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STUDY ON MECHANICAL PROPERTIES OF RECYCLED AGGREGATE CONCRETE CONTAINING STEEL FIBERS

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ABSTRACT

The study on steel fiber in concrete had shown considerable improvement in the mechanical properties of recycled aggregate concrete. There were total of 16 batches of concrete mixes M20 and M30 with 0.0%, 0.5%, 1.0% and 1.5% volume of the steel fibers. Water cement ratio of 0.54 and 0.42 for the above two grades of concrete have been used with aspect ratios of 40 and 60. Each batch of concrete has 12 specimens of which 3 cubes, 3 prisms and 6 are cylinders. A total of 192 specimens have been cast for the present experimental program. The overall compressive strength increases 3% and 2% for aspect ratio 40 and 60 respectively. For flexural strength it increases 6% and 2%. In splitting tensile strength increases 8% and 1%. Similarly modulus of elasticity increases from 2% to 1% for both the aspect ratios at 28 days respectively. There is a significant improvement in the properties of concrete when recycled aggregate is used.

Keywords: Recycled aggregate concrete; fiber reinforced concrete; conventional concrete; strength characteristics; mechanical properties; steel fibers

1. INTRODUCTION

Recycling is the act of the processing the used material for using creating new product. The usage of the natural aggregate is getting more and more intense with the advanced development in infrastructure area. In order to reduce the usage of natural aggregate, recycled aggregate can be used as the replacement materials. Recycled aggregate comprised of crushed, graded in organic particles processed from the materials that have been used in the constructions and demolition debris. These materials are generally from buildings, roads, bridges, and some times even from catastrophes, such as wars and earthquakes. Large quantities of crushed aggregates are used in the Pavement systems. Crushed aggregates are used as sub base and base layers, for surfacing in low traffic or temporary applications, and to

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improve unstable sub grade materials. The significant aggregate characteristics of these specific applications are as follows.

Crushed aggregates are used as a structural component in many pavement sections. Crushed aggregate is used for surfacing of temporary roads or for no low traffic applications, such as country roads or parking lots. Stability and resistance to rutting are primary considerations for surfacing materials. Dusting is also a concern in many applications. Localized sun grade problems are frequently addressed by removal and replacement with crushed aggregate. Ease of compaction is frequently the primary consideration in this application. Secondary considerations are the ability to distribute and support construction loads. Traditionally, the application of recycled aggregate is used as land fill. Nowadays, the applications of recycled aggregate in construction areas are wide. In many countries research on applications of the recycled aggregate concrete as a structural grade concrete are going on and the results are encouraging. Some of the research findings across the world are as given below:

1.1 Literature review

Shah Suendra and Rangan [1], in their investigations conducted uni-axial compression test on fiber reinforced concrete specimens. The results shown the increase in strength of 6% to 17% compressive strength, 18% to 47% split tensile strength, 22% to 63% flexural strength and 8% to 25% modulus of elasticity respectively. The specimens are casted with steel fiber volume fractions viz., 0.0% and 0.5% with aspect ratio of 60. Byung Hwan [2], in their investigations, the mechanical properties of concrete have been studied, these results shown the increase in strength of 6% to 17% compressive strength, 14% to 49% split tensile strength, 25% to 55% flexural strength and 13% to 27% modulus of elasticity respectively. The specimens are casted with steel fiber volume fractions viz, 0.0% and 2.0% with aspect ratio of 60.Barrows and Figueiras [3], in their investigations the mechanical properties of concrete have been studied, these results shown the increase in strength of 7% to 19% compressive strength, 19% to 48% split tensile strength, 25% to 65% flexural strength and 7% to 25% modulus of elasticity respectively. The specimens are casted with two steel fiber volume fractions viz, 0.0% and 1.5% with aspect ratio of 60 and 83. Chen [4] invested the strength of 15 steel fiber reinforced and plain concrete ground slabs. The slabs were 2x2x0.12m, reinforced with hooked end steel fibers and mill cut steel fibers. All slabs were centrally loaded hydraulic and electric pump through 100x100mm steel plate. He concluded that the load bearing capacity of could be affectively increased when the slabs are reinforced with steel fibers. Dwaraknath and Nagaraj [5], predicted flexural strength of steel fiber concrete by these parameters such as direct tensile strength, split cylinder strength and cube strength. This experimental test results and evaluates determination of direct tensile strength for the composite, was reflects by the combined effects of fiber volume and ratio of length and diameter parameters in steel fiber reinforced concrete. James [6] stated that the minimum fiber volume dosage rate for steel, glass and polypropylene fibers in the concrete matrix is calculated approximately 0.31%, 0.40% and 0.75%. Luo et. al [7], studied and conducted test on the mechanical properties and resistance against impact on steel fiber reinforced high-performance concrete. Five different geometry of fibers included steel-sheet-cut fibers and steel ingot milled fibers with four fiber volume fractions (4%, 6%, 8% and 10%) were applied in to the mix. Patton and Whittaker [8], investigated on steel fiber concrete for dependence of modulus of elasticity and correlation changes on damage due to load. They found out that there is approximately 3.3% increase over the modulus of elasticity of plain concrete for every 1.0% increase in fiber concrete by volume. Rossi et. Al[9], analyzed that the effects of steel fibers on the cracking at both local level (behavior of steel fibers) and global level (behavior of the fiber/cement composite) were dependent to each other. Sener et. al [10], calibrated the size effect of the 18 concrete beams under four-point loading. The all beams thickness are uniformed at 40mm and length of 800mm, but the height of the beams were varies at 40mm, 80mm and 160mm. steel fibers was used with the same length/ height ratio of five and volume fraction of 0.6% and 1.2%, while the cement/aggregate/sand ratio of 1:2:4. it results that as height of the beam increased, the ultimate flexural strength increased. Swami and Sa'ad [11], had done an investigation on deformation and ultimate strength of flexural in the reinforced concrete beams under 4 point loading with the usage of steel fibers, where consists of 15 beams (dimensions of 130x203x2500mm) with same steel reinforcement (2Y-10 top bar and 2Y-12 bottom bar) and variables of fibers volume fraction (0%, 0.5% and 1.0%). Tan et. al [12], concluded some investigation on the shear behavior of steel fiber reinforced concrete. 6 simply supported I-beams were tested under two- point loading with hooked steel fibers of 30mm long and 0.5mm diameter, as the fiber volume fraction increased every 0.25% from 0% to 1.0%. Vandewalle [13], had done a similar crack behavior investigation, which based on combination of five full scale reinforced concrete beams (350x200x3600mm) with steel fibers (volume fraction of 0.38% and 0.56%). In this investigation, the experimental results and theoretical prediction on the crack width was compared. Bhikshma and Jailsingh [14] investigated the increase in compressive strength of 17% for the M30 grade of concrete with 1% volume of fibers.

2. NEED FOR THE WORK

The randomly oriented steel fibers assist in controlling the propagation of micro cracks present in the matrix, first by improving the overall cracking resistance of the matrix and later by bridging across even smaller cracks formed after the application of load on to the member, thereby preventing their widening into major cracks. Thus proper introduction of fibers in concrete improves both mechanical properties and durability. Therefore an attempt has been made in the present study to assess the mechanical properties such as compressive strength, flexural strength, splitting tensile strength and modulus of elasticity of various concrete mixtures containing steel fibers.

3. OBJECTIVE OF THE WORK

The aim of this study is to determine the mechanical properties of recycled aggregate concrete containing steel fibers.

4. EXPERIMENTAL PROGRAMME

4.1 General

The experimental program was designed to evaluate the mechanical properties i.e., compressive strength, flexural strength, splitting tensile strength and modulus of elasticity of concrete with M20 and M30 grades using recycled aggregate concrete and using ordinary Portland cement (ultra-tech cement 53 grade) with addition of steel fibers. The program involved casting and testing of total of 192 specimens. The specimens were cast using standard cubes (150 x 150 x 150 mm), standard cylinders (150 mm diameter x 300 mm height) and standard prisms (100 x 100 x 500 mm), with and without steel fibers. Universal testing machine was used to test all the specimens. In 1st series, the specimens were cast with M20 concrete with volume of steel fibers as 0.0%, 0.5%, 1.0% and 1.5%. in the 2nd series, the same levels of addition with M30 grade of concrete were cast.

4.2 Materials

Ordinary Portland cement (ultratech cement) of 53 grade confirming to IS: 12269 were used. It was tested for its physical properties as per IS: 4031 (part II)-1988. The details of test results are given in the Tables 1. Locally available natural sand was used specific gravity and fineness modulus was found to be 2.63 and 3.14 respectively. Recycled aggregate chips (angular) of maximum size 20mm were used. Specific gravity and fineness modulus was found to be 2.67 and 7.2 respectively. The properties of straight steel fibers are given in Table 2. Two concrete mixes were designed for a compressive strength of 20MPa and 30MPa with water-cementations ratios of 0.54 and 0.42 respectively. Details of various mixes are given in the Table 3.

Table 1: Physical properties of cement

Property	Test method	Test result
Normal consistency	Vicat apparatus (IS: 4031-Part IV)	32%
Specific gravity	Specific gravity bottle (IS: 4031-Part II)	3.15%
Initial and final setting time	Vicat apparatus (IS: 4031-Part V)	50 min 180 min
Fineness	Seive test on sieve no.9 (IS: 4031-Part IV)	4%

Tables 2: Physical properties of steel fibers

Property	Value
Diameter	0.5 mm
Lengths	20 mm and 30 mm
Aspect ratios	40 and 60
Specific gravity	0.78
Tensile strength (MPa)	1100
Young’s modulus (GPa)	210

Table 3: Proportions of constituent of materials

Grade of concrete	W/C Ratio	Properties of constituent materials		
		C	FA	CA
M20	0.54	1	1.76	2.93
M30	0.42	1	1.17	2.43

4.3 Workability

Slump cone test is a very common test for determination of workability of concrete. This test was carried out before casting the specimens. The slump was measured and the values are presented in Table 4and 5. The compaction factor values obtained by this test are presented in Table 4 and 5.

Table 4: Slump and compaction factor values of RAC for *l*/*d* = 40

% of Steel fibers	M20		M30	
	Slump	Compaction factor	Slump	Compaction factor
0.0	Collapse	1.0	Collapse	0.99
0.5	90	0.99	90	0.98
1.0	75	0.98	80	0.95
1.5	65	0.97	70	0.95

Table 5: Slump and compaction factor values of RAC for *l*/*d* = 60

% of Steel fibers	M20		M30	
	Slump	Compaction factor	Slump	Compaction factor
0.0	Collapse	0.97	Collapse	0.98
0.5	70	0.93	80	0.94
1.0	68	0.91	70	0.93
1.5	66	0.90	65	0.92

4.4 Testing of specimens

The specimen cured for the required period i.e. 28 days were taken out of the water tank and prepared for testing. The specimens of cubes, prisms, cylinders were tested in accordance with IS: 516-1969, The testing was done on universal compression testing machine of 2000kN capacity. All the mechanical properties are presented in Tables 6-9. Fibers, test setup, cracking patterns are presented in plates 1-5.

Table 6: Compressive strength of RAC

% of Steel fibers	Compressive strength (MPa) 28 days			
	M20 *l*/*d* = 40	**M30 *l*/*d* = 40**	**M20 *l*/*d* = 60**	**M30 *l*/*d* = 60**
0.0	30.67	31.40	32.65	34.55
0.5	35.84	36.20	37.64	38.40
1.0	37.33	39.67	40.30	40.60
1.5	38.40	40.30	42.67	42.20

Table 7: Splitting tensile strength of RAC

% of Steel fibers	Splitting tensile strength (MPa) 28 days			
	M20 *l*/*d* = 40	**M30 *l*/*d* = 40**	**M20 *l*/*d* = 60**	**M30 *l*/*d* = 60**
0.0	2.78	3.00	2.88	3.12
0.5	3.20	3.85	3.45	3.93
1.0	3.54	4.02	3.64	4.08
1.5	3.56	4.17	3.75	4.24

Table 8: Flexural strength of RAC

% of Steel fibers	Flexural strength (MPa) 28 days			
	M20 *l*/*d* = 40	**M30 *l*/*d* = 40**	**M20 *l*/*d* = 60**	**M30 *l*/*d* = 60**
0.0	4.65	5.10	4.95	5.70
0.5	5.45	6.30	5.88	6.89
1.0	5.62	6.40	6.05	7.05
1.5	5.74	6.60	6.18	7.20

Table 9: Modulus of elasticity of RAC

% of Steel fibers	Modulus of elasticity (GPa) 28 days			
	M20 *l*/*d* = 40	**M30 *l*/*d* = 40**	**M20 *l*/*d* = 60**	**M30 *l*/*d* = 60**
0.0	25.2	29.5	25.60	30.40
0.5	34.5	38.2	34.89	38.70
1.0	38.7	40.4	40.20	41.50
1.5	40.4	42.7	42.50	43.30

5. DISCUSSIONS ON TEST RESULTS

5.1 Slump and compaction factor

The slump test values of M20 and M30 with 0.0%, 0.5%, 1.0% and 1.5% of fibers are tabulated in the Tables 4-5, indicates a decreasing trend in workability when the % of steel fiber is increased. The maximum slump obtained for M20 was 90 mm and the minimum slum was 65mm for aspect ratio 40, similarly the highest and the lowest slump values obtained for M20 for aspect ratio 60 are 70 mm and 66 mm. The highest slump obtained for M30 was 90 mm and the lowest slump was 70 mm for aspect ratio 40, similarly the highest and the lowest slump values obtained for M30 for aspect ratio 60 are 80 mm and 65 mm.

The compaction factor test values of M20 and M30 with 0.5%, 1.0% and 1.5% of fibers are tabulated in the Table 4-5, indicates decreasing trend in workability when the % of steel fiber is increased. In M20, but the compaction factor values indicates a decreasing trend of workability when the % of steel fiber is increased in M30.The highest compaction factor value obtained for M20 was 12 mm and lowest was 10 mm for aspect ratio 40, similarly the highest and the lowest compaction factor values obtained for aspect ratio 60 are 10 mm and 80 mm. The highest compaction factor test obtained for M30 was 12 mm and the lowest was 10 mm for aspect ratio 40, similarly the highest and the lowest compaction factor values obtained for aspect ratio 60 are 8 mm and 6 mm. For the both grades of concrete the workability observed was higher. The reason was because of the higher water absorption capacity of recycled aggregate. From the result obtained it shows that the workability was getting lower when recycled aggregate and steel fibers were used.

5.2 Compressive strength

The compressive strength of values presented in Table 6 indicated increase in strength of M20 grade concrete with addition of 0.5%, 1.0% and 1.5% of steel fiber and the values observed to be 17%, 22% and 25% for aspect ratio 40, and 15%, 23% and 31% for aspect ratio 60 respectively when compared plain concrete. For M30 grade concrete the increase in strength with addition of steel fibers was observed to be 15%, 27% and 28% for aspect ratio 40, and 11%, 18% and 22% for aspect ratio 60 when compared to plain concrete.For both grades of concrete, increase in the compressive strength for aspect ratios 40 and 60 are 25%, 31% in M20.respectively for aspect ratio 40 was 28% and 60 was 22% in M30 The strength variation in the both grades of concrete is very marginal.

5.3 Splitting tensile strength

The percentage increase in the Splitting tensile strength of various concrete mixtures over plain concrete is also tabulated in Table 7. The increase in strength of M20 grade concrete with addition of 0.5%, 1.0% and 1.5% steel fiber was observed to be 15%, 24% and 28% for aspect ratio 40, similarly 20%, 26% and 30% for aspect ratio 60, when compared to plain concrete. For M30 grade concrete the increase in strength with addition of steel fibers was observed to be 28%, 34% and 39% for aspect ratio 40, and 26%, 31% and 36% for aspect ratio 60, when compared to plain concrete.For both grades of concrete increase in the splitting tensile strength for aspect ratios 40 and 60 are 28%, 30% in M20 respectively for aspect ratio 40 was 39% and 60 was 36% in M30. The strength variation in the both grades of concrete is very marginal.

5.4 Flexural strength

The increase in flexural strength of M20 grade concrete indicated in Table 8 with addition of 0.5%, 1.0% and 1.5% steel fiber was observed to be 17, 21% and 23% for aspect ratio 40, similarly 19%, 22% and 25% for aspect ratio 60, when compared to plain concrete. For M30 grade concrete the increase in strength with addition of steel fibers was observed to be 24%, 26% and 29% for aspect ratio 40, and 21%, 24% and 26% for aspect ratio 60, when compared to plain concrete. For both grades of concrete increase in the splitting tensile strength for aspect ratios 40 and 60 are 23%, 25%, in M20 respectively for aspect ratio 40 was 29% and 60 was 26%. The strength variation in the both grades of concrete is very small.

5.5 Modulus of elasticity

The average value of 3 specimens for each category at the age of 28 days is tabulated in the Table 9 indicated the increase in modulus of elasticity of M20 grade concrete with addition of 0.5%, 1.0% and 1.5% as 40%, 49% and 55% for aspect ratio 40, similarly 37%, 45% and 51% for aspect ratio 60, when compared to plain concrete. For M30 grade concrete, the increase in strength with addition of steel fibers was observed to be 45%, 51% and 55% for aspect ratio 40, and 38%, 44% and 51% for aspect ratio 60,when compared to plain concrete. For both grades of concrete increase in the modulus of elasticity for aspect ratios 40 and 60 are 55%, 51% in M20 respectively for aspect ratio 40 was 55% and 60 was 51% in M30. The strength variation in the both grades of concrete is insignificant.

Plate 1. Steel fibers

Plate 2. Cube test setup

Plate 3. Cylinder test setup

Plate 4. Cracking pattern of cylinders

Plate 5. Cracking pattern of prisms

6. CONCLUSIONS

1. The maximum compressive strength obtained is 38.40 MPa for M20 and 40.30 MPa for M30 of aspect ratio 40. Similarly for aspect ratio 60, the maximum compressive strength obtained is 42.20 MPa for M20 and 42.67 MPa for M30 with 1.5% addition of steel fiber at the age of 28 days.
2. The increase in the steel fibers content from 0.0% to 1.5% by volume of concrete, the compressive strength, splitting tensile strength and flexural strength were enhanced.
3. The optimum values for M20 grade concrete obtained using 1.5% steel fiber with aspect ratio 40 at the age of 28 days were increase of 25% for compressive strength, 28 % for splitting tensile strength and 23% for flexural strength.
4. The maximum values for M20 grade concrete obtained using 1.5% steel fiber with aspect ratio 60 at the age of 28 days were compressive strength of 31% increase, splitting tensile strength of 30% increase and flexural strength of 25% increase.
5. The maximum values for M30 grade concrete obtained using 1.5% steel fiber for aspect ratio 40 at the age of 28 days were increase of 28% for compressive strength, 39% for splitting tensile strength and 29% for flexural strength.
6. The maximum values for M30 grade concrete obtained using 1.5% steel fiber for aspect ratio 60 at the age of 28 days were increase of 22% for compressive strength, 36% for splitting tensile strength and 26% for flexural strength.
7. The maximum values for modulus of elasticity both grades and aspect ratios obtained using 1.5% steel fiber at the age of 28 days were increases from 30% to 37%.

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