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EXPERIMENTAL STUDY ON STRENGTH BEHAVIOUR OF FIBRE REINFORCED SELF COMPACTING CONCRETE USING RECYCLED AGGREGATE

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ABSTRACT

The construction of modern structures alarming the attention of use of materials with improved properties in respect of strength, stiffness, toughness and durability. Concrete is one of the most widely used construction material having several advantages such as high strength, good mould ability and high durability. The major disadvantages of concrete are its poorer tensile strength and lesser ductility (toughness). Conventional concrete used in building construction and engineering applications requires compaction to attain strength, durability and homogeneity. The typical method of compaction, by vibration, generates delays and additional costs in projects and could pose a serious health hazard due to noise pollution in and around construction sites.

Self Compacting Concrete (SCC) is a concrete which is highly flowble, can flows readily into place, fill the formwork without any compaction and without undergoing any significant segregation.

Recycling is the act of processing the used material for creating a new useful product. Construction and Demolished waste also generate Recycled Aggregate (RA). Such a Recycled Aggregate proved to be a reliable alternative to Natural Aggregates (NA) in concrete. There is a growing need for renovation from a usual consumption based society to a sustainable society owing the natural environment pollution, exhaustion of natural resources and as decreasing capacity of disposal facilities for final waste. Use of aggregates from Building Demolished Waste (BDW) in structural concrete is definitely an important stride. Use of RA in developing SCC is certainly a novel thought towards achieving a sustainable concrete.

As concrete is basically used to resist compression, the knowledge of its behaviour in compression is very important. The usual reinforced concrete exhibits superior ductile characteristics because of direct and indirect imprisonment of concrete by lateral ties and fibres respectively. The provision of fibres acts as crack arrestors, restricting the development of crack and thus, transferring the brittle nature of concrete to ductile concrete. This indirectly helps in the safeguard of concrete under compressive load. Due to the inert confinement of fibres in the core concrete, there is a good bond with core and cover. Thus, the spalling of cover is less in this type of imprisonment. In addition with lateral ties, the addition of fibres was found to improve the characteristics of deformation and in particular the veracity of concrete.

From the above literature review, it may be renowned that there is a pressing demand for the use of Recycled Aggregate in recent concretes, as sustainability is given the highest importance in today's world. This has necessitated the make use of Recycled Aggregates in SCC and fibre based SCC. However, it is evident, that there is no work available which has attempted developing Self Compacting Concrete (SCC) based on Recycled Aggregate (RA). It is also noticed that no work available on fibre

based SCC developed using RA. Hence Reinforced Self Compacting Concrete using Recycled Aggregate with fibres may be a potential material in construction. In order to clearly understand the performance of such a concrete, there is a call for to study the stress-strain and flexural strength behaviour.

The present study focuses on flexural bond strength behaviour of Fibre Reinforced Self Compacting Concrete by replacing the natural Aggregate with Recycled Aggregate. BDW is used as coarse aggregate in the concrete, with an aim to achieve sustainable concrete.

Introduction

Self-Compacting Concrete (SCC) can be defined as a concrete that is able to flow in the interior of the formwork, filling it in a natural manner and passing through the reinforcing bars and other obstacles, flowing and consolidating under the action of its own weight (Okamura 1997). SCC was originally developed with the intention of simplifying casting operations in Civil Engineering constructions of large dimensions, where high percentage of reinforcement or complex geometries difficult concrete flow. Soon it became clear, though, that the great productivity increase associated to SCC technology also habilitates it as a good solution for housing construction, precast industry and other applications (Lofgren 2005).

The fresh SCC requirements are mainly resumed to the filling ability, the passing capacity and the resistance to segregation. These properties are evaluated at the mix design stage, based on a series of tests in fresh samples with distinct apparatus (EFNARC 2002). Self-compacting ability in concrete depends on the performance level reached by the fresh mix in these tests.

The introduction of steel fibers in concrete is another issue of interest on the concrete technology. Steel fibers proved to have the potential to increase the post-cracking energy absorption capacity of cement based materials, enhancing the ductile character of concrete structures behavior, mainly of those with high redundant supports (Barros and Figueiras 1998).

The advantages associated to the addition of steel fibers to concrete mixes may be joined with the ones resulting from the self-compacting ability concept in concrete, with the formulation of steel fiber reinforced concrete mixes exhibiting self-compacting ability. The resulting material is, in this work, designated by Steel

Fiber Reinforced Self Compacting Concrete (SFRSCC) and, when compared to conventional concretes, presents clear technical advantages in terms of costs/benefits ratio. There exist, however, some drawbacks associated to the SFRSCC formulations, and the most relevant one is related to the strong perturbation effect produced by steel fibers on the flowing ability of fresh concrete. On one side, it is clear that the fluid properties of the fresh

SCC formulations are beneficial for the inclusion and homogeneous dispersion of steel fibers. On the other side, steel fibers are rigid and, consequently, do not easily accommodate to the dynamically changing shape of the bulk paste located between the particles constituting the granular skeleton structure. As a result, the design procedure and the optimization technique followed to achieve self-compacting requirements must be sensible to the fiber content, as well as to the geometrical and material properties of the fibers.

Recycling is the act of processing the used material for creating a new useful product. Construction and Demolished waste also produces Recycled Aggregate (RA). Such a Recycled Aggregate proves to be a reliable alternative to Natural Aggregates (NA) in concrete construction. There is a growing need for transformation from a conventional consumption based society to a sustainable society due to the pollution of natural environment, exhaustion of natural resources and due to the decreasing capacity of final waste disposal facilities. Use of aggregates from Building Demolished Waste (BDW) in structural concrete is definitely an important stride. Use of recycled aggregate in developing Self Compacting Concrete (SCC) is certainly a novel thought towards achieving a sustainable concrete.

As concrete is basically used to resist compression, the knowledge of its behaviour in compression is very important. The normal reinforced concrete exhibits improved ductile characteristics due to direct and indirect confinement of concrete by lateral ties and fibres respectively. The provision of fibres acts as crack arrestors, restricting the development of crack and thus, transferring the brittle nature of concrete to ductile concrete. This indirectly helps in the confinement of concrete under compressive load. Due to the passive confinement of fibres in the core concrete, there is a good bond with core and cover. Thus, the spalling of cover is less in this type of confinement. The addition of fibres along with the lateral ties was found to improve the deformation characteristics and especially the integrity of concrete.

From the literature review, it may be noted that there is a pressing demand for use of Recycled Aggregate in new concretes, as sustainability is given the highest importance in today's world. This has necessitated the use of Recycled Aggregates from Building Demolished Waste in SCC and fibre based SCC. However, it is evident, that there is no work available which has attempted developing Self Compacting Concrete (SCC) based on Recycled Aggregate (RA). There is also no work available on fibre based SCC developed using RA. Fibre Reinforced Self Compacting Concrete using Recycled Aggregate may be a potential material in construction. In order to clearly understand the behaviour of such a concrete, there is a need to study the stress-strain and flexural bond strength behaviour.

Objectives and Scope of Study

The present study focuses on flexural strength behaviour of Fibre Reinforced Self Compacting Concrete by replacing the natural Aggregate with Recycled Aggregate. Building Demolished Waste is used as aggregate in the concrete, with an aim to achieve sustainable concrete.

Literature Review

Extensive research works are being carried out globally using various types of materials. Sonebi et al (2003), reported the structural performance of full scale beams cast using ordinary concrete and SCC with steel fibres. A total of eight beams of class C35 and C60 were cast and tested. His investigation showed that the ultimate moment capacity of SCC60 beam was comparable with RC60 beams. The maximum deflection of SCC60 beam was higher than that of RC beam.

Ganesan et al (2006), reported an experimental investigation consisted of casting and testing of eighteen SFRSCC flexural elements. Their study showed that all the theoretical models available in the literature were found to underestimate the ultimate strength of SFRSCC beams. They suggested that modifications are required in these models to reduce the range of the predicability of the ultimate moment of SFRSCC members.

Moncef Nehdi and Jennifer Duquette Ladanchuk (2004), investigated the effects of fibre combinations on the workability and ability of SCC to flow around obstructions, its compressive and flexural strengths, flexural toughness and post first crack behaviour. Their aim was not to optimise FRSCC mixtures but rather to identify the synergistic effects of hybrid fibres in FRSCC that can serve for such optimisation in future. Their investigations show that all mixtures containing combinations of steel fibres had higher first crack loads than that of mixtures containing only one type of steel fibre. This is probably because fibres with different shapes and lengths could better control the micro mechanics of crack formation at different strain levels than single type of fibres.

Hemanth et al (2007), developed SCFRC for application in pre-stressed concrete beams. SCFRC mixes proved to have greater normalised tensile strength than the traditional fibrous concrete mixes for the same fibre factor.

Materials & Properties

General

The materials used for Fibre Reinforced Self Compacting Concrete (FRSCC) are selected from those by the conventional concrete industry. Typical materials used for FRSCC are coarse aggregate, fine aggregate, cement, mineral admixtures (fly ash, ground – granulated blast furnace slag), fibres and chemical admixtures (super – plasticizer, viscosity – modifying agents). FRSCC can be designed and constructed using a broad range of normal concreting materials, and that this is essential for FRSCC to gain popularity.

Materials

1.Cement

2.Aggregate

3.Water

4.Super plasticizer

5.Mineral Admixtures

6.Fibres

7.Recycled coarse aggregates

Cement

Cement is produced by calcining at high temperature an intimate mixture of calcareous, siliceous and aluminous substances and crushing the resulting clinkers to a fine powder. The properties of cements depend upon the chemical composition, the process of manufacture and the degree of fineness to which they are ground. When cement is mixed with water, a chemical reaction takes place as a result .of which the cement paste first sets and then hardens to a stone like mass. Depending upon their chemical composition, setting and hardening properties, cements can be broadly divided in the following two categories. :

a.Portland Cement , b.Special Cement

Aggregates

Fine and coarse aggregates make up the bulk of a concrete mixture. Sand, natural gravel and crushed stone are used mainly for this purpose. Recycled aggregates (from construction, demolition and excavation waste) are increasingly used as partial replacements of natural aggregates, while a number of manufactured aggregates, including air-cooled blast furnace slag and bottom ash are also permitted.

Decorative stones such as quartzite, small river stones or crushed glass are sometimes added to the surface of concrete for a decorative "exposed aggregate" finish, popular among landscape designers.

The presence of aggregate greatly increases the robustness of concrete above that of cement, which otherwise is a brittle material and thus concrete is a true composite material. Redistribution of aggregates after compaction often creates in homogeneity due to the influence of vibration. This can lead to strength gradients.

In terms of size, there are two broad categories of aggregate as below:

1)Coarse Aggregate-Retained over 4.75 mm IS Sieve.

2)Fine Aggregate -Passing through 4.75 mm IS Sieve.

Fibres

Steel fiber of diameter 0.92mm, fiber had a tensile strength and a specific gravity of 331Mpa and 7.850, respectively. The main variables used in the study are three different values of aspect ratios (15, 25 and 35) and the corresponding lengths are 13.8mm, 23 mm and 32.2mm respectively. Three different values of percentage of volume fraction of steel fibers (0.5%, 1.0% and 1.5%) and the corresponding weights are 39.25, 78.50, and 117.75 kg/m3 respectively.

Mineral Admixtures

Blast Furnace Slag

Throughout the world there is an increasing focus on the need to recycle and to more fully utilise co-products of manufacturing processes in an attempt to conserve our finite natural resources. Technical evaluation supported by field experience has shown that co-products such as blast furnace slag have, in many applications, properties suitable to replace or supplement and improve traditional materials used.

Types of Blast Furnace Slag: Blast furnace slag in India is currently produced in three forms:

a) Blast Furnace Rock Slag (BFS): Molten slag on leaving the furnace is directed into ground bays where it air-cools to form a crystalline rock-like material (Figure 2.1). BFS is suitable for varied uses in building applications as aggregates in concrete, construction of roads in base and sub-base courses either unbound or bound. It can also be mixed with other materials for mechanical stabilising or as a cementing or stabilising binder.

Blast Furnace Rock Slag

When compacted, BFS develops a high degree of mechanical particle interlock resulting in high shear strength partly due to the rough texture (vesicular nature) of the slag. The chemical reactivity of the slag causes it to be self-cementing and produces engineering fill, which over a period of time forms a semi-rigid mass.

BFS can be crushed and screened to a full range of aggregate sizes. BFS should not be simply substituted for natural aggregate in an existing concrete mix without considering differences in grading, particle shape, water absorption and particularly particle density. As for any aggregate, a concrete mix should be specifically designed to suit the characteristics of the aggregate. Therefore, the slightly lower particle density and higher water absorption of slag, due to its vesicular structure, should be taken into account in the mix design.

b) Granulated Blast Furnace Slag (GBFS): Molten slag, on leaving the blast furnace is directed into a specialized plant known as a granulator in which high pressure, high volume, cold water sprays to rapidly cool the molten slag resulting in the formation of an amorphous, coarse sand sized material exhibiting hydraulic cementitious properties.

Granulated Blast Furnace Slag

Although the principal use of GBFS is in the manufacture of slag blended cement and Ground Granulated Blast Furnace Slag, it can be used as lightweight aggregate where its high fire resistance and insulation properties make it an excellent aggregate for concrete and masonry units where high fire resistance is required. It can also be used in geopolymer concrete, as an additive for glass manufacture, as a lightweight fill and in engineered fill applications.

c) Ground Granulated Blast Furnace Slag (GGBFS): Granulated Blast Furnace Slag when dried and milled to cement fineness and in the presence of a suitable activator becomes a cementitious binder.

Ground Granulated Blast Furnace Slag (GGBFS)

Currently, GGBFS is predominately used in the form of blended cement to manufacture concrete or as a direct supplementary cementitious material addition in concrete manufacture. The reportable properties for GGBFS are specified in Australian Standard AS3582.211, Supplementary Cementitious Materials for Use with Portland and Blended Cement: Part 2: Slag – Ground Granulated Blast Furnace Slag. The specified properties for slag blended cement are detailed in Australian Standard AS397212, Portland and Blended Cement.

TESTS for FRSCC

It is important to appreciate that none of the test methods for FRSCC has yet been standardized and the test described are not yet perfected or definitive. The methods presented here test procedures are descriptions rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised specifically for FRSCC.

Existing rheological test procedures have not been considered here, through the relationship between the results of these tests and the rheological characteristics of concrete is likely to figure out highly in future work, including standardization work. Many of the comments made come from the experience of the partners in the EU-funded research project on FRSCC. A further EU project on test methods is about to o far destart.In considering these tests, there are number of points which should be taken in to account.

One principal difficulty in devising such tests is that they have to assess three distinct, though related, properties of fresh SCC-its filling ability(flow ability),its passing ability(free from blocking at reinforcement),and its resistance to segregation(stability).No single test so far devised can measure all three properties.

There is no clear relation between test results and performance on site.

There is little precise data, therefore no clear guidance on compliance a limits.

Duplicate tests are advised.

The test methods and values are started for maximum aggregate size of up to 20 mm; different test values and for different equipment dimensions may be appropriate for other aggregate sizes.

Different test values may be appropriate for concrete being placed in vertical and horizontal elements.

Similarly different test values may be appropriate for different reinforcement densities.

In performing the tests, concrete should be sampled in accordance with EN 12350-1.It is wise to mix the concrete first with a scoop, unless the procedure indicates otherwise.

SLUMP FLOW & T50 TEST

Slump flow is one of the most commonly used SCC tests at the current time. This test involves the use of slump cone used with conventional concretes as described in ASTM C 143(2002).The main difference between the slump flow test and ASTM C 143 is that the slump flow test measures the “spread” or “flow” of the concrete sample once the cone is lifted rather than the traditional “slump” (drop in height) of the concrete sample. The T50 test is determined during the slump flow test. It is simply the amount of time the concrete takes to flow to a diameter of 50 centimeters .Typically, slump flow values of approximately 24 to 30 inches are within the acceptable range; acceptable T50 times range from 2 to 5sec.

Fig: Slump test

L-BOX TEST

The L-box value is the ratio of levels of concrete at each end of the box after the test is complete at each end of the box after the test is complete. The L-box consists of a "chimney "section and a "trough "section after the test is complete, the level of concrete in the chimney is recorded as H1,the level of concrete in the trough is recorded as H2.The L-box value(also referred to as the "L-box ratio", "blocking value", or "blocking ratio" is simply H2/H1.Typical acceptable values for the L-box value are in the range of 0.8 to 1.0.If the concrete was perfectly level after the test is complete, the L-box value would be equal to 1.0.Conversely,if the concrete was too stiff to flow to the end of the trough the L-box value would be equal to zero.

FUNNEL TEST AND–FUNNEL TEST AT T5 MINUTES

V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20 mm. The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus is measured .After this the funnel can be refilled concrete and left for 5 minutes to settle .If the concrete shows segregation then the flow time will increase significantly.

Fig: L Box Test

Fig: V-Funnel Test And–Funnel Test At T5 Minutes

Acceptance criteria for SCC

S. No.	Method	Unit	Typical range of values	
			Minimum	Maximum
1.	Slump flow test	mm	650	800
2.	T50cm slump flow	Sec	2	5
3.	V-funnel test	Sec	6	12
4.	V-funnel at T_5 minutes	Sec	6	15
5.	L-Box test	H2/H1	.8	1.0

Compressive strength of concrete

Compressive strength of concrete is defined as the load, which causes the failure of a standard specimen. (Ex 100 mm cube according to ISI) divided by the area of cross-section in uni-axial compression under a given rate of loading. The test of compressive strength should be made on 150mm size cubes.

Fig:cubes

Fig: curing

Place the cube in the compression-testing machine. The green button is pressed to start the electric motor. When the load is applied gradually, the piston is lifted up along with the lower plate and thus the specimen application of the load should be 300 KN per minute and can be controlled by load rate control knob. Ultimate load is noted for each specimen. The release valve is operated and the piston is allowed to go down. The values are tabulated and calculations are done.

Fig:compersive strength

Split Tensile strength of concrete.

A concrete cylinder of size 150mm dia×200mm height is subjected to the action of the compressive force along two opposite edges, by applying the force in this manner .The cylinder is subjected to compression near the loaded region and the length of the cylinder is subjected to uniform tensile stress.

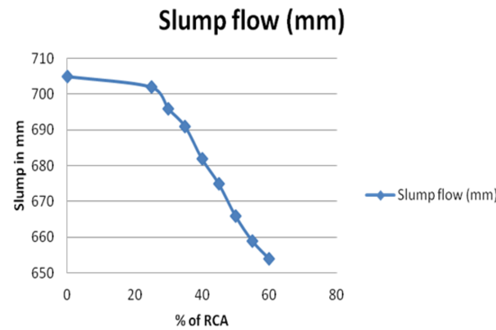
Horizontal tensile stress = $2P/\pi DL$

Where P = the compressive load on the cylinder.

L = length of the cylinder

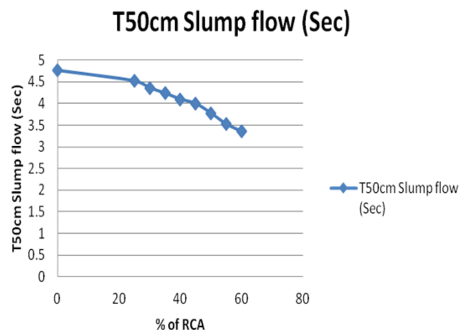
D = dia of cylinder

Fig: Split Tensile strength of concret**e**

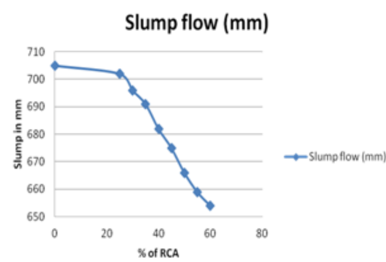


RESULTS AND DISCUSSION

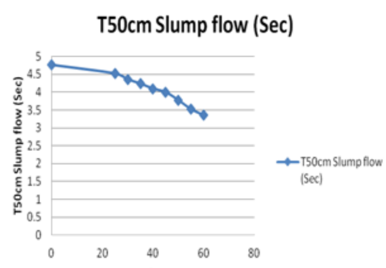
Fresh Concrete Properties of FRSCC



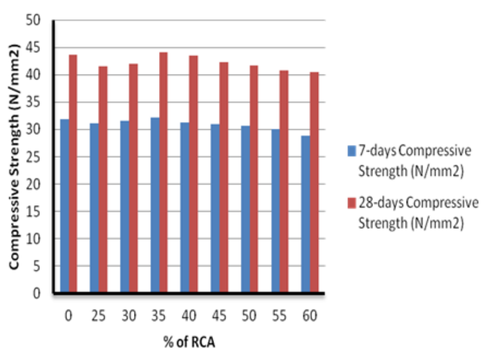
The rheological properties are assessed by using rheology tests such as Filling, Passing and Segregation resistance. When coarse aggregate is replaced with RCA, a lower dosage of Super plasticizer is required to maintain the same filling ability. T50 times indicate the viscosity of highly flowable concrete mixes. Lower time indicates greater flowability. The T50 was influenced by the dosage of water and super plasticizer. V funnel test was performed to assess the flowabilty and stability of the SCC. The rheological properties are shown in Table.



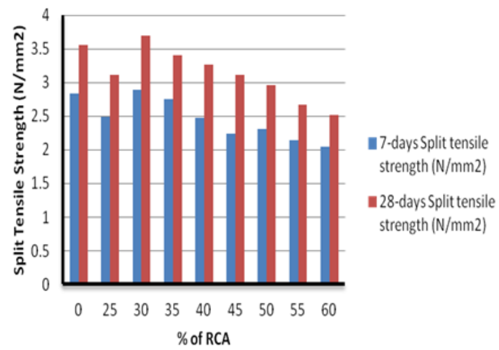
Mix	Slump flow (mm)	T_{50cm} Slump flow (Sec)	V-funnel (Sec)	V-funnel $T_{5\ minutes}$ (Sec)	L-Box H_2/H_1
SCC	705	4.76	8	1.62	0.92
S- RCA 25%	702	4.52	9	1.75	0.91
S- RCA 30%	696	4.36	9	1.89	0.89
S- RCA 35%	691	4.24	10	1.99	0.89
S- RCA 40%	682	4.10	10	2.08	0.85
S- RCA 45%	675	4.00	10	2.19	0.83
S- RCA 50%	666	3.78	11	2.33	0.80
S- RCA 55%	659	3.53	11	2.65	0.77
S- RCA 60%	654	3.36	12	2.99	0.75



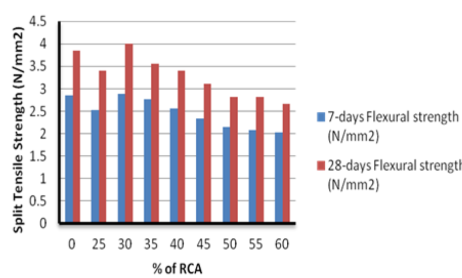
Mix	7-days Compressive Strength (N/mm²)	28-days Compressive Strength (N/mm²)
SCC	**31.80**	**43.70**
SCC_25% RCA	31.11	41.48
SCC_30% RCA	31.56	42.07
SCC_35% RCA	**32.15**	**44.15**
SCC_40% RCA	31.26	43.56
SCC_45% RCA	30.96	42.37
SCC_50% RCA	30.67	41.63
SCC_55% RCA	30.07	40.74
SCC_60% RCA	28.89	40.44



Specifications	7-days Split tensile strength (N/mm²)	28-days Split tensile strength (N/mm²)
SCC	2.84	**3.56**
SCC_25% RCA	2.49	3.11
SCC_30% RCA	**2.89**	**3.70**
SCC_35% RCA	2.76	3.41
SCC_40% RCA	2.48	3.26
SCC_45% RCA	2.24	3.11
SCC_50% RCA	2.31	2.96
SCC_55% RCA	2.14	2.67
SCC_60% RCA	2.04	2.52



Specifications	7-days Flexural Strength (N/mm²)	28-days Flexural Strength (N/mm²)
SCC	2.86	**3.85**
SCC_25% RCA	2.52	3.41
SCC_30% RCA	**2.89**	**4.00**
SCC_35% RCA	2.77	3.56
SCC_40% RCA	2.56	3.40
SCC_45% RCA	2.33	3.11
SCC_50% RCA	2.14	2.81
SCC_55% RCA	2.08	2.81
SCC_60% RCA	2.03	2.67



Conclusions & Recommendations

In the present investigation, the replacement of coarse aggregate was carried out in the range of 25% - 60% at an increment of 5%. From the various experiment results, the following conclusions are drawn.

- It is found that as the natural aggregate replaced by RCA the strength of the concrete decreases.

- Use of the waste aggregate in the new concrete as the recycled concrete aggregate reduces the environmental pollution as well as providing an economic value for the waste material and water absorption of RCA is higher than natural aggregate.

- There is an increase in the strength of FRSCC when the coarse aggregate was replaced by RCA at 30-35% than other mixes. This also reduces the coarse aggregate content by increasing the RCA thus reducing the further cost of SCC mixes developed.

- Therefore, based on the test results, it is recommended that the RCA can be replaced with natural aggregate 30% to 35%.

Further Scope of Study

1.In this study it is confined to replacement of aggregate with RCA, RCA concrete with % variation of fibres can be studied.

2.Durability investigations for longer periods say six months, one year and three years of the concrete samples can be made with % variation RCA and % Fibres.

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