% RAC at 2% fibre content is increased by 25% compared to that of NAC with no fibre.

6. The load carrying capacity of specimens with 100 %(RCA) with 2% fibre content is increased by 11% compared to that of 100% (RCA) with 0.5% fibre content

7. Higher percentages of Glass fibres from 2% affect the workability of concrete, and may require super plasticizers to maintain the workability.

8. With the use of glass fibres in concrete it has shown an improvement in mechanical properties such has compressive strength and flexural tests for M30 grade of natural and recycled aggregate concrete.

4.3 Scope for Further Investigation

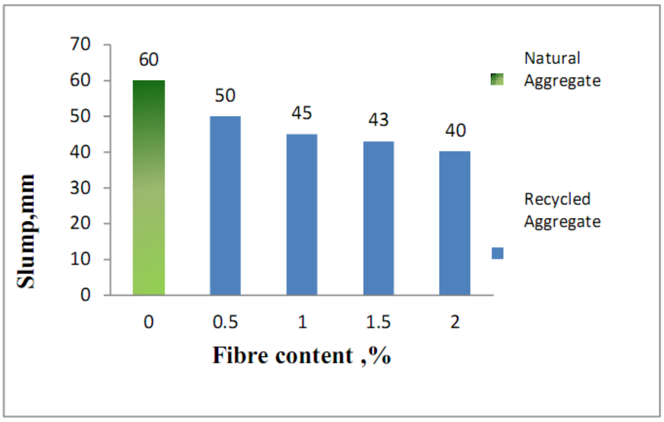
1. To strengthen the observations and conclusions made in the present investigation, more number of beams, cubes, cylinders, prisms with different grades, and varying percentages of fibres may be investigated.

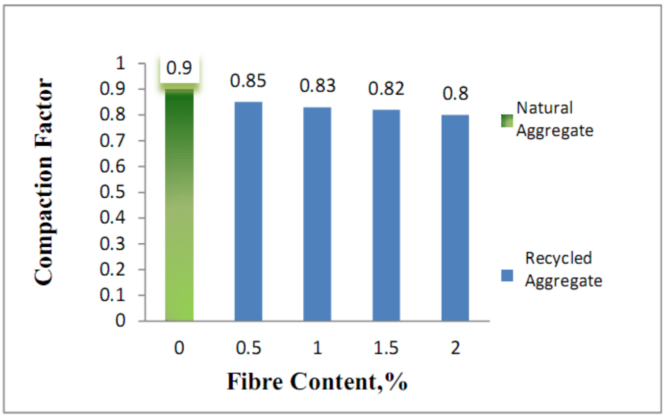
2. Mathematical formulations may be developed to verify the experimental observations.

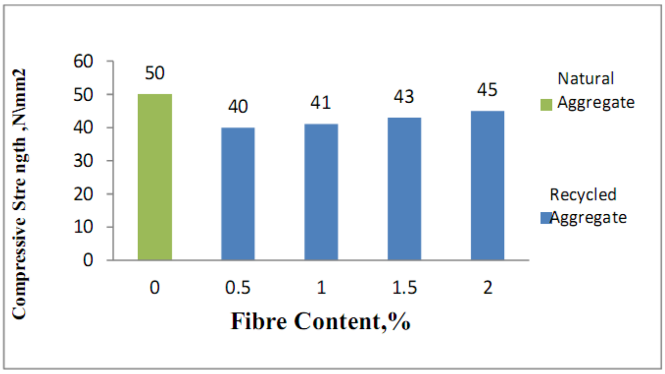
3. Further research can be carried out to study the mechanical properties of glass fibre reinforced self-compacting concrete with partial replacement of natural aggregate with recycled.

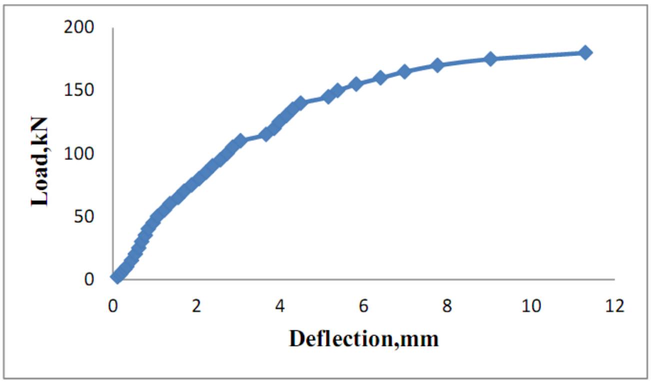
4. The investigations on behavior of high strength concrete with hybrid fibres for various percentages of recycled coarse aggregate.

5. Further testing and studies on the recycled aggregate concrete with mixing of different fibres is highly recommended to indicate strength characteristics of recycled aggregates for application in structural concrete.

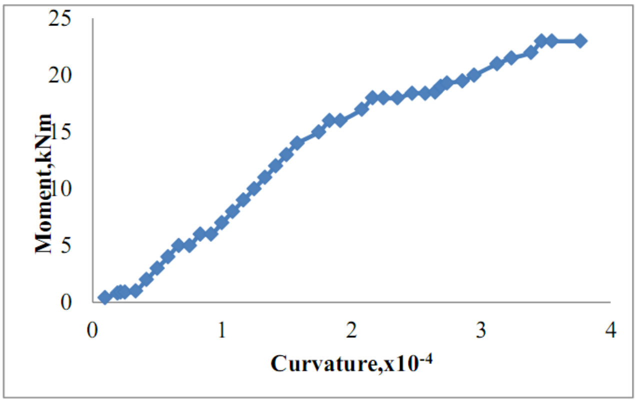




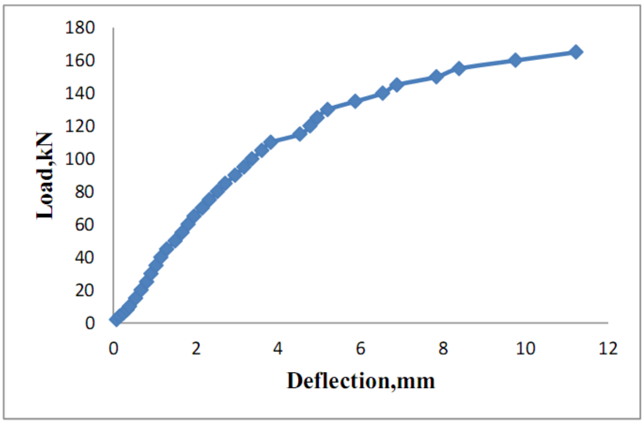




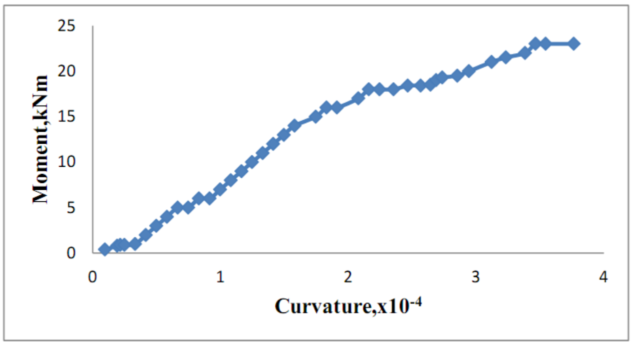
Load- Deflection Curve for the Test Beam (A) NCA with 0% Fibre Content



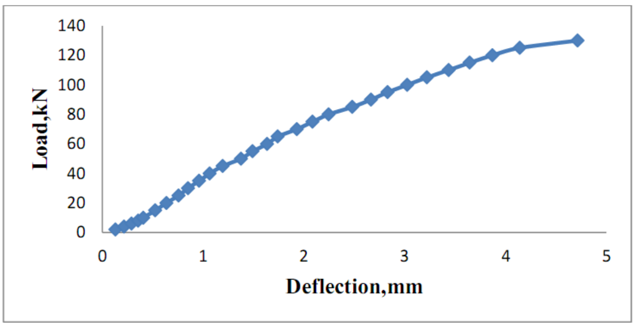
Moment- Curvature Relation for the Test Beam (A) NCA with 0% Fibre Content



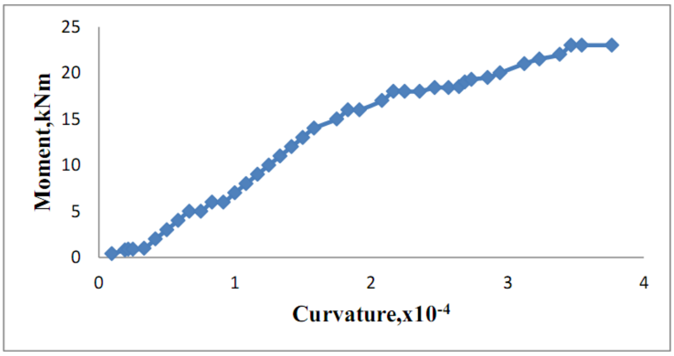
Load-Deflection Curve for the Test of Beam (B) RCA with 0.5 % Fibre Content



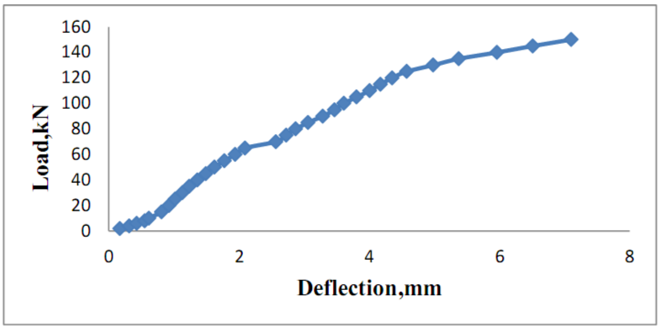
Moment-Curvature Relation for the Test Beam (B) RCA with 0.5% Fibre Content



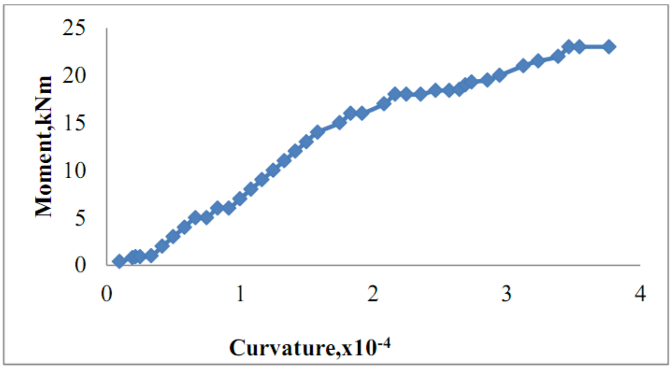
Load-Deflection Curve of the Test Beam(C) RCA with 1% Fibre Content



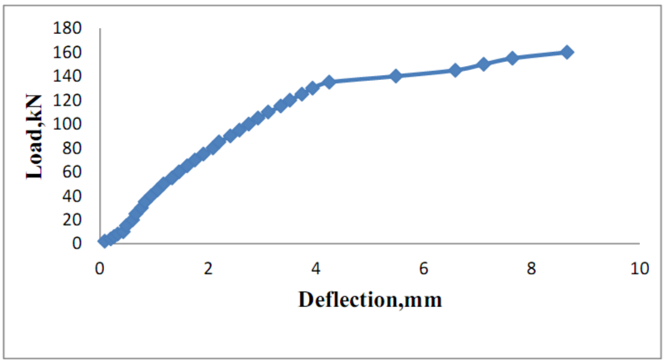
Moment-Curvature Relation for the Test Beam(C) RCA with 1% Fibre Content



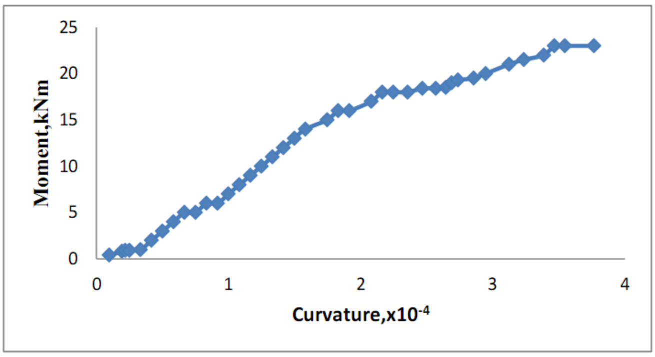
Load- Deflection Curve for the Test Beam (D) RCA with 1.5% Fibre Content



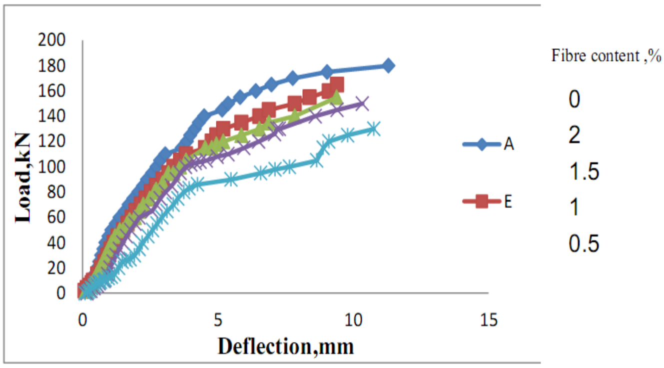
Moment-Curvature Relation for the Test Beam (D) RCA with 1.5% Fibre Content



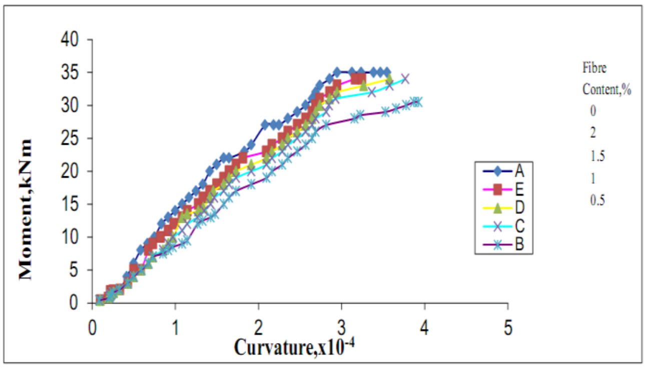
Load- Deflection Curve for the Test Beam (E) RCA with 2% Fibre Content



Moment -Curvature Relation for the Test Beam (E) RCA with 2% Fibre Content

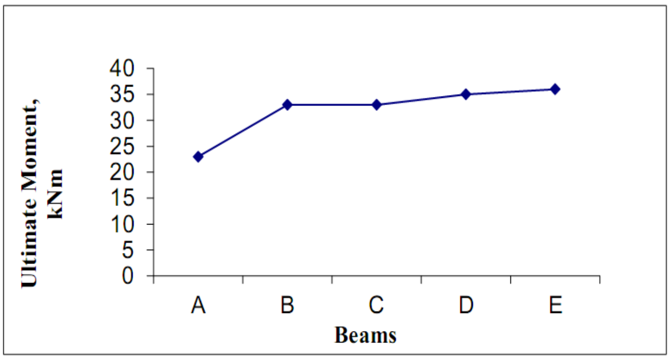


Load –Deflection Curves for the Test Beams (A, B, C, D, and E)

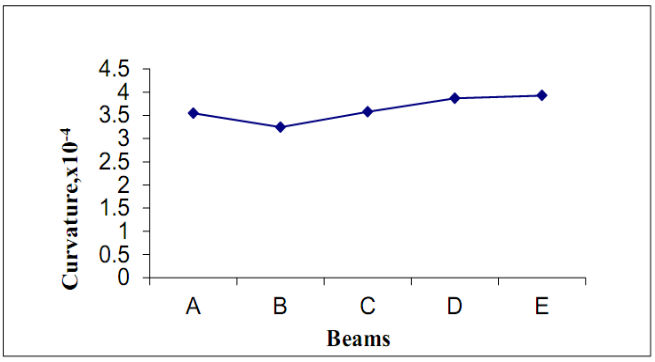


N. Ashwini Gandhi[1] M. A. Haleem[2] Mohd Younus Mohiuddin[3]

Moment -Curvature Relation for the Test Beams (A, B, C, D, and E)



Ultimate Moments of Beam Specimens (A, B, C, D, and E)



Ultimate Curvatures of Beam Specimens (A, B, C, D, and E)

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