Mechanical Properties of Fibre Reinforced Concrete using Preserved Quality of Recycled Coarse Aggregate

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Abstract – Over the past 50 years the construction industry worldwide has generated a huge amount of waste. The depletion of virgin aggregate sources has become a wide spread issue. This has brought forth a need for an alternate aggregate source. Recycled concrete aggregates (RCA) sourced from balance fresh hardened concrete are a sustainable alternative to natural crushed aggregates. The strength and mechanical properties of concrete containing Preserved Quality of RCA were evaluated and are compared with normal concrete. Replacement of virgin aggregate (25%, 50%, 75% and 100%) were done. Also by using Hooked End Steel Fibres varying from (0.5%, 1%, 1.5% and 2%) improves other mechanical properties. The strength properties such as compressive strength, split tensile strength, flexural strength and modulus of elasticity are studied. The test results showed that at 25% replacement of normal aggregate, the cube compressive strength obtained is comparable with that of normal aggregate. Also by adding 1.5% of Hooked End Steel Fibre it improves the strength properties of concrete.

Key Words: Preserved quality Recycled Coarse Aggregate, Hooked End Steel Fibre, Cube Compressive Strength, Flexural Strength, Split Tensile Strength, Modulus of Elasticity .

1. INTRODUCTION

In recent times due to rapid urbanization generation of large amount of construction and demolition (C&D) waste is annually expanding worldwide. Concrete is known as one of the most highly consumed construction materials. The primary ingredients of a concrete mixture are cement, aggregates (coarse and fine), water and admixtures. Among the aforementioned components, aggregate takes up about 70% to 80% of concrete's volume.

The depletion of virgin aggregate sources has become a widespread issue. This has brought forth a need for an alternate aggregate source. Preserved quality of recycled coarse aggregate are aggregates which are made from fresh hardened concrete of strength more than 25MPa. These aggregates are taken from concrete that are left due to excess in quantity or when its fresh properties like slump flow test does not meet the requirements. These hardened concrete is crushed and processed to produce RCA. Using recycled coarse aggregate to maintain natural resources and replacing proportion of the aggregate by using the preserved quality RCA thereby negates the requirement of disposal. The greater the proportion of aggregates replaced by recycled materials, the more sustainable the concrete is. Also, such usage can also minimize the discharge of the amount of carbon-dioxide and reduces the energy consumption in the production of concrete. In conclusion, the extraction of virgin aggregates can cause enormous damage to the environment while on the other hand vast amount of energy is required during the extraction and crushing process, due to the awareness towards using recycled aggregates which is generated from the hardened fresh concrete is on the increase as opposed to natural aggregates.

Andal et al. [2016](1) studied that concrete made with preserved-quality RCA showed higher strength when compared to the same grade of concrete containing commercial RCA. And also by using preserved-quality RCA at partial replacement of coarse aggregate was found to produce concrete of performance similar to that of concrete with virgin aggregates. An experimental study was carried out on evaluating recycled concrete aggregate (RCA) of high quality produced through a protocol that preserves the original properties of the concrete to be recycled. Results showed that concrete with RCA of preserved quality performed significantly better in compressive strength, drying shrinkage, and salt scaling resistance. Furthermore, the use of 30% RCA with preserved quality produced concrete of comparable quality to that of concrete with natural aggregate.

Kwan et al. [2012](2)conducted a study on the influence of the amount of recycled coarse aggregate in concrete design and its durability properties. Here parameters like compressive strength, ultrasonic pulse velocity (UPV), shrinkage, water absorption and intrinsic permeability were examined in this experiment. The target strength was achieved even when 80% of the total coarse aggregate content was replaced by the RCA.

Florea et al. [2013](3) done research on properties of various size fractions of crushed concrete related to process conditions and re-uses and also studied about a conventional jaw crusher used for the crushing methods to obtain the RC-1 and RC-2 materials (one time crushing and 10 times returning through the crusher, respectively) and a specially designed smart crusher prototype was used to obtain the third material (RC-3). The obtained recycled concrete aggregates were collected and separated into different fractions based on the particle sizes.

Fathifazl et al. [2012](5) studied about creep and drying shrinkage characteristics of concrete produced with coarse recycled concrete aggregate. Here they discussed about the effect of mix proportioning method on the creep and shrinkage of concrete produced with RCA and the result was quite noticeable. The effect of aggregate type on creep was more noticeable in RCA-concrete mixes proportioned with conventional mix proportioning methods than in the natural aggregate concrete mixes.

2. EXPERIMENTAL PROGRAM

2.1 Test Specimens

The specimens were cast using 150×150×150mm steel cube moulds, 150×300mm cylinder moulds and 100×100×500mm beam moulds. The ingredients of concrete were mixed in a pan mixer. First coarse aggregate and fine aggregate were mixed thoroughly in a dry condition, then required quantities of cement is added and mixed it thoroughly. Then water is added to the mixture and mix it. The prepared concrete is poured in the required moulds and compacted it using Tamping Rod. The mould is striped after 24 hours. The test specimens were cured for 28 days in a curing tank.
Preserved quality of RCA is prepared from crushing fresh hardened concrete into a size around 20-25mm then it is treated with hydrochloric acid of 0.8 molar concentration for 48 hours and then thoroughly washed in clean water. The virgin aggregates are replaced by (25%, 50%, 75% and 100%) of RCA. Also 1.5% of hooked end steel fibre were also added.

Table -1: Details of Specimens

Sl.No.	Mix Designation	Description
1	C_0	100% NCA
2	CR_{25}	75% of NCA + 25% of RCA
3	CR_{50}	50% of NCA + 50% of RCA
4	CR_{75}	27% of NCA + 75% of RCA
5	CR_{100}	100% RCA

Table -2: Details of Specimens

Sl. No.	MIX ID	Description
1	C_0	Conventional concrete mix
2	$CS_{0.5}$	Concrete mix with 0.5% steel fiber
3	CS_1	Concrete mix with 1% steel fiber
4	$CS_{1.5}$	Concrete mix with 1.5% steel fiber
5	CS_2	Concrete mix with 2% steel fiber
6	$CR_{25}S_{1.5}$	Concrete mix with 1.5% steel fiber and 25% of RCA
7	$CR_{50}S_{1.5}$	Concrete mix with 1.5% steel fiber and 50% of RCA
8	$CR_{75}S_{1.5}$	Concrete mix with 1.5% steel fiber and 75% of RCA
9	$CR_{100}S_{1.5}$	Concrete mix with 1.5% steel fiber and 100% of RCA

2.2 Material Properties

Ordinary Portland cement was used for the present study of 53 grade. A concrete mix of M25 was used in this study. Natural fine aggregate used for the experimental study was manufactured sand. Fine aggregate under saturated surface dry condition was used for preparing concrete mixes. Crushed granite angular aggregate from a local source, having a maximum size of 20mm, was used for the present study. Fresh hardened concrete were crushed into aggregates of size ranging from 20-25 mm. To improve the properties of preserved quality of RCA, HCl pre-treatment was demonstrated. RCA were pre-soaked for 48 hours in 0.8 molar HCl and then undergone washing using clean water. Thus removing unwanted debris and mortar content. Hence preserved quality of RCA were obtained. The fresh properties of normal concrete were tested and listed in Table 3.

Hooked end steel fibers were used to make fiber reinforced concrete. The steel fibers had a length of 30mm, diameter of 0.5mm, aspect ratio of 60 and density of 7850kg/m^3. The steel fibers were distributed randomly into the concrete mixtures and the percentages were 0%, 0.5%, 1.5% and 2% to the volume of concrete.

Table -3: Fresh Properties of concrete

Mix Designation	Slump Value
CR_0	75
CR_{25}	80
CR_{50}	83
CR_{75}	85
CR_{100}	87

2.3 Specimen Preparation

The concrete was filled in standared size moulds and compaction is provided using tamping rod. The specimens contain replacement of virgin aggregate with preserved quality RCA(0%, 25%, 50%, 75% and 100%) and also steel fibre of varying percentage like 0.5%, 1%, 1.5% and 2%. After casting the specimens were undergone curing for 28 days.

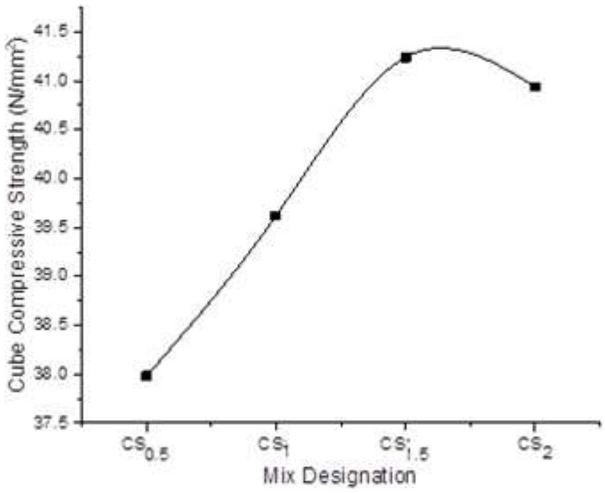
2.4 Test Setup

Compressive strength test was performed in universal testing machine using 150 × 300 mm cylinders with ground ends at 28 days. All results were recorded and presented as an average of three test specimens. Compressive strength testing was performed on all three classes of concrete: normal concrete, fibre reinforced concrete and fibre reinforced concrete containing preserved quality RCA. A comparison between the commercial concrete containing fibre and RCA of preserved quality was carried out. Splitting tensile strength test was performed according to UTM using 150 × 300 mm cylinders at 28 days. The results are recorded and presented as an average of three test specimens. Also flexural strength of concrete is also studied using standared size of specimens and two point load test is used for the present study.

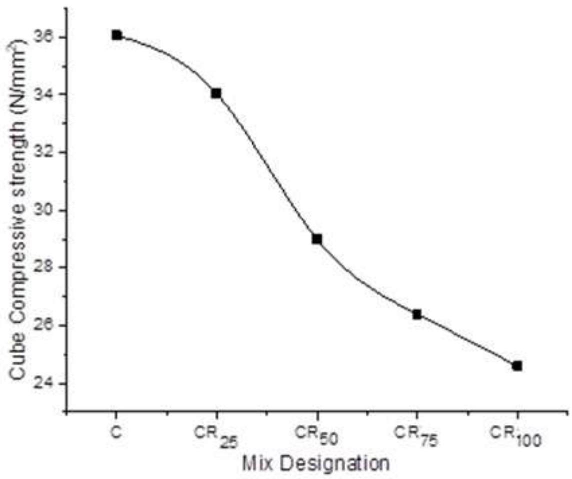
3. RESULTS AND DISCUSSIONS

3.1 Graph showing Cube Compressive Strength

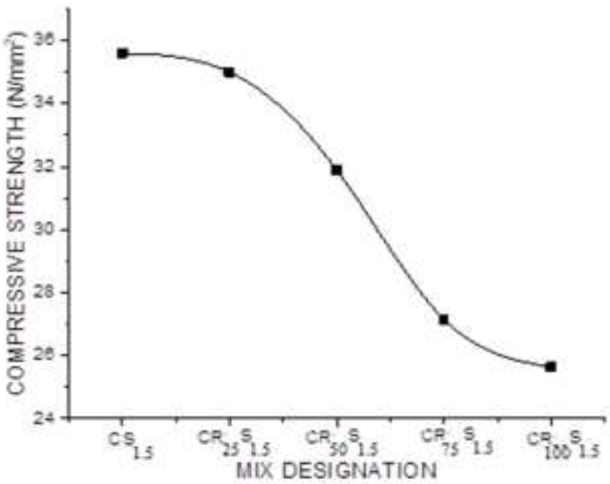
Compressive strength of 150 mm cube were found for 28th day strength. The cube compressive strength test was done to find the optimum percentage of hooked end steel fibre varying from 0.5, 1, 1.5 and 2%. The graph showing percentage of fibre Vs compressive strength is shown below.



(a)



(b)



(c)

Graph (a) shows the Compressive strength of 150 mm cube were found for 28th day strength. The cube compressive strength test was done to find the optimum percentage of hooked end steel fibre varying from 0.5, 1, 1.5 and 2%. From the above graph, the cube compressive strength obtained for $CS_{0.5}$ is 37.98Mpa. CS_1 and $CS_{1.5}$ are increasing to 39.62 and 41.24 respectively. It can be observed that for CS_2 there was a slight decrease in the compressive strength. Hence the optimum percentage of fibre obtained as 1.5%.

Graph (b) shows cube compressive strength of CR_{100} is less than target compressive strength. This may due to the presence of 100% RCA used for preparing CR_{100}, which results in poor adhesion. Cube compressive strength of CR_{25}, CR_{50} and CR_{75} are more than CR_{100}. It may due to the higher strength of NA when compared with Preserved Quality of RCA. From the above graph it can also be observed that by replacing 25% of RCA, it shows a comparable compressive strength to that of conventional mix. Hence from the above graph, the optimum percentage replacement of RCA obtained as 25%.

Graph (c) shows that compressive strength obtained by the replacement of preserved quality RCA with normal aggregate is comparable with that of normal concrete. Also by adding optimum percentage of fibre along with RCA shows comparable results to that of normal concrete.

3.2 Flexural Strength

The results of flexural strength tests of various samples at 28 days of curing and its variations are depicted in chart 1.

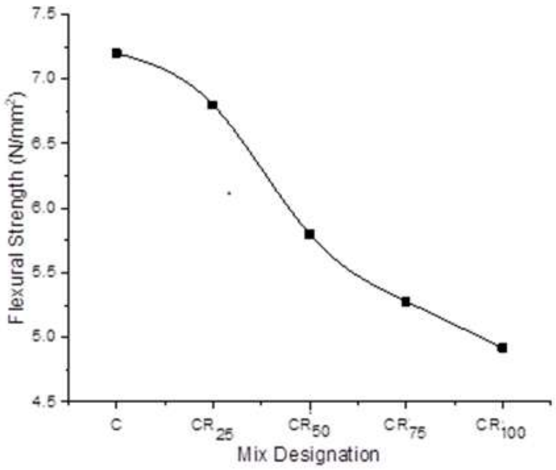


Chart -1: Flexural Strength Vs Mix Designation

From Figure it can be seen that flexural strength of CR100 is less than compare to CR_{25}, CR_{50}, CR_{75} and CR_{100}. This may due to the presence of 100% preserved quality recycled aggregate used for preparing CR_{100}. Higher flexural strength of CR_{25}, CR_{50} and CR_{75} is due to the higher strength of NA when compared with RA. Additionally, in new combination method the use of hooked end steel fibre along with RCA improves the bonding and interlocking of hardened concrete.

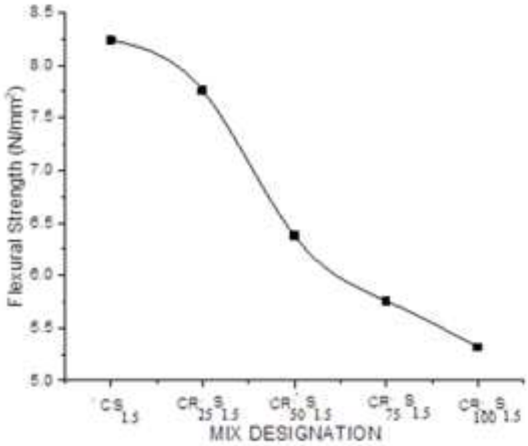


Chart -2: Flexural Strength Vs Mix Designation

Chart 2 shows that, the variation in flexural strength after 28 days of curing is 8.13% between C and $CS_{1.5}$. Whereas 9.09% and 10.10% between CR_{25}-$CR_{25}S_{1.5}$ and CR_{50}-$CR_{50}S_{1.5}$ respectively. The variation in flexural strength after 28 days curing are 14.18%, 14.5% between CR_{75}-$CR_{75}S_{1.5}$ and CR_{100}-$CR_{100}S_{1.5}$ respectively. Hence it can be concluded that, comparing all mixes $CR_{25}S_{1.5}$ gives greater flexural strength.

3.3 Split Tensile Strength

Split Tensile strength (τ_{sp}) is given by the formula;

$$Tsp = 2P/\pi DL$$

Where Tsp = Split tensile strength (N/mm2) ,P = Applied load (N), D = Diameter of the specimen (mm) , L = Length of the specimen (mm)

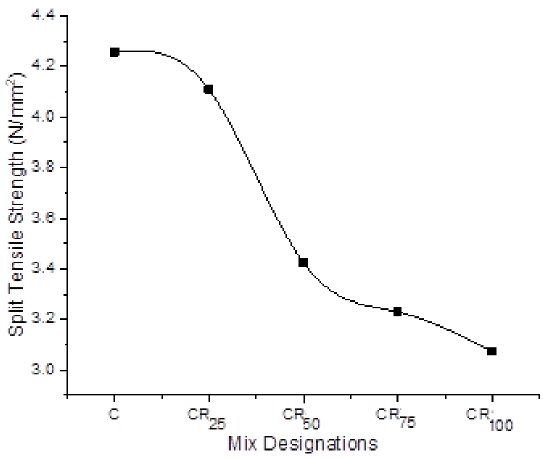


Chart -3: Split Tensile Strength Vs Mix Designation

Split tensile strength of each mix was determined for each mix at 28 of curing and reported in Fig. 5.4. From Fig. 5.4 it can be seen that split tensile strength of CR_{100} is less than compare to CR_{25}, CR_{50} and CR_{75} . This may due to the presence of 100% recycled aggregate used for preparing CR_{100}. Higher split tensile strength of CR_{25}, CR_{50} and CR_{75} is due to the higher strength of NA when compared with RA.

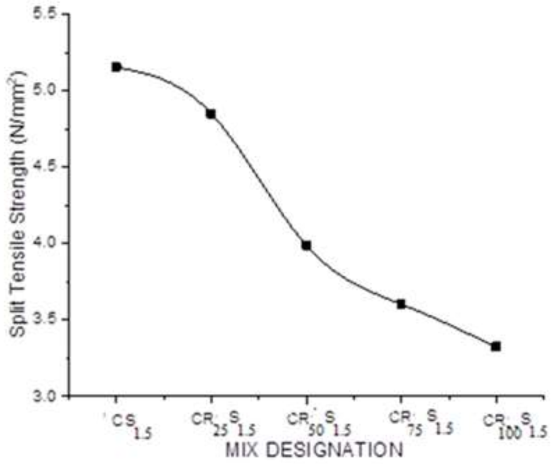


Chart -4: Split Tensile Strength Vs Mix Designation

From Figure, it can be observed that, the variation in split tensile strength after 28 days of curing is 21.06 % between C and $CS_{1.5}$. Whereas 18.05% and 16.49% between CR_{25} – $CR_{25}S_{1.5}$ and CR_{50}-$CR_{50}S_{1.5}$ respectively. The variation in split tensile strength for CR_{75} –$CR_{75}S_{1.5}$ and CR_{100}-$CR_{100}S_{1.5}$ after 28 of days curing are 11.61%, 8.13%. Hence it can be concluded that, comparing all mixes $CR_{25}S_{1.5}$ gives greater split tensile strength. This is due to the presence of interlocking effect of Steel Fibre in it.

4. CONCLUSIONS

The changes in fresh and hardened properties of Preserved Quality of RCA by using the new combination method proposed has investigated. From the experimental results, the important conclusions are summarized as follows:

• The slump value for new combination method mix is higher than control mix and hence new combination method mix is more workable.

• New combination method improves significantly the mechanical properties of RCA when 1.5% of Hooked End Steel Fibre is used.

• The pretreated RCA improves the mechanical properties of fresh and hardened concrete. The replacement of 25% of virgin aggregates shows comparable cube compressive strength to that of normal concrete.

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