STUDY OF EFFICACY OF USING RECYCLED WASTE CONCRETE AS FINE AGGREGATES IN SELF-COMPACTING CONCRETE

A thesis submitted

In partial fulfilment of the requirements for

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MASTERS OF ENGINEERING

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STRUCTURAL ENGINEERING

Submitted by

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JULY 2013

DECLARATION

I hereby declare that the thesis entitled " **Study of Efficacy of Using Recycled Waste Concrete as Fine Aggregates in Self- Compacting Concrete** "is an authentic record of my own work carried out as requirements for the award of degree M.E. (Structures) at Thapar University, Patiala, under the guidance of Dr. Mehtab Alam, Prof. & Head, CED, JMI, New Delhi and Dr. Shruti Sharma, Assistant Professor, CED, during year July 2013.

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CERTIFICATE

This is to certify that the thesis entitled " **Study of Efficacy of Using Recycled Waste Concrete as Fine Aggregates in Self- Compacting Concrete** " being submitted by **Charush, Roll No.820922006** in partial fulfilment for the award of degree of **Masters of Engineering in Structural Engineering** at **Thapar University,Patiala** is a bonofide work carried out by him under my guidance and that no part of this thesis has been submitted for the award of any other degree.

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ABSTRACT

“Self-Compacting Concrete (SCC) represents one of the biggest modern innovations in the construction field worldwide. Until now, on an international level, the number of constructions using SCC as a main material is limited. A self-compacting concrete (SCC) is the one that can be placed in the form and can go through obstructions by its own weight and without the need of vibration. Since its first development in Japan in 1988, SCC has gained wider acceptance in Japan, Europe and USA due to its inherent distinct advantages. SCC provides better quality especially in the members having reinforcement congestion or decreasing the permeability and improving durability of concrete”.

In the present graduate thesis there is a thorough report on mechanical properties and the major attributes of the fresh and hardened concrete, as well as on the methods of production and the ingredients of the recycled materials. The primary study is to explore the acceptability of demolished concrete waste aggregate to make self compacting concrete of high strength and desirable properties. It addresses experiments on various mixes of self compacting concrete – one with fresh coarse and fine aggregates, while the others with replacement of 25%, 50 %, 75% and 100% recycled fine aggregates.

Results showed the fresh, hardened and durability properties of all the concrete mixes were comparable. The compressive strength of all the concrete mixes was measured at the age of 7 and 28 days.

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CHAPTER 1 INTRODUCTION

1.1 General

Construction is the backbone of infrastructural development and it derives its basic ingredients, which are sand and stone aggregate from nature. In the current scenario, the construction works is on boom, which leads to various environmental hazards such as

- The construction industry has ruined the ecological balance up to a great extent by taking away the natural stock of aggregates.
- The heavy machinery involved to extract the stone aggregates from quarrying operates on fuels releasing obnoxious gases and fumes.
- The air pollution from quarrying caused by release of suspended particulate matter into the atmosphere leads to danger for the working staff and the adjoining population.
- The particulate matter from quarrying also runs off to the nearby rivers or water bodies, which pollute the water and destroye the aquetic life.
- The working quarry needs methods of transportation and this means that large amounts of machinery and heavy traffic will be brought into the area, causing an increase in local noise and air pollution.

To facilitate the non use of natural aggregates from the nature, various steps to be taken by the construction industry for the infrastructure development. The use of recycled aggregates is the new step in developing the concrete for the construction practices.

1.2 Objectives of Thesis

- To study the properties of recycled fine aggregates for their use in concrete.
- To compare the fresh and the hardened properties of Self Compacting Concrete made in different proportion of recycled fine aggregates with the Self Compacting Concrete using fresh aggregates and to justify the use of recycled fine aggregates in self compacting concrete.

1.3 Brief Methodology

- The trial mixes were prepared by the use of the guidelines given in **IS: 10262:2009** (code of practice for mix design of normal concrete); published paper of **Su. et al.,**

2001,” A simple mix design method for self compacting concrete” and the mix design of Self compacting concrete (M35) from **Ambuja Cement**.

- Several changes were made through trials in the design to obtain the properties of self compacting concrete.
- Initially the conventional self compacting concrete was made and the fresh and hardened properties was checked.
- Recycled fine aggregates were used in proportion of 100%, 75%, 50% and 25% replacement of natural fine aggregates.
- The results of fresh and hardened properties for the conventional self compacting concrete and the self compacting concrete made from various proportion of replaced recycled fine aggregates were compared.

1.4 Background of Self Compacting Concrete

Self compacting concrete (SCC) is considered to be one of the most important innovations.When large quantity of heavy reinforcement is to be placed in a Reinforced concrete (RC) member, it is difficult to ensure that the formwork gets completely filled with concrete, that is, fully compacted without voids or honeycombs. Compaction by manual or by mechanical vibrators is very difficult in this situation. The typical method of compaction, vibration, generates delays and additional cost in the projects. Underwater concreting always required fresh concrete, which could be placed without the need to compaction; in such circumstances vibration had been simply impossible.This problem can now be solved with self-compacting concrete. This type of concrete flows easily around the reinforcement and into all corners of the formwork. Self-compacting concrete describes a concrete with the ability to compact itself only by means of its own weight without the requirement of vibration. Self-compacting concrete also known as Self-consolidating concrete or self levelling concrete.

Self-compacting concrete is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of Self compacting concrete makes it suitable for placing in difficult conditions and in sections with congested reinforcement. Use of SCC can also help minimize hearing-related damages on the worksite that are induced by vibration of concrete. Another advantage of Self compacting concrete is that the time required to place large sections is considerably reduced.

Self Compacting Concrete was first developed in japan around the year 1980. Professor H. Okamura from the University of Tokyo, Japan is mainly responsible for initiating the development of such concrete. Self compacting concrete can be considered as the greatest technical advancement and most revolutionary development in concrete technology over the years, atleast from 1980 till today. This is the concrete of the future, as it will be replacing the normal concrete because of ts many advantages.

Self-compacting concrete is placed or poured in the same way as ordinary concrete but without vibration. It is very fluid and can pass around obstructions and fill all the nooks and corners without the risk of either mortar or other ingredients of concrete separating out, at the same time there are no entrapped air or rock pockets. This type of concrete mixture does not require any compaction and saves time, labour and energy. The surface finish produced by self-compacting concrete is exceptionally good and therefore, patching will not be required.

A large number of research projects were carried out, followed by recommendations for potential users. Especially for the precast concrete industry self compacting concrete was a revolutionary step forward. Contrary to that, casting of Self compacting concrete at the construction site was regarded with more reservation. The variable conditions at the construction site, the more complicated control of the mixture composition and disagreement with regard to the question how the properties should be measured at the site were retarding factors.

Current Indian scenario in construction shows increased construction of large and complex structures, which often leads to difficult concreting conditions. Vibrating concrete in congested locations may cause some risk to labour in addition to noise stress. There are always doubts about the strength and durability placed in such locations. So it is worthwhile to eliminate vibration in practice, if possible. In countries like Japan, Sweden, Thailand, UK etc., the knowledge of Self compacting concrete has moved from domain of research to application. But in India, this knowledge is to be widespread.

1.5 Properties & Tests

The properties of SCC involves the fresh properties , the hardened properties and the durability properties. These can be classified as following.

1.5.1 Fresh Properties of Self Compacting Concrete

There are three basic characteristics of self-compacting concrete namely filling ability (flowability), passing ability (free from blocking due to presence of reinforcement) and resistance to segregation (Stability/ homogeneity). Therefore, it is necessary to carryout field or mock trials to assess these characteristics.

Filling ability reflects the deformability of Self compacting concrete, i.e. the ability of fresh concrete to change in its shape under its own weight. Deformability includes two aspects: the deformation capacity is the maximum ability to deform, that is, how far concrete can flow; and deformation velocity refers to the time taken for the concrete to finish flowing, that is, how fast concrete can flow. Filling ability is a balance between deformation capacity and deformation velocity. For example, a concrete with high deformation capacity and very low deformation velocity tended to be very viscous and would take long time to fill the formwork. The slump flow test is used to assess the horizontal free flow of Self compacting concrete in the absence of obstructions. This is one of the simplest tests initially developed in Japan for assessment of underwater concrete. The Slump flow test is the most commonly used test for Self compacting concrete and gives a good assessment of the filling ability. However, it gives no indication of the ability of the concrete to pass between the reinforcement without blocking, but may give some indications on resistance to segregation, that too for an experienced eye. This test can be used at site to assess the consistency of supply of ready mixed concrete.

Various test for Fresh Properties of SCC are

- Slump flow test
- J- Ring test
- V- Funnel test
- L- Box test
- U- Box test

The details of these tests are explained in the next chapter.

1.5.2 Strength Properties of Self Compacting Concrete

The mechanical or the hardened properties of Self Compacting Concrete can be predicted during its hardened state. The compressive strength and the tensile strength are the major parameters. Various test for Mechanical Properties of SCC are

a) Compressive Strength Test

b) Modulus of Elasticity Test
c) Modulus of Rupture Test (Flexural Strength Test)
d) Splitting Tensile Test

The details of these tests are explained in the next chapter.

1.5.3 Durability Properties of Self Compacting Concrete

Durability is a general analysis of the service life and the performance of concrete in an aggressive environment. Physical damage to concrete includes wetting/drying, freeze/thaw or heating/cooling cycles. Chemical damage consists of sulphate attack, acid attack, chloride attack and alkali-silica reaction (ASR) in which water acts as a carrier. All are greatly related to the resistance of the cover layer to transport mechanisms such as permeation, absorption and diffusion of gas and liquid. Various test for Durability of SCC are

a) Absorption Test
b) Permeability Test
c) Diffusion Test

The details of these tests are explained in the next chapter.

1.6 Recycled Concrete Aggregate

When structures made of concrete are demolished or renovated, concrete recycling is an increasingly common method of utilizing the rubble. Concrete was once routinely trucked to landfills for disposal, but recycling has a number of benefits that have made it a more attractive options in this age of greater environmental awareness, more environmental laws, and the desire to keep construction costs down.

1.6.1 Recycling of Aggregates

Concrete aggregates collected from demolition site is put through a crushing machine. Crushing facilities accept only uncontaminated concrete, which must be free of trash, wood, paper and other such materials. Metals such as rebar are accepted, since they can be removed with magnets and other sorting devices and melted down for recycling elsewhere. The remaining aggregates chunks are sorted by size. Larger chucks may go through the crusher again. After crushing has taken place, other particles are filtered out through a variety of methods including hand-picking and water flotation.

1.6.2 Advantages of recycling aggregates

Transportation agencies' experiences and research studies have shown that recycled concrete aggregate (RCA), under specific conditions, has the potential to produce strong, durable materials suitable for use in the highway infrastructure. The advantages that occur through usage of recycled aggregate are listed below.

1. **Performance**

The compressive strength and the tensile strength of the concrete made with recycled aggregates may not be as good as the normal concrete but can perform well in various fields.

2. **Resource Conservation**

Recycled material can be used within the same metropolitan area. This can lead to a decrease in energy consumption from hauling and producing aggregate, and can help improve air quality through reduced transportation source emissions.

3. **Economic Benefit**

- Recycled concrete is crushed easily and the entire aggregate product can be used as a base material according to specifications, therefore generating no waste. Production of virgin aggregate can use more fuel to crush due to larger initial size of rock needing to be crushed to desired grade.
- **Reduce disposal costs:** Disposal of concrete rubble and other waste construction materials by dumping or burial is a less attractive and more expensive option. Recycling can therefore alleviate some of these problems.
- **Overall project savings:** There may be considerable project savings by using a less amount of virgin aggregate. This saving is increased by the reduction of transportation and disposal costs. Another economic benefit is the recovery of steel from the recycling process. This material usually becomes property of the contractor, who can sell as scrap metal. There is no potential for cost savings in many areas where aggregates are not locally available, and have to be hauled long distances, often 50 miles or more. Environmental impacts reduction and extending available life of landfills is also a long term benefit that can be experienced by local government due to increased recycling of RCA.

4. **Job Opportunities**

There will be many people involved in this new technology, such as specialized and skilled persons, general workers, drivers and etc.

5. **Sustainability**

The amount of waste materials used for landfill will be reducing through usage of recycled aggregate. This will reduce the amount of quarrying. Therefore this will extend the lives of natural resources and also extend the lives of sites that using for landfill.

6. **Market is Wide**

The markets for recycled concrete aggregate are wide. According to Environmental Council of Concrete Organization, recycled concrete aggregate can be used for sidewalk, curbs, bridge substructures and superstructures, concrete shoulders, residential driveways, general and structural fills. It also mentioned that recycled concrete aggregate can be used in sub bases and support layers such as unstabilized base and permeable bases.

1.6.3 Disadvantages of Recycled Aggregates

Although there are many advantages of using recycled aggregate. But there are still some disadvantages in recycled aggregate usage.

1. **Higher water absorption**

A higher water absorption by the aggregates is always linked with a potential to decrease the strength of the concrete formed by them. Thus their usage involves comprehensive study of the amount and rate of water absorption to alter the mix design accordingly.

2. **Lower density and specific gravity**

Comparatively lower density of recycled aggregate may be a parameter of rejection for them in many cases where very high strength is needed.

3. **Higher content of impurities**

Since recycled aggregates are obtained from rubble, construction and demolition waste and debris the content of impurities and unwanted materials is expected to be higher.

4. **Lack of Specifications and Guidelines**

There is no specification or any guideline when using recycled concrete aggregate in the constructions. In many cases, the strength characteristic will not meet the requirement, when using recycled concrete aggregate. Also the recycled aggregates obtained from every source would have different properties. Thus mix design will be different in every case too without any specific guidelines and codal provisions.

5. **Lower freeze-thawing resistance**

Recycled aggregates are expected to have low freeze and thaw resistance thus limiting their application in highly cold environments.

6. **Increased shrinkage**

The shrinkage problem in recycled aggregates is difficult to handle usually the extent of shrinkage is unpredictable.

7. **Reduced durability**

Recycled aggregates are extracted from an already set state through mechanical impaction means followed by their crushing using jaw crushers. Thus there is a high expectation of reduced durability.

8. **Water Pollution**

This recycled process will cause water pollution. Morris of National Ready Mix Concrete Association (et.al) had mentioned that the wash out water with the high pH is a serious environmental issue. According to Building Green (1993), the alkalinity level of wash water from the recycling plants is pH12. This water is toxic to the fish and other aquatic life.

9. **Time constraint**

Since a lot of judgment, experimentation and technical assessment is involved in the process of selection, extraction, crushing and testing for all properties in a comprehensive manner recycled aggregates may not be a strong contender for projects to be completed within a short notice.

10. **Cost**

Since only aggregates are required from construction and demolition waste their extraction from the debris could become very expensive in case cheap labour is not available.

1.7 Closing Remark

This chapter explain the importance of Self Compacting Concrete in the field of construction industry and the advantages and disadvantages of using recycled aggregates from demolished concrete with the properties and tests conducted on it.

2.1 Self Compacting Concrete

Self-compacting concrete is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of Self compacting concrete makes it suitable for placing in difficult conditions and in sections with congested reinforcement. Use of SCC can also help minimize hearing-related damages on the worksite that are induced by vibration of concrete. Another advantage of Self compacting concrete is that the time required to place large sections is considerably reduced.

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Strength properties of SCC predict the fresh and hardened values of its mixes. The compressive strength and the tensile strength are the most essential properties of every mixes, which gives the strength parameters of SCC.

2.2 Strength properties of SCC

Important engineering properties such as strength, dimensional changes and durability mainly depend on the pore system, such as the total surface area, the total pore volume, the pore size distribution and the pore connectivity (Neville, 1996).

In case of well designed self compacting concrete the homogeneity, mobility, cohesiveness helps placing concrete in formwork without compaction. This helps in better placement and also better interface between coarse aggregate and mortar paste as minimal interfacial zone develops. The microstructure of self compacting concrete can be therefore expected to be superior, promoting strength, impermeability, durability and ultimately longer service life of concrete.

2.3 Test for Fresh Properties of SCC

There are three basic characteristics of self-compacting concrete namely the filling ability, the passing ability and resistance to segregation. Therefore, it is necessary to carryout field or mock trials to assess these characteristics. The various tests are discussed as

2.3.1 Slump Test

Position the slump cone at the centre of the levelled flow table as shown in **Figure 2.1**. Pour the concrete with a scoop from top without tamping to fill the slump cone completely. Strike off excess concrete. Lift the cone vertically without any jerks and allow the concrete to flow freely. On lifting the slump cone, filled with concrete, the concrete flows.

The average diameter of the concrete circle is a measure for the filling ability of the concrete as shown in **Figure 2.2**. The time T50 cm is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm.

High slump flow value indicates greater flowability and lesser resistance to segregation. If T50cm time is observed to be less than the minimum range value specified then it indicates that viscosity is very low leading to segregation. If T50cm time value is observed to be more than maximum range value specified, it indicates very stiff and non flowable concrete.

The permissible range of values for slump flow is 650mm to 800mm and T50 cm test times are 2 to 5seconds.

It is to be noted that the material of the base plate can have some influence on these values. In any case same base material or rather base plate is to be used in all tests, both in the laboratory and on site.

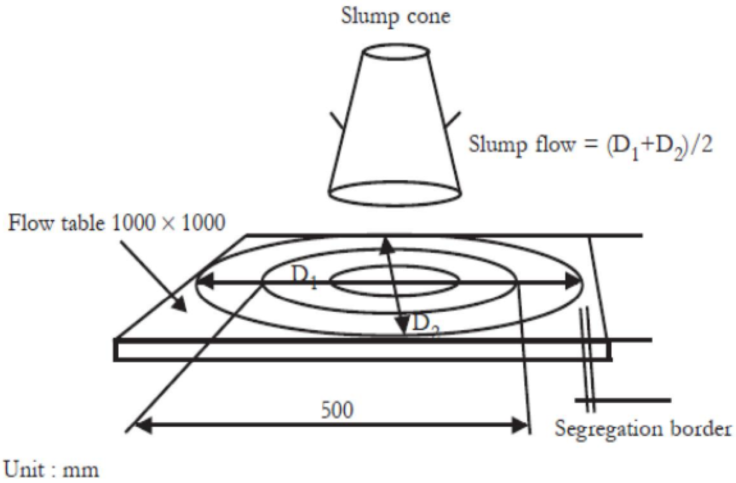


Figure 2.1 Slump Cone Test

(Missouri Department of Transportation Construction and Materials, 2012)

Figure 2.2 Measuring of Diameter

(Missouri Department of Transportation Construction and Materials, 2012)

2.3.2 V-Funnel Test

The equipment consists of a V-shaped funnel, shown in **Figure 2.3**. The flowability and also segregation resistance of the fresh concrete can be tested with the V-funnel test, where by the flow time is measured as shown in **Figure 2.4**. The funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus is measured. Further, T 5minutes is also measured with V-funnel, which indicates the tendency for segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation, the flow time will increase significantly. According to Khayat and Manai, a funnel test flow time less than 6sec is recommended for a concrete to qualify for a Self compacting concrete**.**

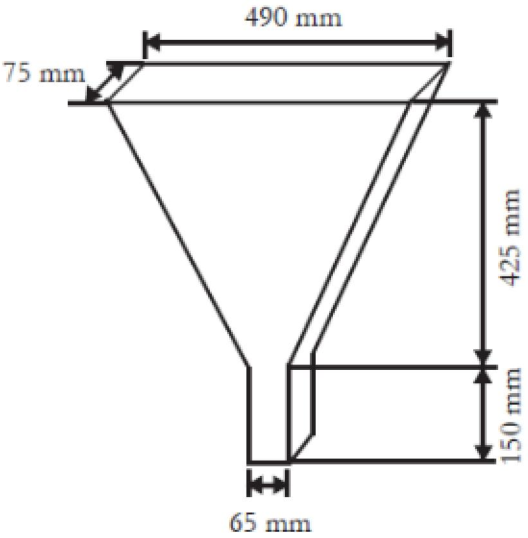


Figure 2.3 V-shaped funnel

(Missouri Department of Transportation Construction and Materials, 2012)

Figure 2.4 Measuring of Flow Time

(Missouri Department of Transportation Construction and Materials, 2012)

2.3.3 L-Box Test

The passing ability and also the filling ability is determined using the L- box test as shown in **Figure 2.5**. The L-box test method uses a test apparatus comprising a vertical section and a horizontal trough into which, the concrete is allowed to flow on the release of a trap door from the vertical section passing through reinforcing bars placed at the intersection of the two areas of the apparatus as shown in **Figure 2.6**. The concrete ends of the apparatus H1 and H2 measure the height of the concrete at both ends. The L-box test can give an indication as to the filling ability and passing ability. The specified requisite is the ratio between the heights of the concrete at each end or blocking ratio to be ≥ 0.8.

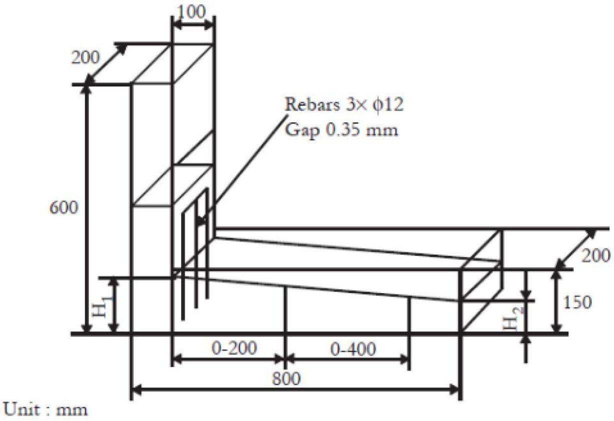


Figure 2.5 L-box Test Apparatus

(Missouri Department of Transportation Construction and Materials, 2012)

Figure 2.6 Testing of Passing & Flow Ability

(Missouri Department of Transportation Construction and Materials, 2012)

2.4 Test for Strength properties of SCC

Strength is one of the most important properties specified for concrete because it is a direct reflection of the capacity of the structure to resist forces and it is a reasonable indicator of other properties.

2.4.1 Compressive strength

Where the W/P ratios are similar, the compressive strength and the strength development of SCC are not significantly different from Normal concrete.

A minimum of 9 compressive strength cylinders were cast for each mix design. All specimens were prepared in accordance with ASTM C 192-07, “Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory”. The molds were lubricated using oil prior to the placement of concrete. The mixes were placed in one continuous lift. After allowing for 16 to 24 hours of setting time, the concrete specimens were removed from the molds and placed inside a temperature-controlled moist curing room until the designated testing date.

The testing of the compressive strength of the experimental mixes was performed in accordance with ASTM C 39-11, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” A minimum of 3 compressive strength cylinders were used at each test age. Testing occurred at 7, and 28 days after batching. At least two hours before the compressive strength test was to occur, the concrete specimens were removed from the moist curing chamber and the moisture was removed from the ends. The specimen was then placed in the apparatus, centered, and brought to just below the upper plate.

Figure 2.7 Compressive Strength Test

(Missouri Department of Transportation Construction and Materials, 2012)

When the setup was complete, the specimen was loaded at the specified rate until it could no longer sustain a load and the load rate dropped to a negative value. The machine was turned off and the peak load was recorded.

The load was then divided by the cross sectional area to get the measured compressive strength in pounds per square inch. A minimum of three specimens were tested at a given test age and the results were averaged to get the final measured compressive strength.

2.4.2 Modulus of Elasticity Test

Specimens used to measure the modulus of elasticity were fabricated according to ASTM C 192–07. These are the same type of specimens that were used for compressive strength testing. A minimum of three specimens were created for each mix design. Specimens were de-molded after 24 hours and placed in the moist curing chamber for 28 days before testing. Before the test was conducted, all test specimens were sulfur capped in the same manner as the compressive strength cylinders.

After the specimens were allowed to cure for 28 days, the specimens were tested in accordance with ASTM C 469–10, “Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression.” The dimensions of the specimens were measured, and before loading, the specimen was fitted with a compressometer in order to measure the deflection of the cylinder during loading. A typical compressometer can be seen in **Figure 2.8.**

The specimen was then placed into a compression loading apparatus and loaded at a constant rate. The load was recorded when the deflection of the specimen reached 0.0004 in. (0.01 mm). The specimen was continually loaded until the load reached 40% of the ultimate strength of the concrete. The value of the ultimate strength was determined from compressive strength tests of companion specimens. When the load on the specimen reached 40% of the measured ultimate load, the deflection was recorded. This test was then performed three additional times on the same specimen. The data recorded during the first test run on each specimen was disregarded and only the following three tests were used for averaging. Using these deflections, the strains were calculated and the corresponding stresses were used to calculate the modulus of elasticity using Equation:

$$= \frac{(\quad - \quad)}{(\quad - 0.00005)}$$

Figure 2.8 Modulus of Elasticity Test

(Missouri Department of Transportation Construction and Materials, 2012)

Where S2 is the stress measured at 40% of the ultimate load and S1 is the stress measured when the deflection of the specimen reached 0.0004 in. (0.01 mm) and ε_2 is the strain produced by S2. The results from the individual tests were then averaged and the averages from the three tests were then averaged to obtain the measured modulus of elasticity.

2.4.3 Modulus of Rupture Test

The modulus of rupture test is used to determine the flexural strength or tensile strength of the concrete. The specimens used for the modulus of rupture test were fabricated in accordance with ASTM C 78–10, “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).” Three specimens were fabricated for every concrete mix. The specimens were filled with two lifts, each lift being rodded 72 times. It should be noted that the SCC was not rodded when specimens were cast. The specimens were cast in one single lift. The specimens were de-molded after 24 hours and stored in a moist curing chamber for 28 days. After 28 days they were prepared for testing.

After 28 days, the specimens were removed from the moist curing chamber. In order to align the specimen on the supports, it had to be divided into thirds.

The load was applied at the aforementioned points. The test setup can be seen in **Figure 2.9**.

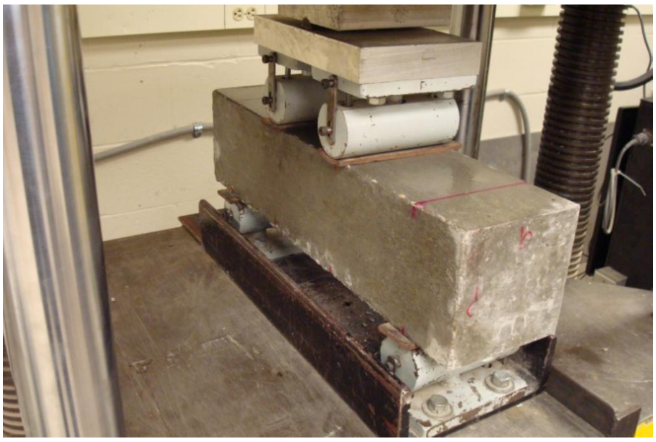


Figure 2.9 Modulus of Rupture Test

(Missouri Department of Transportation Construction and Materials, 2012)

The beam was then loaded at a constant rate until failure. If the beam failed within the middle third, the test was accepted. It should be noted that all beams tested in this investigation failed in the middle third of the beam. A post failure specimen can be seen in **Figure 2.10.**

Figure 2.10 Post Failure Specimen

(Missouri Department of Transportation Construction and Materials, 2012)

The failure load was recorded and subsequently used to calculate the modulus of rupture using Equation:

$$= \frac{\quad}{\quad}$$

The beam was removed from the testing apparatus and its dimensions were measured. The width and depth of the beam were measured three times and averaged.

Where P is the peak load, L is the distance between supports, b is the average width of the beam after testing, and d is the average depth of the beam after testing.

2.4.4 Splitting Tensile Test

The specimens used for the splitting tensile test were fabricated in accordance with ASTM C 496–11, “Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.” A minimum of three specimens were made for each concrete mix. The specimens used for the splitting tensile test were the same types of specimens used for the compressive strength test. The specimens were fabricated according to ASTM C 192. After 24 hours, the specimens were de-molded and placed in a moist curing chamber for 28 days, at which time they were then tested.

After the specimens were allowed to cure for 28 days, the specimens were removed from the curing chamber for testing. The diameter and height of the specimens were recorded. The diameter of the specimen was marked on the top of the specimen. Two lines were then drawn down the long side of the specimen from the previously drawn line. This was done to assist in lining up the specimen in the testing apparatus.

The specimen was then loaded into the testing apparatus on the line drawn down its vertical axis. The specimen was placed on a piece of plywood. Another plywood strip was placed on the top of the specimen between it and the load platen. These strips were used so the load would be distributed along the axis of the specimen. The test setup can be seen in **Figure 2.11.**

Figure 2.11 Spilliting Tensile Test

(Missouri Department of Transportation Construction and Materials, 2012)

The specimen was then loaded at a rate between 100 (45 kg) and 200 lb /min. (91kg/min.) until failure. The load at failure was recorded as the peak load, and the tensile strength was calculated using Equation:

$$= \frac{2}{\quad}$$

Where P was the peak load, L is the length of the specimen, and D is the diameter of the specimen.

2.5 Closing remarks

All the test discussed in this chapter are of paramount importance, mainly for SCC, because these properties not only governs the self compacting characteristics, but also decide the strength and influence the durability of hardened SCC.

3.1 General

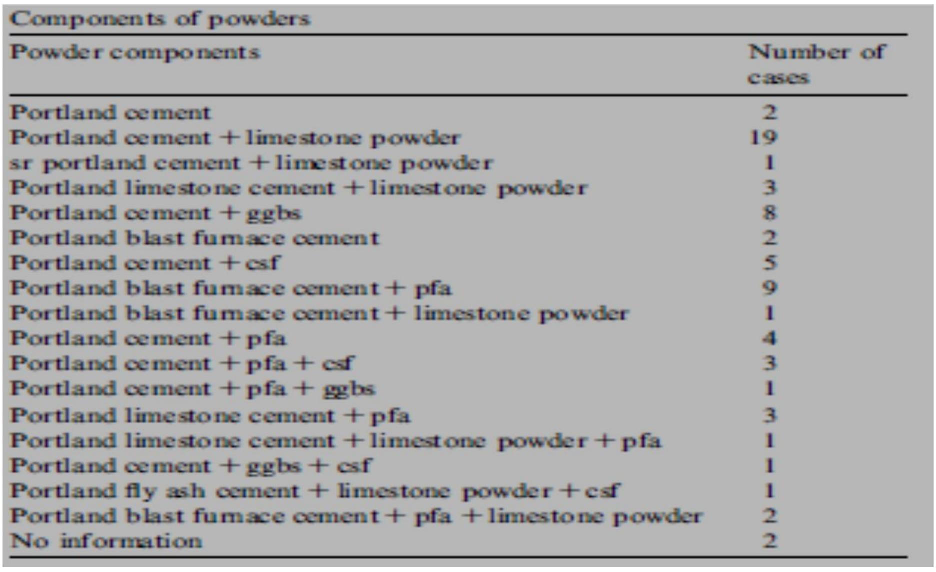
In this chapter the research work concerning to various application and method used for testing of Self compacting concrete mad by various cementitious materials and admixtures are discussed. This chapter gives a compressive review of the work carried out by various researchers in the field of self compacting concrete.

3.2 Review of latest work done on SCC

Domone (2005) analysed the fresh & hardened properties of SCC in Sixty eight cases from 1993 to 2003. He founded that, in forty eight cases, maximum size of aggregate is in the range of 16 – 20 mm. Six cases used larger size of aggregate from 22 – 40 mm. All mixes included superplasticizers.

In thirty cases ,an air-entraining admixture was used and in thirty four cases, a viscosity-modifying agent was also used. The coarse aggregate contents varied from 28% to 38% by volume of the concrete, with 80% of these within the range 29.1–34.8%, equivalent to about 770–925 kg/m3 for aggregate relative density of 2.65.

The paste contents varied from 30% to 42% by volume of the concrete, with 80% of these within the range 32.3–39%. The powder contents ranged from 425 to 625 kg/m3, with 80% in the range 445–605 kg/m3.Water/powder ratios ranged from 0.26 to 0.48, with 80% falling in the range 0.28–0.42. The mortar composition in terms of volume percentage of the fine aggregate varies from 38% to 54%, with 80% in the range 41–52%.



Components of powders

Powder components	Number of cases
Portland cement	2
Portland cement + limestone powder	19
sr portland cement + limestone powder	1
Portland limestone cement + limestone powder	3
Portland cement + ggbs	8
Portland blast furnace cement	2
Portland cement + csf	5
Portland blast furnace cement + pfa	9
Portland blast furnace cement + limestone powder	1
Portland cement + pfa	4
Portland cement + pfa + csf	3
Portland cement + pfa + ggbs	1
Portland limestone cement + pfa	3
Portland limestone cement + limestone powder + pfa	1
Portland cement + ggbs + csf	1
Portland fly ash cement + limestone powder + csf	1
Portland blast furnace cement + pfa + limestone powder	2
No information	2

Table 3.1 Components of Powder Mixes *(Domone, 2005)*

It is concluded that, nearly, 50% of the test result for the slump flow test are in the range of 650-700mm and nearly 90% are in the range of 600-750mm.

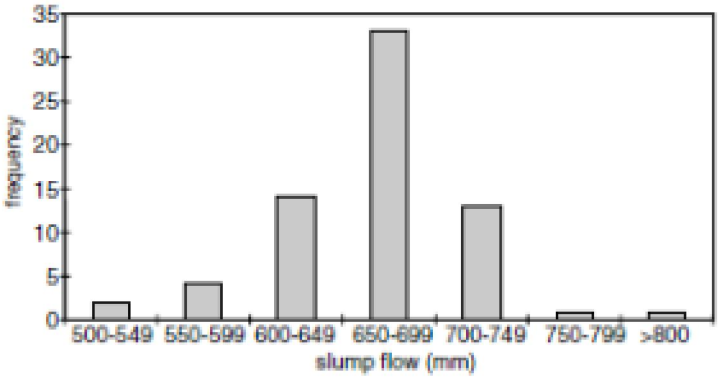


Figure 3.1 Graph showing Slump Flow and Frequency *(Domone, 2005)*

In the V-funnel test, the values are considerably varies from 3 sec to 15 sec making the wide range in this property.

The 28 day compressive strength values ranged from 20 to nearly 100 MPa, with about 80% of mixes having strengths in excess of 40MPa.

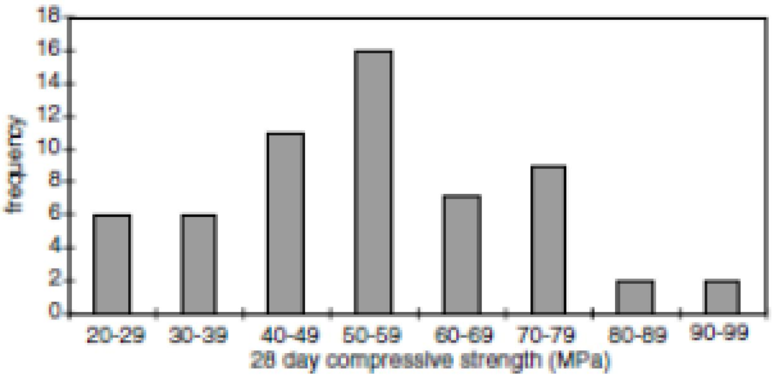
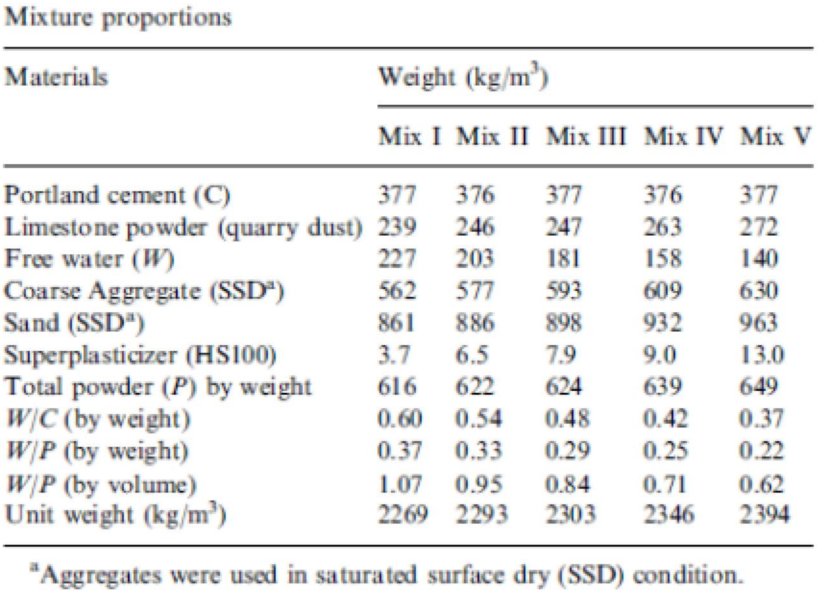


Figure 3.2 Graph showing Compressive strength with Frequency *(Domone, 2005)*

Felekoglu et al. (2006) studied the five SCC mixtures with different combinations of water/cement ratio and super plasticizer dosage and evaluate its fresh and hardened properties. Okamura and Ozawa proposed a simple mixture proportioning system for the coarse and fine aggregate to be kept contents, so that self-compactibility can be achieved easily by adjusting the water/cement ratio and superplasticizer dosage only.

In the mix-proportioning of Normal concrete, the water/cement ratio is kept constant in order to obtain the required strength and durability. But in SCC, the water/powder ratio has to be chosen by taking self- compactibility into account, since self-compactibility is very sensitive to this ratio.

An ordinary Type-I Portland Cement (PC 42.5) was used in all compositions. Its compressive strength was 48.5 Mpa. The superplasticizer was a polycarboxylic acid. The maximum aggregate size was selected 15 mm in order to avoid the blocking effect in the L-box. The gap between rebars in L-box test was 35 mm. As fine aggregate, a mix of crushed 0–5 mm limestone and natural river sand was used.



Mixture proportions

Materials	Weight (kg/m^3)				
	Mix I	Mix II	Mix III	Mix IV	Mix V
Portland cement (C)	377	376	377	376	377
Limestone powder (quarry dust)	239	246	247	263	272
Free water (W)	227	203	181	158	140
Coarse Aggregate (SSD^a)	562	577	593	609	630
Sand (SSD^a)	861	886	898	932	963
Superplasticizer (HS100)	3.7	6.5	7.9	9.0	13.0
Total powder (P) by weight	616	622	624	639	649
W/C (by weight)	0.60	0.54	0.48	0.42	0.37
W/P (by weight)	0.37	0.33	0.29	0.25	0.22
W/P (by volume)	1.07	0.95	0.84	0.71	0.62
Unit weight (kg/m^3)	2269	2293	2303	2346	2394

[a] Aggregates were used in saturated surface dry (SSD) condition.

Table 3.2 Mixes Proportions *(Felekoglu et al., 2006)*

It is concluded that, for the same cement dosage of 377 kg/m3, the free water content was reduced from 227 lit/m3 to 140 lit/m3 and at the same time the super plasticizer dosage was increased from 3.7 lit/m3 to 13 lit/m3.

It is concluded that the optimum water powder ratio for producing SCC is in the range of the 0.84 to 1.07 by volume. The ratio above and below this range may cause blocking or segregation of the mixture.

The rapid strength can be obtained by reducing the free water content, which is more dominant than the retardation effect of superplasticizer.

Jacobs and Hunkeler found that at a given strength, the modulus of elasticity of SCC is lower than the normal concrete because of smaller maximum grain size of SCC and high amount of cement paste.

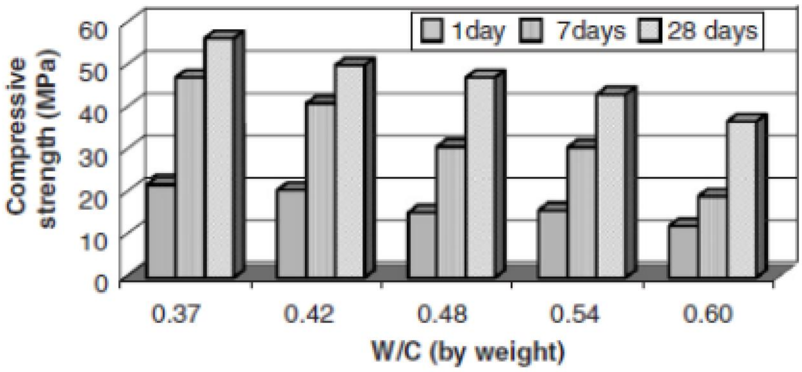


Figure 3.3 Graph showing W/C ratio with compressive strength ***(Felekoglu et al., 2006)***

Filho (2008) studied the variability of bond and mechanical properties of self compacting concrete. This main objective of this research is to evaluate the variability of the mechanical properties (compressive strength, modulus of elasticity and tensile strength) and bond strength of the self-compacting concrete (SCC), with 50 MPa compressive strength at 28 days, varying the maximum aggregate size and the Self compacting concrete fluidity. The tests were made in 15 x 30 cm concrete cylinders and in beams standardized by Rilem-Ceb-Fib (1973). In agreement with the obtained results, can be concluded that the variability of the self-compacting concrete is small for the modulus of elasticity and for the compressive strength, but the tensile strength presented a significant variability due to the failure mode. About the bond strength, the variability was small showing that the self-compacting concrete is reliable and possesses great potential for use in the civil construction.

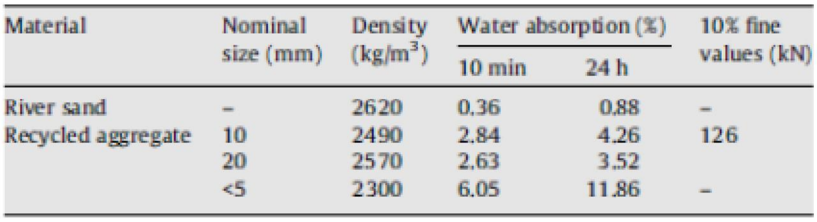
Kou and Poon (2009) study, the fresh and hardened properties of self-compacting concrete (SCC) using recycled concrete aggregate as both coarse and fine aggregates.

Three series of SCC mixtures were prepared with 100% coarse recycled aggregates, and different levels of fine recycled aggregates. The cement content was kept constant for all concrete mixtures. The SCC mixtures were prepared with 0, 25, 50, 75 and 100% fine recycled aggregates, the corresponding water-to-binder ratios (W/B) were 0.53 and 0.44 for the SCC mixtures in Series I and II, respectively. The SCC mixtures in Series III were prepared with 100% recycled concrete aggregates (both coarse and fine) but three different W/B ratios of 0.44, 0.40 and 0.35 were used. Different tests covering fresh, hardened and durability properties of these SCC mixtures were executed. The results indicate that the properties of the SCCs made from river sand and crushed fine recycled aggregates showed only slight differences

Khatib, reported that when natural fine aggregates in concrete were replaced by 0%, 25%, 50%, 75% and 100% fine recycled aggregates and the free water/cement ratio was kept constant for all the mixes, the 28-day strength of the concrete developed at a slower rate.

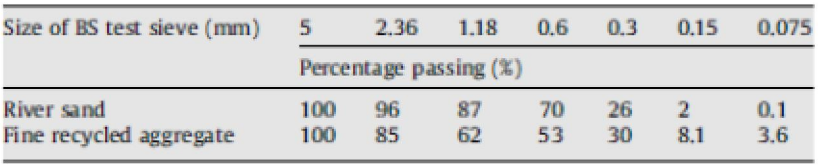
Evangelista and de Brito, indicated that the use of fine recycled concrete aggregates up to 30% replacement ratios would not effect the mechanical properties of concrete. The nominal sizes of the coarse recycled aggregates were 20 mm and 10 mm.

The corresponding physical and mechanical properties of the aggregates are shown in **Table 3.3** and the particle size distribution of fine recycled aggregates and river sand are shown in **Table 3.4**. The chemical admixtures used were a superplasticizer (Grace, ADVA-109) and a viscosity agent (Grace, V -MAR 2) commercially available in Hong Kong.



Material	Nominal size (mm)	Density (kg/m^3)	Water absorption (%)		10% fine values (kN)
			10 min	24 h	
River sand	–	2620	0.36	0.88	–
Recycled aggregate	10	2490	2.84	4.26	126
	20	2570	2.63	3.52	
	<5	2300	6.05	11.86	–

Table 3.3 Properties of Aggregates ***(Kou and Poon, 2009***)

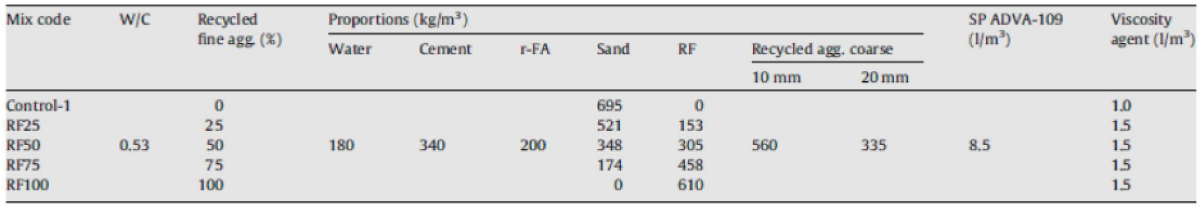


Size of BS test sieve (mm)	5	2.36	1.18	0.6	0.3	0.15	0.075
	Percentage passing (%)						
River sand	100	96	87	70	26	2	0.1
Fine recycled aggregate	100	85	62	53	30	8.1	3.6

Table 3.4 Particles Size Distribution ***(Kou and Poon, 2009***)

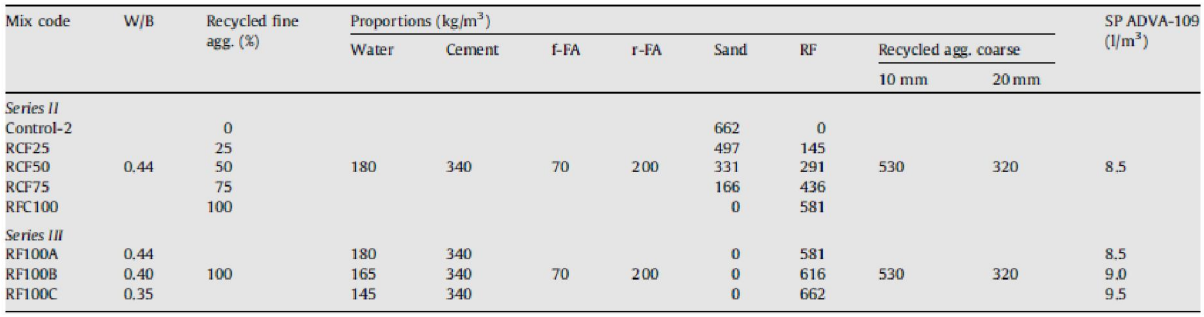
Three series of SCC mixtures with different fine recycled aggregate contents and water-to-binder (W/B) ratios were prepared. In the paper, only the OPC and f-FA are treated as binder, while the r-FA is treated as a filler. f-FA was added to increase the cementitious materials content.

The mix proportions of the mixtures in Series I, II and III are summarized in **Tables 3.5 and 3.6**, respectively. The amounts of water added to the mixes were higher due to the high water absorption of the recycled aggregates. The actual added water in the mixtures is shown in **Table 3.7.**



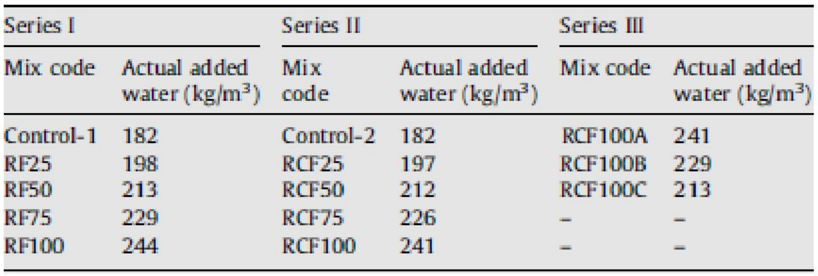
Mix code	W/C	Recycled fine agg. (%)	Proportions (kg/m³)							SP ADVA-109 (l/m³)	Viscosity agent (l/m³)
			Water	Cement	r-FA	Sand	RF	Recycled agg. coarse			
								10 mm	20 mm		
Control-1	0.53	0	180	340	200	695	0	560	335	8.5	1.0
RF25		25				521	153				1.5
RF50		50				348	305				1.5
RF75		75				174	458				1.5
RF100		100				0	610				1.5

Table 3.5 Mix Proportion of Series I *(Kou and Poon, 2009*)



Mix code	W/B	Recycled fine agg. (%)	Proportions (kg/m³)								SP ADVA-109 (l/m³)
			Water	Cement	f-FA	r-FA	Sand	RF	Recycled agg. coarse		
									10 mm	20 mm	
Series II											
Control-2	0.44	0	180	340	70	200	662	0	530	320	8.5
RCF25		25					497	145			
RCF50		50					331	291			
RCF75		75					166	436			
RFC100		100					0	581			
Series III											
RF100A	0.44	100	180	340	70	200	0	581	530	320	8.5
RF100B	0.40		165	340			0	616			9.0
RF100C	0.35		145	340			0	662			9.5

Table 3.6 Mix Proportions of Series II & III *(Kou and Poon, 2009*)



Series I		Series II		Series III	
Mix code	Actual added water (kg/m³)	Mix code	Actual added water (kg/m³)	Mix code	Actual added water (kg/m³)
Control-1	182	Control-2	182	RCF100A	241
RF25	198	RCF25	197	RCF100B	229
RF50	213	RCF50	212	RCF100C	213
RF75	229	RCF75	226	–	–
RF100	244	RCF100	241	–	–

Table 3.7 Quantity of Actual Water Added *(Kou and Poon, 2009*)

In the slump flow test, the measurements were repeated 1 hour after the initial mixing (during the 1 hour rest period, the concrete mixture was not agitated, but the mixture was remixed for about 1 min using the initial mixing speed before the second slump test was preformed) to evaluate the slump loss properties of the SCC mixtures.

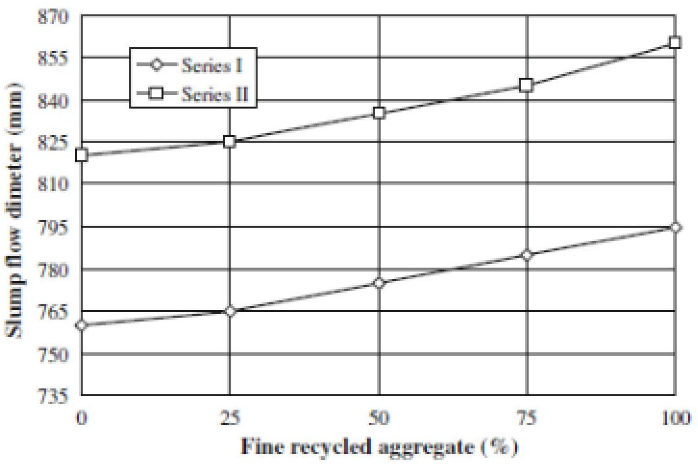
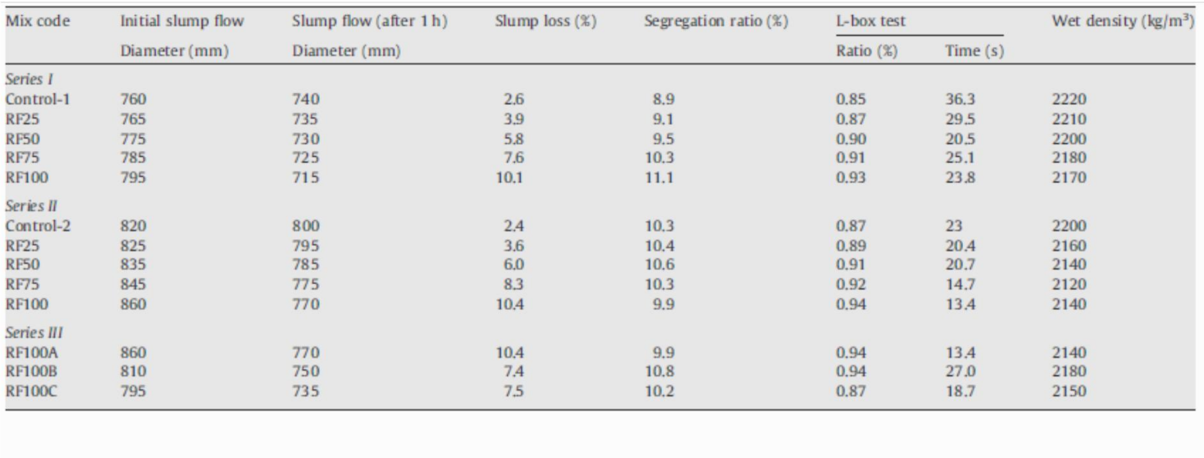


Figure 3.4 Graph showing % Fine Recycled Aggregates & Slump Flow
(Kou and Poon, 2009)

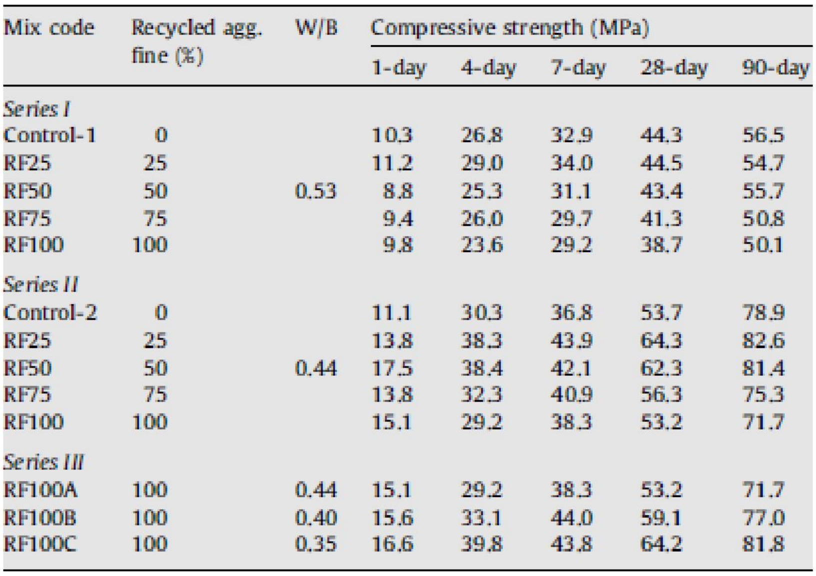
The slump flow diameter increased with an increase in the fine recycled aggregate content. This was attributed to the high water absorption capacity of the fine recycled aggregates compared to river sand. The results indicated that the RA-SCC mixtures prepared in this study achieved adequate passing ability and maintained sufficient resistance to segregation.



Mix code	Initial slump flow Diameter (mm)	Slump flow (after 1 h) Diameter (mm)	Slump loss (%)	Segregation ratio (%)	L-box test		Wet density (kg/m³)
					Ratio (%)	Time (s)	
Series I							
Control-1	760	740	2.6	8.9	0.85	36.3	2220
RF25	765	735	3.9	9.1	0.87	29.5	2210
RF50	775	730	5.8	9.5	0.90	20.5	2200
RF75	785	725	7.6	10.3	0.91	25.1	2180
RF100	795	715	10.1	11.1	0.93	23.8	2170
Series II							
Control-2	820	800	2.4	10.3	0.87	23	2200
RF25	825	795	3.6	10.4	0.89	20.4	2160
RF50	835	785	6.0	10.6	0.91	20.7	2140
RF75	845	775	8.3	10.3	0.92	14.7	2120
RF100	860	770	10.4	9.9	0.94	13.4	2140
Series III							
RF100A	860	770	10.4	9.9	0.94	13.4	2140
RF100B	810	750	7.4	10.8	0.94	27.0	2180
RF100C	795	735	7.5	10.2	0.87	18.7	2150

Table 3.8 Fresh Properties of Mixes *(Kou and Poon, 2009*)

The compressive strength of the RA-SCC mixtures in Series I prepared with 75% and 100% fine recycled aggregates was approximately 10% lower than that of the control-1. This may be due to the presence of f-FA, and the pozzolanic reaction between Ca(OH)2 in the fine recycled aggregate and the fly ash forming additional C–S–H and enhancing strength.



Mix code	Recycled agg. fine (%)	W/B	Compressive strength (MPa)				
			1-day	4-day	7-day	28-day	90-day
Series I							
Control-1	0		10.3	26.8	32.9	44.3	56.5
RF25	25		11.2	29.0	34.0	44.5	54.7
RF50	50	0.53	8.8	25.3	31.1	43.4	55.7
RF75	75		9.4	26.0	29.7	41.3	50.8
RF100	100		9.8	23.6	29.2	38.7	50.1
Series II							
Control-2	0		11.1	30.3	36.8	53.7	78.9
RF25	25		13.8	38.3	43.9	64.3	82.6
RF50	50	0.44	17.5	38.4	42.1	62.3	81.4
RF75	75		13.8	32.3	40.9	56.3	75.3
RF100	100		15.1	29.2	38.3	53.2	71.7
Series III							
RF100A	100	0.44	15.1	29.2	38.3	53.2	71.7
RF100B	100	0.40	15.6	33.1	44.0	59.1	77.0
RF100C	100	0.35	16.6	39.8	43.8	64.2	81.8

Table 3.9 Compressive Strength Test Results *(Kou and Poon, 2009*)

For the RF100 mix, the lower strength recorded was probably due to the excessive amount of water added to compensate for the water absorption of the recycled fine aggregates.

Table 3.9 shows the compressive strength of RA-SCC mixtures in Series III prepared by using 100% fine recycled aggregate as the fine aggregate. As expected, the compressive strength increased as the W/B ratio decreased at all the test ages.

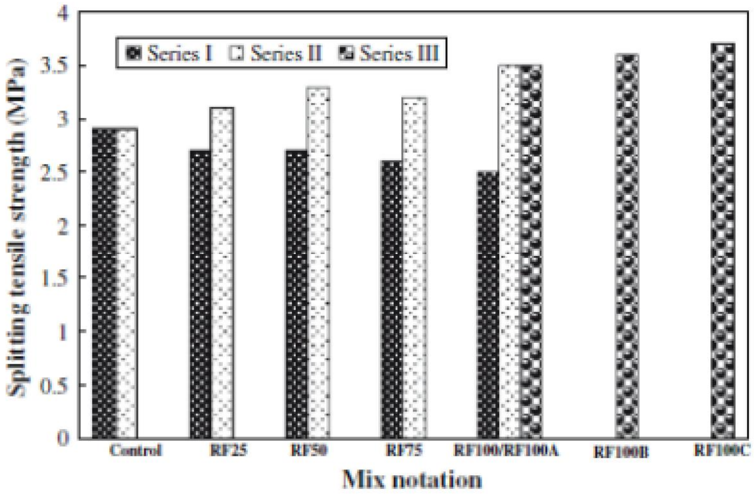


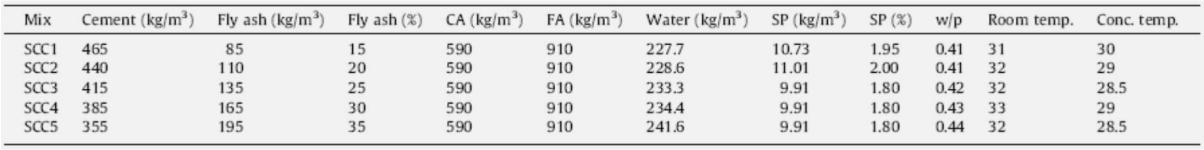
Figure 3.5 Graph showing Mixes & Spilliting Tensile Strength

***(Kou and Poon, 2009*)**

The results of the tensile splitting strength of the SCC mixtures in Series I, II and III at 28 days are shown **Figure 3.5**. Each presented value is the average of three measurements. It can be seen that the 28-day tensile splitting strengths of the RA-SCC mixtures in Series I were slightly lower than that of the control-1 mixture. But the tensile splitting strengths of the Series II mixes were higher than that of the control-2, as was seen for compressive strengths.

Siddique (2010) study the properties of self-compacting concrete (SCC) made with Class F fly ash. Five mixes were prepared with percentages of class F fly ash ranging from 15% to 35% . The fresh properties, hardened properties and the durability properties were investigated.

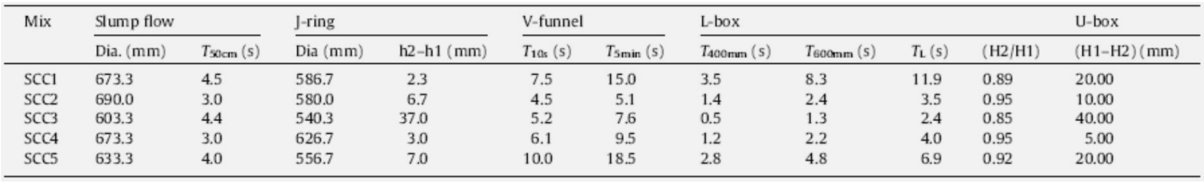
Five concrete mixes were made, which had total powder content to 550 kg/m3 (cement + fly ash). Coarse aggregate content was maintained at 39% by volume (590 kg/m3) of concrete and fine aggregate content at 45% by volume of mortar in concrete (910 kg/m3), the w/p ratio was kept at 0.41–0.44 by weight with air-content being assumed to be 2%. The various SCC mixes with fly ash as 15%, 20%, 25%, 30% and 35% by weight of total powder content were developed, and their mix proportions are given in **Table 3.10**.



Mix	Cement (kg/m^3)	Fly ash (kg/m^3)	Fly ash (%)	CA (kg/m^3)	FA (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	SP (%)	w/p	Room temp.	Conc. temp.
SCC1	465	85	15	590	910	227.7	10.73	1.95	0.41	31	30
SCC2	440	110	20	590	910	228.6	11.01	2.00	0.41	32	29
SCC3	415	135	25	590	910	233.3	9.91	1.80	0.42	32	28.5
SCC4	385	165	30	590	910	234.4	9.91	1.80	0.43	33	29
SCC5	355	195	35	590	910	241.6	9.91	1.80	0.44	32	28.5

Table 3.10 Mix Proportion of SCC Mixes (*Siddique, 2010*)

The results of fresh properties tested by slump flow test, J-ring test, L-box test, V-funnel test and U-box test for various mix compositions are given in **Table 3.11**.



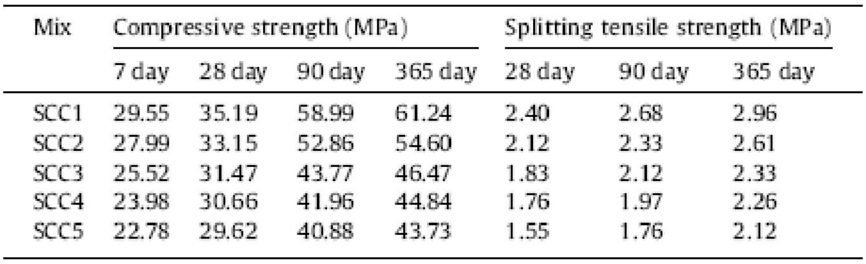
Mix	Slump flow		J-ring		V-funnel		L-box				U-box
	Dia. (mm)	T_{50cm} (s)	Dia (mm)	h2–h1 (mm)	T_{10s} (s)	T_{5min} (s)	T_{400mm} (s)	T_{600mm} (s)	T_L (s)	(H2/H1)	(H1–H2) (mm)
SCC1	673.3	4.5	586.7	2.3	7.5	15.0	3.5	8.3	11.9	0.89	20.00
SCC2	690.0	3.0	580.0	6.7	4.5	5.1	1.4	2.4	3.5	0.95	10.00
SCC3	603.3	4.4	540.3	37.0	5.2	7.6	0.5	1.3	2.4	0.85	40.00
SCC4	673.3	3.0	626.7	3.0	6.1	9.5	1.2	2.2	4.0	0.95	5.00
SCC5	633.3	4.0	556.7	7.0	10.0	18.5	2.8	4.8	6.9	0.92	20.00

Table 3.11 Fresh Properties of SCC Mixes (*Siddique, 2010*)

All the mixes of SCC mixes is in the range of 600–700 mm. The slump flow time for the concrete to reach diameter of 500 mm for all the mixes were less than 4.5 seconds. The J-ring diameter and difference in concrete height inside and outside J-ring were in the range of 540–625 mm and the difference in height was less than 40 mm. The V-funnel flow times were in the range of 4–10 seconds. The L-box ratio H2/H1 for the mixes was above 0.8. U-box difference in height of concrete in two compartments was in the range of 5–40 mm.

The compressive strength tests results of SCC mixes are given in **Table 3.12** and shown in **Figure 3.6**. It is found that, with increase in fly ash content from 15–35%, SCC mixes developed compressive strengths between 29.5 and 22.8 MPa at 7 day; between 35.2 and 29.6 at 28 day; between 58.9 and 40.8 at 90 day; and between 61.2 and 43.7 MPa at 365 day. The compressive strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio.

Splitting tensile strength test results of SCC mixes are given in **Table 3.12**, and shown in **Figure 3.7**. SCC mixes achieved splitting tensile strength from 1.55 to 2.40, 1.76 to 2.68, and 2.12 to 2.96 MPa at 28, 90 and 365 days, with the increase in fly ash content from 15 to 35%. Splitting tensile strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio.



Mix	Compressive strength (MPa)				Splitting tensile strength (MPa)		
	7 day	28 day	90 day	365 day	28 day	90 day	365 day
SCC1	29.55	35.19	58.99	61.24	2.40	2.68	2.96
SCC2	27.99	33.15	52.86	54.60	2.12	2.33	2.61
SCC3	25.52	31.47	43.77	46.47	1.83	2.12	2.33
SCC4	23.98	30.66	41.96	44.84	1.76	1.97	2.26
SCC5	22.78	29.62	40.88	43.73	1.55	1.76	2.12

Table 3.12 Hardened Properties of SCC (*Siddique, 2010*)

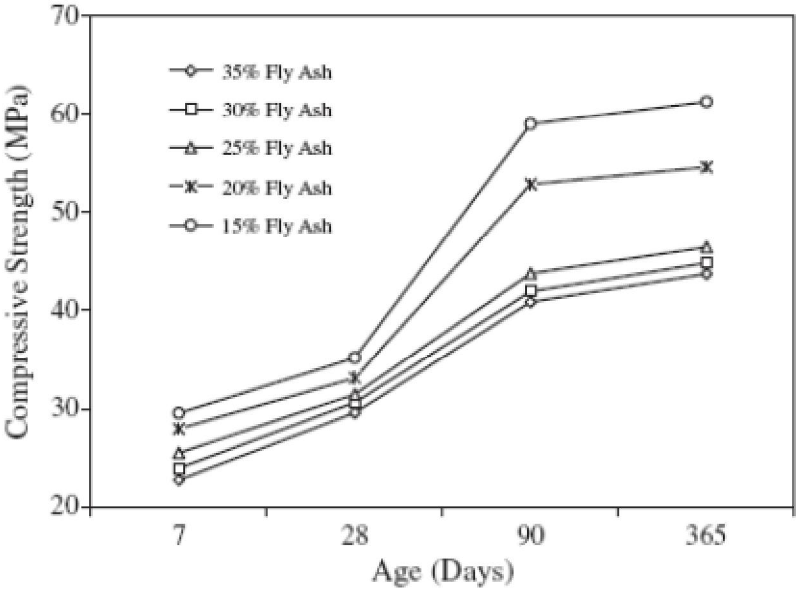


Figure 3.6 Compressive Strength of SCC Mixes at various ages (*Siddique, 2010*)

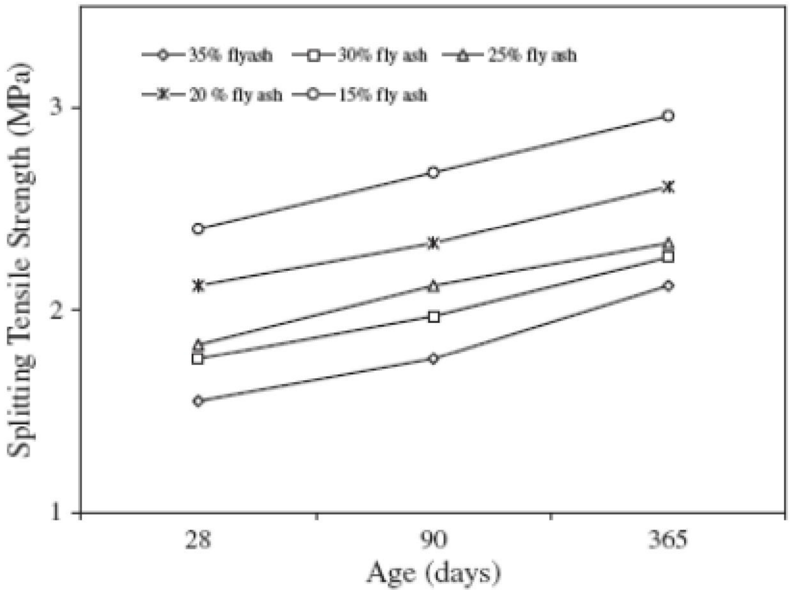


Figure 3.7 Splitting Tensile Strength of SCC Mixes at various ages (*Siddique, 2010*)

It was concluded that, SCC mixes developed 28 day compressive strength between 30 and 35 MPa and splitting tensile strength between 1.5 and 2.4 MPa. The carbonation depth increased with the increase in age for all the SCC mixes. Maximum carbonation depth was observed to be 1.67 mm at 90 days and 1.85 mm at 365 days for SCC with 20% fly ash content. Also, the pH value for all the mixes was observed to be greater than 11. Deicing salt surface scaling weight loss increased with the increase in fly ash content except with mix containing 15% fly ash. At 365 days age, the weight loss was almost consistent for all percentages of fly ash varying between 0.525 and 0.750 kg/m2. SCC mixes made with fly ash exhibited very low chloride permeability resistance (less than 700 and 400 Coulomb) at the age of 90 and 365 days respectively.

Grdic et al. (2010) explained the potential for usage of coarse recycled aggregate obtained from crushed concrete for making of self-compacting concrete, which may solve the issue of the waste disposal sites created by the demolition of old structures. On the otherhand the issue of the waste disposal sites created by the demolition of old structures is solved.

In the experiment, three types of concrete mixtures were made, where the percentage of substitution of coarse aggregate by the recycled aggregated was 0%, 50% and 100%. In the process of mixing, equal consistence of all concrete mixtures was achieved.

Control concrete was made only with the river aggregate, test concrete P50 with 50% of recycled coarse aggregate, which entirely substituted the fraction 8/16 mm and test concrete

P100 with 100% of recycled coarse aggregate, where all of the coarse aggregate was substituted by the recycled aggregate.

Slump-flow, L-box test and sieve aggregation test were performed to check the properties of self compacting concrte. Slump-flow test for flow ability and viscosity, L-box test for testing passing ability and Sieve segregation test for testing the segregation resistance.

It was concluded from the experiment that the compressive strength of control concrete is more than the concrete made from recycled aggregate aggregates. But the difference between them is very less and can be controlled by using some adhesive material. The reason for less compressive strength can be because of the use of recycled aggregates. In recycled aggregates, there is change of shape i.e. irregular and inconsistent shape, especially in the cases of the aggregate obtained by demolition of structural elements of a building.

As opposed to natural aggregate, recycled aggregate has two components: natural aggregate and cement paste which is bound to it and which reduces its quality to a certain extent. The old cement paste is the cause of lower density, higher absorption capacity, lower abrasion resistance and high content of sulphates in the composition of the recycled aggregate in comparison to natural. In the course of setting and hardening, the new cement paste first reacts with the old paste residue on the grains of recycled aggregate, which requires a part of the water that is a part of the concrete mixture composition, and reduces compressive strength.

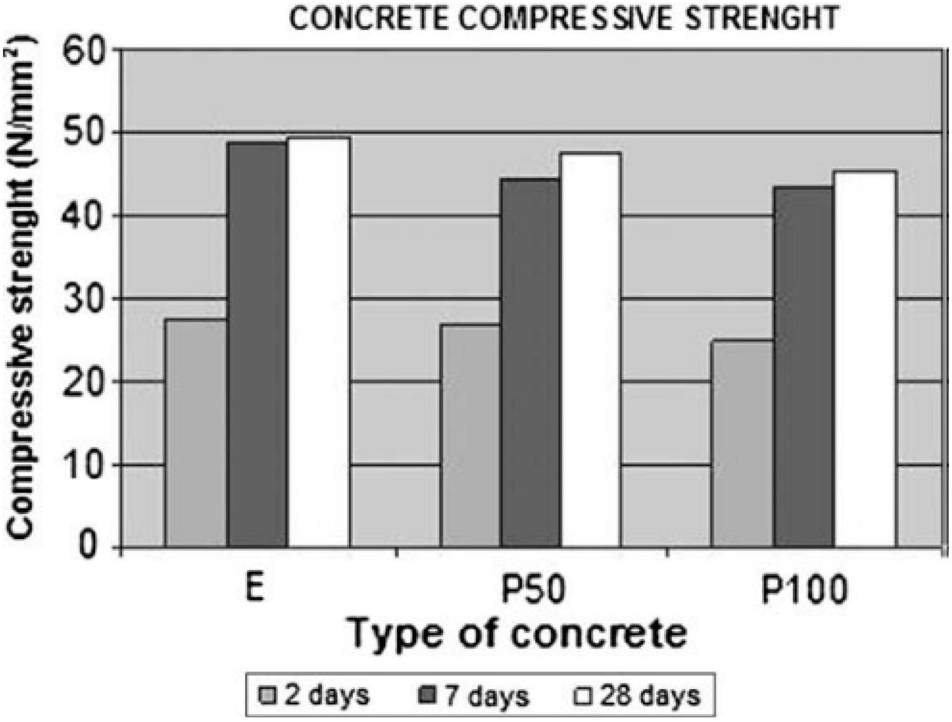


Figure 3.8 Graphic Presentation of Compressive Strength testing results (*Grdic et al., 2010)*

Similarly, Usage of 50–100% of coarse recycled aggregate decreased the tensile strength tested by bending for 2.49–13.95%.

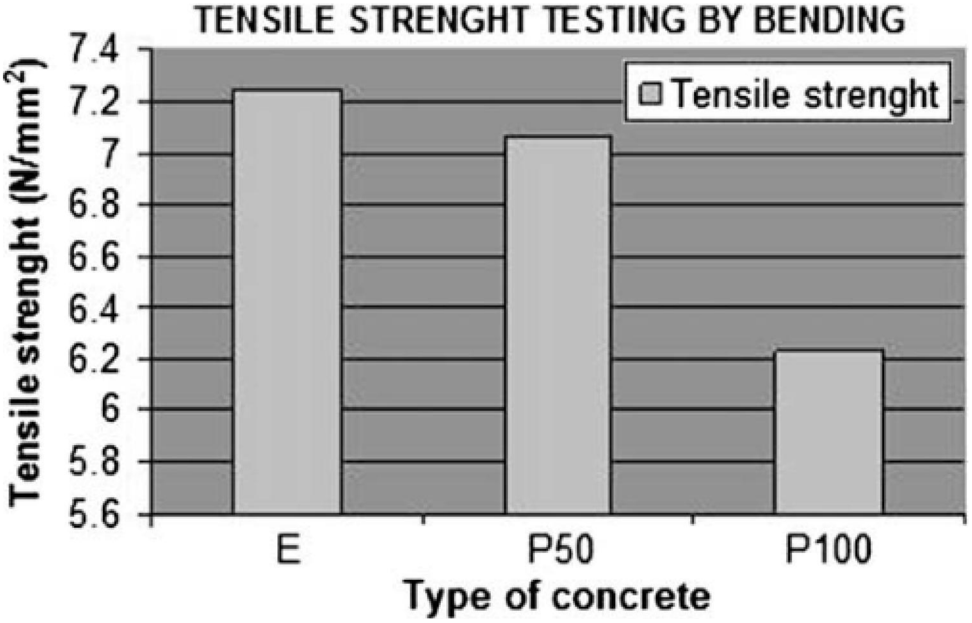


Figure 3.9 Graphic Presentation of Tensile Strength testing results (*Grdic et al., 2010)*

And also the quantity of recycled aggregate affects water absorption, in the sense that the increase of the recycled aggregate quantity causes increase of the water absorption which is a consequence of increased porousness. Usage of 50–100% of coarse recycled aggregate increase the water absorption for 0.15–0.37%.

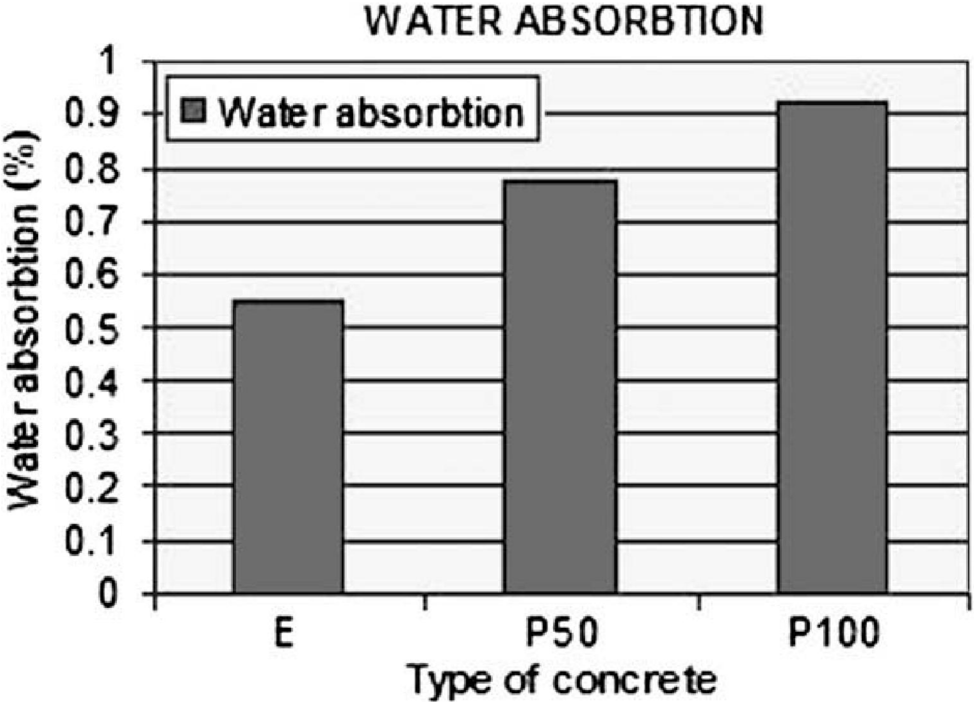


Figure 3.10 Graphic Presentation of water absorption test results (*Grdic et al., 2010)*

On the samples P50 and P100 no water penetration was recorded, whereas the control sample had a penetration of 10 mm, so it can be concluded that all the samples are water-proof which is in full accordance with the structure of self-compacting concrete. This property is affected by the capillary porousness both of the old cement powder residual on the aggregate and the capillary porousness of the cement rock new concrete. If the aggregate was obtained by crushing the concrete of low porousness, water-proofness of the new concrete will depend on the achieved structure of the new cement stone.

It was concluded that the usage of recycled aggregate for making of Self compacting concrete is justified. By an appropriate choice of material and design of the mixture.

Tokyay (2009) studied the transport and mechanical properties of self consolidating concrete that contain high percentages of low-lime and high-lime fly ash (FA). For this purpose, self consolidating concretes (SCC) containing five different contents of high-lime fly ash and low-lime fly ash as a replacement of cement (30, 40, 50, 60 and 70 by weight of total cementitious material) were examined. For comparison, a control Self compacting concrete mixture without any fly ash was also produced. The fresh properties of the Self compacting concretes were observed through, slump flow time and diameter, V-funnel flow time, L-box height ratio, and segregation ratio. The hardened properties included the compressive strength, split tensile strength, drying shrinkage and transport properties (absorption, sorptivity and rapid chloride permeability tests) up to 365 days. Test results confirm that it is possible to produce Self compacting concrete with a 70% of cement replacement by both types of fly ash . The use of high volumes of fly ash in Self compacting concrete not only improved the workability and transport properties but also made it possible to produce concretes between 33 and 40 MPa compressive strength at 28 days, which exceeds the nominal compressive strength for normal concrete (30 MPa).

Karatas **(2010)** studied the mechanical properties of NC (Normal Concrete) and various Self compacting concrete mixtures such as, compressive, splitting tensile strength, ultrasound pulse velocity (UPV) and the modulus of elasticity have been investigated with different dosage of fly ash/ silica fume. For this purpose, silica fume (SF) and fly ash (FA) were added separately as partial replacement of cement from 5% to 20% and from 25% to 40% at 5% intervals, respectively. In case, eight types of self-compacting concrete (SCC) were designed, in comparison with normal concrete (NC). Tests were conducted for 3, 28 and 130 days whilst the elasticity modulus test was only performed for 28 days.

Test results indicated that Self compacting concrete specimens with silica fume / fly ash had higher the compressive and tensile strength than Normal concrete specimens for all ages whilst the compressive strength of Self compacting concrete specimens decreased with an increase in both fly ash and silica fume content for 3 days. However, an increase in silica fume / fly ash content led to generally an increase in compressive and tensile strength for 130 days. Moreover, Self compacting concrete specimens with fly ash had the highest UPV values followed by Normal concrete and Self compacting concrete specimens with silica fume for 28 and 130 days, though, the UPV values of Self compacting concrete specimens in general decreased for all ages when fly ash / silica fume content increased. The elasticity modulus of Self compacting concrete with silica fume was highest in all specimens tested whilst Self compacting concrete specimens with fly ash had lowest elasticity modulus.

Debs et al. (2010) studied on the variability of the mechanical properties of hardened self-compacting concrete which include properties like compressive strength*(fc),* splitting tensile strength *(ft)* and modulus of elasticity*(E)*. For this purpose an experiment is performed to find the mechanical properties of Self compacting concrete. The experimental results were then compared with the those derived from several codes and recommendations that allows evaluating if the hardened properties of self compacting concrete can be appropriate for predicting by the existing formulations.

For this purpose an experiment was made in which the mixing, casting and testing of 150 x 300mm cylinders of the three Self compacting concrete mixes for determination of compressive strength (fc) , tensile Strength (ft) , and modulus of Elasticity (E) up to a 30% of the concrete compressive strength. Three Self compacting concretes of the same strength level but varying the MAS(Maximum Size Aggregate) and paste content were analyzed **(see Table 3.13)**. All specimens remained in a humidity chamber (90% < RH < 95%) until the time of testing, at 28 days. Before testing, the specimens were weighted and the height and diameter measured to calculate the material density in the hardened state.

Components	**SCC1**	**SCC2**	**SCC3**
Cement	363	329	334
Limestone filler	109	99	100
Water	181	165	167
Superplasticizer	6.2	5.6	5.7
Sand 0-2 mm	711	607	603
Sand 0-5 mm	398	340	337
Gravel 5-12 mm	526	451	447
Gravel 12-18 mm	-	330	329
W/C	0.45	0.45	0.45
SP/C (%)	1.7	1.7	1.7
LF/C	0.3	0.3	0.3
Paste volume (%)	38.0	34.5	35
Sand volume (%)	42.2	36.0	35
Gravel volume (%)	19.8	29.5	29.3
Self-compactability measures			
Slump flow, D_f (mm)	740	570	740
Slump flow, T_{50} (s)	1.0	1.5	1
L-box, T_{60} (s)	1.0	3.0	1

L-box, C_{bl}	1.0	0.7	1
V-funnel, Tv (s)	2.5	5.5	5
J-ring, T_{50j} (s)	1.0	2.0	1
J-ring, D_{ff} (mm)	743	555	735

Table 3.13 Mix Proportions and measures of Self – Compactibility (*Debs et al., 2010)*

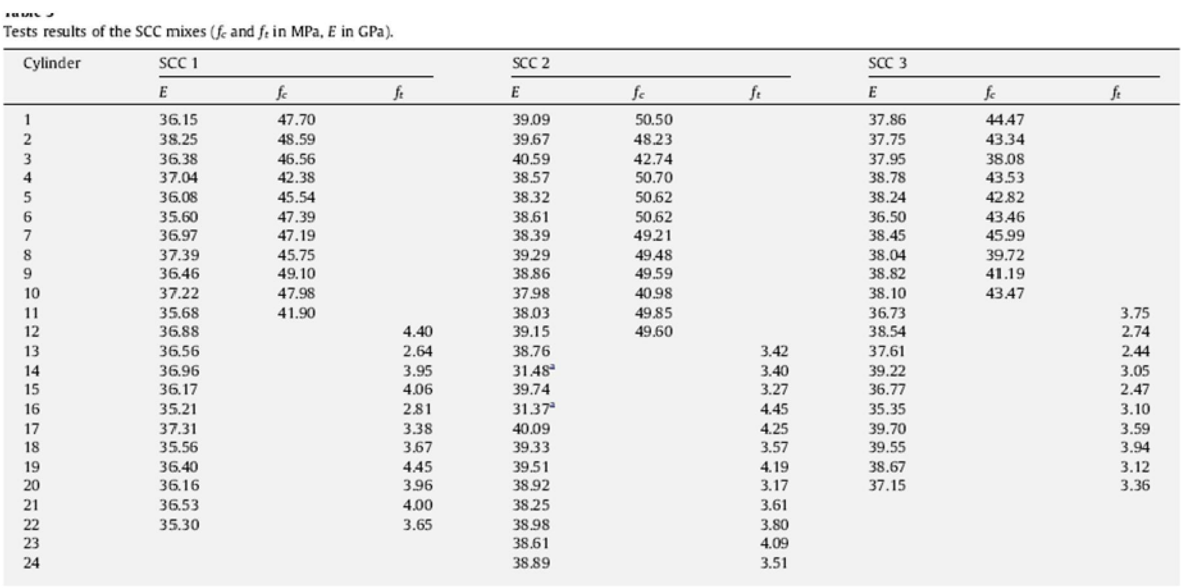
Comparison with formulations

Table 3.14 shows the expressions of some codes and by several authors to predict the values of E, fc and ft. In the case of the Norwegian code, also the material density is required. Such predictions are plotted together with the mean experimental results in **Figure 3.11 & 3.12**, for E and ft, respectively. The experimental values in **Figure 3.12** were obtained from the average result of compression and tension tests, which gives one value per mix.

	Modulus of Elasticity	Tensile Strength
EHE[13]	$Ec = 1000 \sqrt[3]{fc}$	$ft = 0.21 \sqrt[3]{fc^2}$
NBR 61 18 [14]	$Ec = 5600\sqrt{fc}$	$ft = 0.3 \sqrt[3]{fc^2}$
CEB[15]	$Ec = 21.5 \sqrt[3]{\frac{fc}{10}}$	$ft = 1.56 \sqrt[3]{\frac{fc - 8^2}{10}}$
ACI 318[16]	$Ec = 43. \rho c^{1.5} \sqrt{fc}.10^{-6a}$	$ft = 0.56\sqrt{fc}$
Hueste et al. [17]	$Ec = 5230. \sqrt{fc}$	$ft = 0.55. \sqrt{fc}$
Norwegian code[18]	$Ec = 9.5 . ([fc] \uparrow 0.3).([\rho c/2400] \uparrow 1.5)$	-
Gardener and Zao[19]	$\sqrt[3]{fc}$	
Olokun[20]	-	$ft = 1.39. f_c^{0.69}$
Ahmad and Shah	-	$ft = 4.34 f_c^{0.55}$
Burg and Ost	-	$ft = 7.3\sqrt{fc}$

Table 3.14 Formulation to predict the E and *ft* from *fc* (*Debs et al., 2010)*

Where ρc is the density of concrete



Tests results of the SCC mixes (f_c and f_t in MPa, E in GPa).

Cylinder	SCC 1			SCC 2			SCC 3		
	E	f_c	f_t	E	f_c	f_t	E	f_c	f_t
1	36.15	47.70		39.09	50.50		37.86	44.47	
2	38.25	48.59		39.67	48.23		37.75	43.34	
3	36.38	46.56		40.59	42.74		37.95	38.08	
4	37.04	42.38		38.57	50.70		38.78	43.53	
5	36.08	45.54		38.32	50.62		38.24	42.82	
6	35.60	47.39		38.61	50.62		36.50	43.46	
7	36.97	47.19		38.39	49.21		38.45	45.99	
8	37.39	45.75		39.29	49.48		38.04	39.72	
9	36.46	49.10		38.86	49.59		38.82	41.19	
10	37.22	47.98		37.98	40.98		38.10	43.47	
11	35.68	41.90		38.03	49.85		36.73		3.75
12	36.88		4.40	39.15	49.60		38.54		2.74
13	36.56		2.64	38.76		3.42	37.61		2.44
14	36.96		3.95	31.48[a]		3.40	39.22		3.05
15	36.17		4.06	39.74		3.27	36.77		2.47
16	35.21		2.81	31.37[a]		4.45	35.35		3.10
17	37.31		3.38	40.09		4.25	39.70		3.59
18	35.56		3.67	39.33		3.57	39.55		3.94
19	36.40		4.45	39.51		4.19	38.67		3.12
20	36.16		3.96	38.92		3.17	37.15		3.36
21	36.53		4.00	38.25		3.61			
22	35.30		3.65	38.98		3.80			
23				38.61		4.09			
24				38.89		3.51			

Table 3.15 Test Results of the SCC mixes (*Debs et al., 2010)*

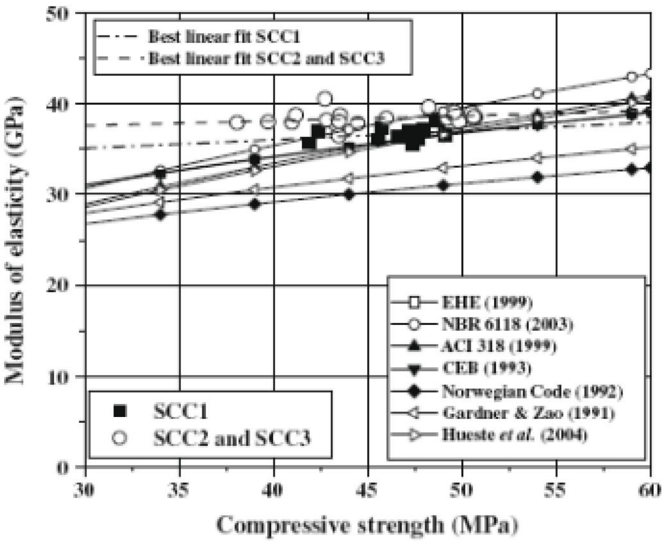


Figure 3.11 Relationships between the modulus of elasticity and compressive strength for SCC 1, SCC 2 and SCC 3 – formulations and experimental values. (*Debs et al., 2010)*

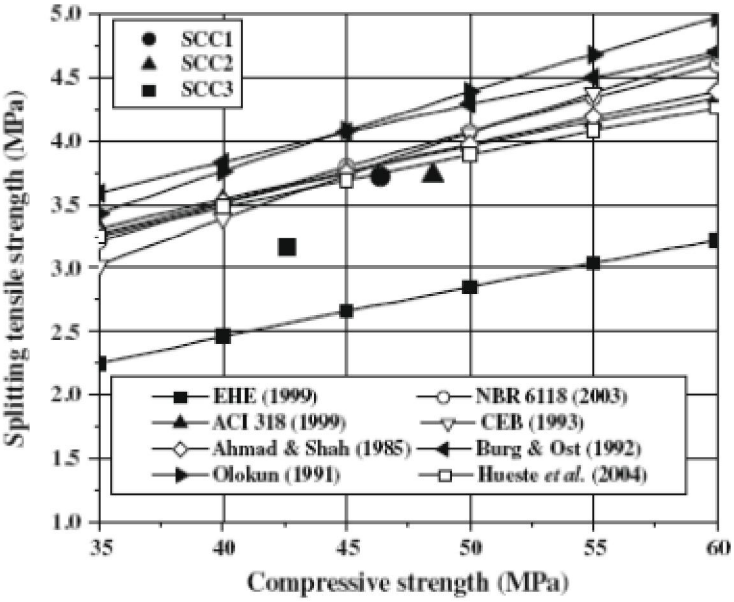
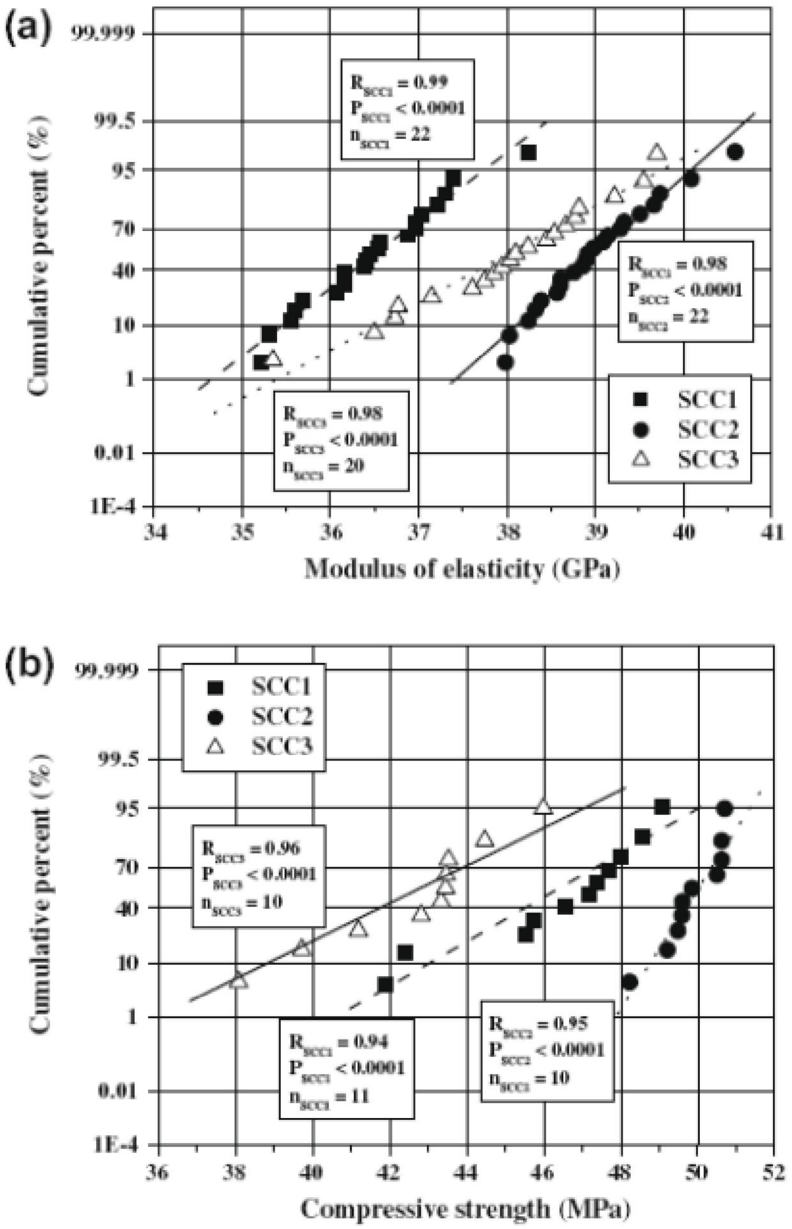


Figure 3.12 Relationship between splitting tensile strength and compressive strength for SCC 1, SCC 2 and SCC 3 – formulations and experimental values.
(*Debs et al., 2010)*

Figure 3.11 shows that the relationship fc and E obtained experimentally appears slightly above the majority of the code provisions, which is an expected behaviour also in the case of conventional vibrated concrete. With particular regard to the Spanish EHE code, that should give the better estimation since the concretes were elaborated with locally available materials in the Catalonian region, all the experimental values appear clearly above predictions for the studied stress range. In general, code estimations approximate better the experimental values at higher compressive strengths, between 45 and 50 MPa, but clearly underestimate the value of E for Self compacting concretes at strengths lower than 40–45 MPa. As mentioned before, the value of E appeared relatively constant along the analyzed strength interval.

On the other hand, it can be seen from **Figure 3.12,** that the experimental relationship between fc and ft obtained by splitting tension is beneath the majority of the code provisions, but above the Spanish EHE; with this code showing a clear underestimation of the concrete tensile strength. From the results of this limited study, the formulation by Hueste et al. seems to give the better estimation at compressive strength levels above 45 MPa. For the lower compressive strength, the CEB approximates better the experimental results.


(a)
99.999
99.5
95
70
40
10
1
0.01
1E-4
Cumulative percent (%)
R_SCC1 = 0.99
P_SCC1 < 0.0001
n_SCC1 = 22
R_SCC2 = 0.98
P_SCC2 < 0.0001
n_SCC2 = 22
R_SCC3 = 0.98
P_SCC3 < 0.0001
n_SCC3 = 20
SCC1
SCC2
SCC3
34
35
36
37
38
39
40
41
Modulus of elasticity (GPa)
(b)
99.999
99.5
95
70
40
10
1
0.01
1E-4
Cumulative percent (%)
SCC1
SCC2
SCC3
R_SCC3 = 0.96
P_SCC3 < 0.0001
n_SCC3 = 10
R_SCC1 = 0.94
P_SCC1 < 0.0001
n_SCC1 = 11
R_SCC2 = 0.95
P_SCC2 < 0.0001
n_SCC1 = 10
36
38
40
42
44
46
48
50
52
Compressive strength (MPa)

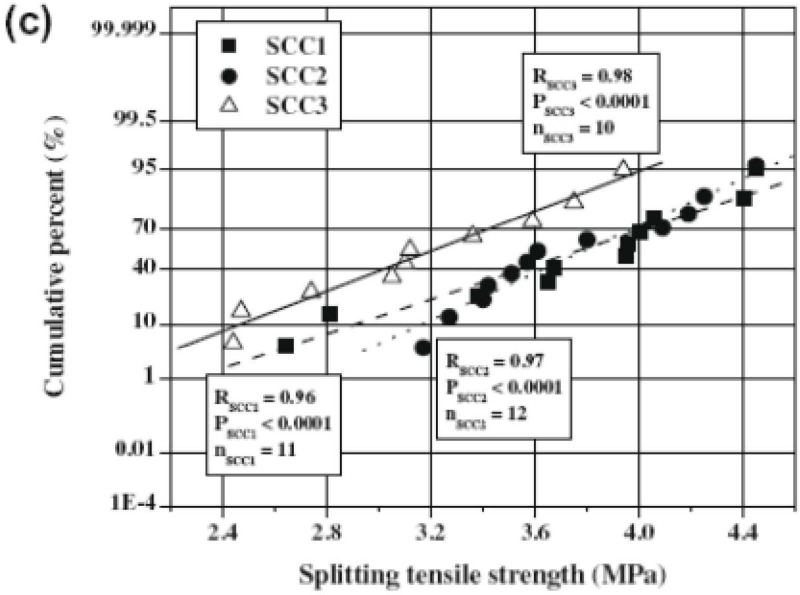


Figure 3.13 Normal probability plots for (a) modulus of elasticity (b) compressive strength (c) Splitting tensile strength. (*Debs et al., 2010)*

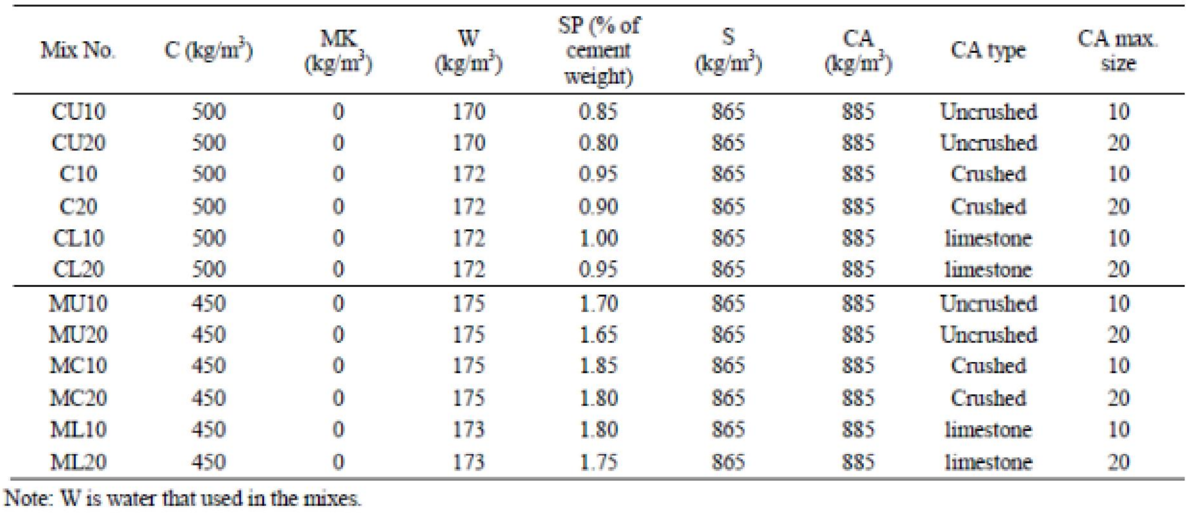
As it can be observed from **Figure 3.13**, the cumulative frequencies obtained from the experimental data are close to a straight line in a normal probability paper,therefore, indicating an appropriate fit to the normal distribution for the three properties analyzed in this study.

The study has presented a statistical analysis on the main resistance properties (the modulus of elasticity, compressive strength and tensile strength) of three Self compacting concrete mixes varying the maximum aggregate size, paste and gravel content. Results are in accordance with the expected trends for conventional concrete, with E being sensitive to the paste and gravel content. For a given compressive strength, Self compacting concretes elaborated with a larger maximum size aggregate and higher volume of coarse aggregate presented higher values of E. The same behaviour was observed when a given tensile strength is considered. E noticeably increased with the hardened material density.

The relationship between fc and E obtained experimentally appeared slightly above the majority of the estimations from the considered formulations. In general, formulations approximate better the experimental values at higher compressive strengths, between 45 and 50 MPa, but visibly underestimate E of SCCs at strengths lower than 40–45 MPa.

Considering the special characteristics of the casting process when using Self compacting concrete, where, for instance, the workmanship influences the final structural homogeneity to a much lesser extent than for normal concrete due to the lack of compaction, the values obtained for cylinder specimens could also be adopted when considering structural elements.

Razak et al.(2011) study the properties of coarse aggregates for SCC in its fresh & hardened state using three types of coarse aggregates namely crush gravel, uncrushed gravel and crush limestone.The cement used was ordinary Portland cement. Metakaolin was used as a partial replacement for cement with the percentage of replacement at (10%). The superplasticizer used was Glenium 51. Glenium 51 is considered one of the new generations of copolymer based superplasticizers. The three types of coarse aggregate were uncrushed gravel, crushed gravel, and crushed limestone with a maximum size of 20 mm and specific gravity (2.68, 2.62 and 2.58) and absorption (0.6,0.64 and 2%) respectively.



Mix No.	C (kg/m^3)	MK (kg/m^3)	W (kg/m^3)	SP (% of cement weight)	S (kg/m^3)	CA (kg/m^3)	CA type	CA max. size
CU10	500	0	170	0.85	865	885	Uncrushed	10
CU20	500	0	170	0.80	865	885	Uncrushed	20
C10	500	0	172	0.95	865	885	Crushed	10
C20	500	0	172	0.90	865	885	Crushed	20
CL10	500	0	172	1.00	865	885	limestone	10
CL20	500	0	172	0.95	865	885	limestone	20
MU10	450	0	175	1.70	865	885	Uncrushed	10
MU20	450	0	175	1.65	865	885	Uncrushed	20
MC10	450	0	175	1.85	865	885	Crushed	10
MC20	450	0	175	1.80	865	885	Crushed	20
ML10	450	0	173	1.80	865	885	limestone	10
ML20	450	0	173	1.75	865	885	limestone	20

Note: W is water that used in the mixes.

Table 3.16 Mixes Proportion (*Razak et al., 2011)*

The T50cm of mixes with (10mm) maximum size of coarse aggregate was less than the T50cm of mixes with (20mm) maximum size of coarse aggregate. The mixes made from uncrushed gravel had lower values of T50cm than the T50cm values of the mixes made from crushed gravel and crushed limestone, due to the smooth texture of the surface of uncrushed gravel. The incorporation of high reactivity metakaolin as a partial replacement by weight of cement leads to an increase in T50cm values. This is attributed to the fact that the high reactivity metakaolin has plate-like particles (Justice, 2005) which increase the inter-particles friction (Hadhrati, 2006).

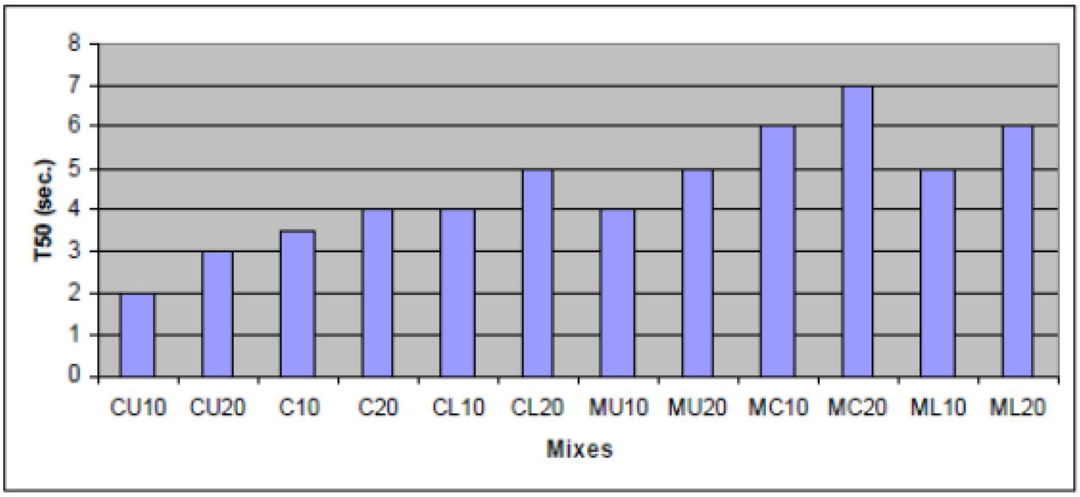


Figure 3.14 Slump Flow Test Results (*Razak et al., 2011)*

The compressive strength of the mixes made with the 10mm maximum size of coarse aggregate is higher than the values of the mixes made with the 20mm maximum size of coarse aggregate. This is due to the smaller maximum size of coarse aggregate that has the larger surface area that results in a higher bonding strength in the transition zone (ITZ) around aggregate particles when concrete is under loading.

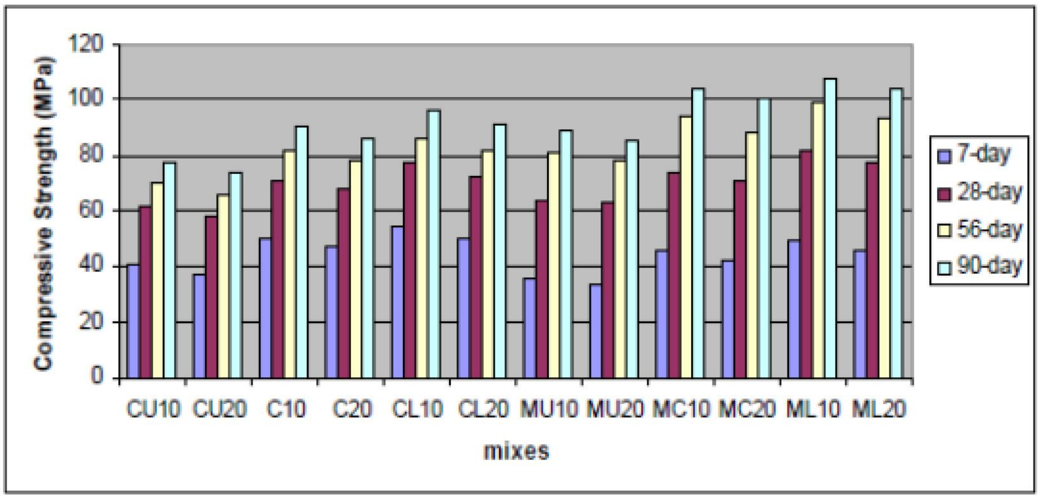


Figure 3.15 Compressive Strength Test Results (*Razak et al., 2011)*

The crushed limestone in the mixes gave higher compressive strengths than crushed gravel in the mixes. This behavior is attributed to the effect of chemical interaction and the rougher surface texture of particles, where the bond between aggregate and paste is stronger. In addition, the results indicate that mixes that have crushed gravel give the compressive strength values higher than uncrushed gravel. This may be attributed to the roughness of the surface of crushed gravel as compared with the surface of uncrushed gravel.

It was concluded, that the flowability of SCC decreases with the increase in the maximum size of coarse aggregates.The uncrushed gravel, when use in the SCC mixes increases the fowability, passing ability and segregation resistance as compared to SCC made from crushed gravel and crush limestone.The partial replacement of 10 % of cement with the high reactivity metakaolin decreases the flowability but increases the strength because it has plate-like particles (Justice 2005) which increase the inter-particles friction (Hadhrati 2006).The SCC made with crushed limestone gives higher strength and elasticity than the SCC made with the crushed gravels, and the SCC made with crushed gravels gives higher strength and elasticity than the SCC made with the uncrushed gravels.The mechanical properties of SCC mixes containing the 10 mm aggregates size of coarse aggregate are higher than the SCC mixes with 20 mm maximum size of coarse aggregates.

Brito et al.(2012) studied the effect on mechanical properties of concrete containing fine recycled aggregate by adding two types of super plasticizers. The fine recycled aggregate (FRAs) used throughout the experiment were obtained from a source concrete (SC) produced by a ready mixed concrete plant and module in the laboratory. The chemical composition of source concrete is given below:

	Contents(kg/m^3)
Cement ll/A-L 42.5R	224
Fly ash	121
Water	165
Fine natural sand	216
Coarse natural sand	437
Fine natural limestone gravel	215
Medium natural limestone gravel	326
Coarse natural limestone gravel	633
Plasticizer	3.45

Table 3.17 Source Concrete Composition (*Brito et al., 2012)*

Super plasticizers Used

Two types of super plasticizer were used: a current one henceforth called SP 1, whose chemical basis is lignosulfonate, with additions; a high-performance super plasticizer, henceforth called SP 2, whose chemical basis is a combination of modified polycarboxylates in an aqueous solution. Two reference concrete mixes with super plasticizer (RC1 and RC2) were prepared in addition to the reference concrete without admixtures (RC0), all without RA. When used, the super plasticizer content was kept constant at 1% of the cement mass.

Concrete mixes composition

In this experiment, fine natural aggregates are being replaced by fine recycled aggregates and the effect of that is also being observed. Based on Faury's method, five mixes were produced for each superplasticizer (and also without admixtures): a reference concrete (RC) and four FRACs with replacement ratios of FNA by FRA of 10%, 30%, 50% and 100%. Faury's method is based on an empirical reference grading curve that optimizes compacity for a given mix, whose main design characteristics are known.

Observations

Some conclusions can be drawn from this experimental campaign concerning the effect of superplasticizers on concrete made with fine recycled aggregates (FRA). Several replacement ratios (ranging from 10% to 100%) were used and compared with reference concrete (RC), made solely with natural aggregates. FRACs show worse mechanical performances than the corresponding RCs. But it can be said that, in all the situations analysed, their quality was good enough for structural use. The following conclusions are based on the experimental results:

- There was a loss of splitting tensile strength (from 15.6% to 24.3%) with FRA incorporation either with superplasticizers or without them; FRAC with superplasticizers yield better absolute results (from 26.6% to 52.8%), even though within each concrete family studied (i.e. comparing the improvement in FRAC with that in RC) the admixtures' performance in FRAC is worse.
- The modulus of elasticity is also negatively influenced by FRA (reductions from 9.5% to 17%); in terms of improvement linked to the superplasticizers, mixes with SP 1 performed worse than those with SP 2 (20.7% against 33.0%) and the absolute values of the latter are also higher; in relative terms the efficiency in RC lies between those in FRAC with SP 1 and SP 2.
- Both splitting tensile strength and modulus of elasticity can be correlated with compressive strength, but only if additional parameters, such as replacement ratio and effective water cement ratio are also taken into account.
- With the exception of abrasion resistance it is predicted that small increments of the superplasticizer content and the reduction of the w/c ratio will make it possible to produce FRACs of the same or better performance than the corresponding RCs with no admixtures, with less efficient ones or with lower admixture content.

3.3 Closing Remark

This chapter gives brief description of the experiments performed by different authors to find various properties like fresh properties, hardened properties and the durability properties of self compacting concrete and their results.

CHAPTER 4 EXPERIMENTAL STUDIES

4.1 General

The experimental program aimed to compare the hardened properties of various mixes of Self Compacting Concrete made from different proportion of recycled fine aggregates and conventional concrete. The basic materials used in making the Self Compacting Concrete are discussed in this chapter, followed by a brief description about mix design and curing procedure adopted. At the end various tests conducted on the specimens are discussed.

4.2 Materials used for making SCC

In this section brief description on physical properties of the material used to prepare SCC mixes is discussed.

4.2.1 Cement

Ordinary Portland Cement of Grade 43 from Ambuja Cement Ltd. has been used for making the Self Compacting Concrete. Properties of Cement are tabulated below.

Properties	Ordinary Portland Cement		
Specific Gravity	2.193		
Initial Setting Time	200 Minutes		
Final Setting Time	10 Hours		
Compressive Strength of mortar cubes(Conforming to IS:4031 part-6-1988)	3 day	7 day	28 day
	30.24MPa	39.1MPa	43.8MPa

Table 4.1 Physical properties of Cement

4.2.2 Fine Aggregates

The natural fine aggregates were procured from Kotputli source. The recycled fine aggregates were obtained by crushing demolished concrete waste in a laboratory jaw crusher. The fine recycled aggregates was sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm. Poperties of the natural fine aggregate and recycled fine aggregates used in the experimental work are tabulated in **Table 4.2** and **Table 4.3.** The aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in **Table 4.4.**

Sr.No	Characteristics	Value
1	**Specific gravity**	2.69
2	**Bulk Density**	1,976 Kg/m^3
3	**Water Absorption**	0.87%

Table 4.2 Physical properties of Fresh/Natural Fine Aggregate

Figure 4.1 Natural Fine Aggregate

Sr.No	Characteristics	Value
1	**Specific gravity**	2.54
2	**Bulk Density**	1,842 Kg/m^3
3	**Water Absorption**	6.65%

Table 4.3 Physical properties of Recycled Fine Aggregate

Figure 4.2 Recycled Fine Aggregates

Sr.No	Sieve Size	Mass retained	Percentage retained	Cumulative Percentage retained	Percent passing
1	**4.75 mm**	4.0g	0.4	0.4	99.6
2	**2.36mm**	75.0g	7.5	7.9	92.1
3	**1.18**	178.0g	17.8	25.7	74.3
4	**600µm**	220.0g	22	47.7	52.3
5	**300µm**	274.0g	27.4	75.1	24.9
6	**150µm**	246.5g	24.65	99.75	0.25
				Σ=256.55	

Table 4.4 Sieve Analysis of Recycled Fine Aggregates

Total Weight taken = 1000gm

Fineness modulus of Sand = 2.56

Zone = II

4.2.3 Coarse aggregate

Crushed stone is generally used as a coarse aggregate. Locally available coarse aggregate having the maximum size of 10 to 20 mm was used in our work. The aggregates were tested as per IS: 383-1970. The results of various tests conducted on coarse aggregate are given in **Table 4.5** and **Table 4.6** shows the sieve analysis results.

Sr. No	Characteristics	Value
1	**Type**	Crushed
2	**Specific Gravity**	2.66
3	**Total Water Absorption**	0.56
4	**Fineness Modulus**	6.83

Table 4.5 Physical Properties of Coarse aggregate

Sr No	Sieve Size	Mass Retained	Percentage retained	Cumulative Percentage retained	Percent Passing
1	**20mm**	0	0	0	100
2	**10mm**	2516	83.89	83.87	16.13
3	**4.75mm**	474	15.8	99.67	0.33
4	**PAN**	10	0.33	Σ=183.54	

Table 4.6 Sieve Analysis of Coarse Aggregate

Total Weight taken = 3Kg

Fineness Modulus of 10mm coarse aggregate = (183.54 + 500)/100 =6.83

4.2.4 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete.

4.2.5 Fly Ash

Class F Fly ash obtained from —National Thermal Power Corporation (NTPC) Faridabad, Haryana was used.

4.2.6 Admixture

Admixture used in this work is Superplasticizer of CICO brand, which complies with IS: 9103:1979 and BS: 5075 Part 3 and ASTM-C-494 type ‘F’ as a high range water reducing admixture. Ultracon SP 430 is ready to use admixture that is added to the concrete at the time of batching. Ultracon SP430 is differentiated from conventional superplasticizers in that it is based on aqueous solution of lignosulphonates, organic polymer with long lateral chains. This greatly improves cement dispersion. Ultracon SP430 is supplied as brown liquid instantly dispersible in water and specially formulated to give high water reduction up to 25% without loss of workability. Specific gravity is 1.22 to 1.225 at 30 degree C.

Figure 4.3 Superplasticizer (Ultracon)

4.3 Mix Design

The base mix was designed for M35 concrete according to the guidelines given in IS: 10262 2009 (code of practice for mix design of normal concrete) and several changes were made through trials in the design to obtain the properties of self compacting concrete. Changes include:

1. Increase in the quantity of powder content (particle size < 150µ)
2. Optimal dosage of super plasticizer.

Initially two types of SCC were prepared- one completely with fresh coarse and fine aggregate and other with fresh coarse aggregate and 100% replacement of fresh fine aggregate with recycled one. The w/c and water to binder ratio of the base mix was kept as 0.45 and 0.35 respectively. However, slight modifications in the water quantity were introduced on the spot to achieve the desired workability, flowability and to account for more water absorption of recycled fine aggregates than fresh ones.

The intermediate mix designs with the replacement of 25%, 50% and 75% of recycled fine aggregates were prepared for the comparison of fresh and hardened properties.

Figure 4.4 Mix Proportioning

4.4 Specimen casting and curing

Before casting, the moulds for the concrete cube, cylinder and the beam were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. All concrete trials were mixed for 20 minutes in a laboratory mixer. Before casting Slump flow, U box, L box and V funnel tests were conducted to determine the fresh properties of the SCC. For each concrete mixture, twelve 150x150x150 mm cubes were casted to determine the hardened and durability properties and three 700x150x150 mm beam were casted for flexure strength test.

Figure 4.5 Making of Self Compacting Concrete

Figure 4.6 Cubes Filling

SCC trial mix details			
Date:		Time:	Trial 1
Ingredients	Source/ Type	Conventional SCC	Remarks
		(Kg/m³)	
Cement		400	0% replacement of recycled fine aggregates
Fly Ash		150	
Fine Aggregate	Fresh	800	
Aggregate 1 (20 mm)	Fresh	270	
Aggregate 2 (10 mm)	Fresh	500	
Water		180	
Admixture		5	

Table 4.7 Trial with fresh coarse and fine aggregates

SCC trial mix details			
Date:		Time:	Trial 1
Ingredients	Source/ Type	RAC 100	Remarks
		(Kg/m³)	
Cement		400	100% replacement of recycled fine aggregates.
Fly Ash		150	
Fine Aggregate	Recycled	800	
Aggregate 1 (20 mm)	Fresh	270	
Aggregate 2 (10 mm)	Fresh	500	
Water		280	
Admixture		14	

Table 4.8 Trial with fresh coarse and recycled fine aggregates

After casting, the specimens were covered with wet jute bags for 24 hours. They were then de-molded. The rest of the specimens were then kept in water curing tank at 27°C until the time of test.

The Mix Design prepared by Replacing 0%, 25%, 50%, 75% and 100% of Recycled Fine aggregates are listed below:-

Mix ID	Cement Kg/m^3	Fly Ash Kg/m^3	CA (20mm) Kg/m^3	CA (10mm) Kg/m^3	FA Kg/m^3	RFA Kg/m^3	SP Kg/m^3	Water Kg/m^3	W/C Ratio
Conventional SCC	400	150	270	500	800	-	5	180	0.45
RFA 25	400	150	270	500	600	200	8	184	0.46
RFA 50	400	150	270	500	400	400	10	192	0.48
RFA 75	400	150	270	500	200	600	12	200	0.5
RFA 100	400	150	270	500	-	800	14	208	0.52

Table 4.9 Mixes Prepared

Where Conventional SCC –Normal Self compacting concrete with Fresh material

RFA 25 - Self compacting concrete with 25% replacement of Recycled Fine aggregate

RFA 50 - Self compacting concrete with 50% replacement of Recycled Fine aggregate

RFA 75 - Self compacting concrete with 75% replacement of Recycled Fine aggregate

RFA 100 -Self compacting concrete with 100% replacement of Recycled Fine aggregate

FA – Fine aggregate

RFA- Recycled Fine Aggregate (0-4mm)

SP – Super Plasticizer

4.5 Tests Conducted

4.5.1. Tests for Fresh properties of Self Compacting Concrete

- Slump Flow Test
- L-Box Test
- V-Funnel Test
- U-Box Test

- **Slump Flow Test**

It is the most commonly used test and is used to assess the horizontal free flow of the concrete in the circular diameter to measure the filling ability of the concrete. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation.

Procedure

- Moisten the base plate and inside of slump cone, Place base plate on level stable ground and the slump cone centrally on the base plate and hold down firmly.
- Fill the cone with the scoop.
- Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.
- Remove any surplus concrete from around the base of the cone.
- Raise the cone vertically and allow the concrete to flow out freely.
- Start the stopwatch and record the time taken for the concrete to reach the 500mm spread circle. (This is the T50 time).
- Measure the final diameter of the concrete in two perpendicular directions.
- Calculate the average of the two measured diameters. (This is the slump flow in mm).

Results

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of at least 650mm is required for SCC.

Figure 4.7 Slump Cone Test

- **L- Box Test Method**

This test is conducted to visualize the concrete blocking by reinforcement. The apparatus is shown below in Fig. 4.4.

Test Procedure

- The level of ground should be plain; so that the apparatus should be set levelled ensuring that the sliding gate can open freely and then close it.
- Fill the vertical section of the apparatus with the concrete sample.
- Lift the sliding gate and allow the concrete to flow out into the horizontal section.
- When the concrete stops flowing, the distances “H1” and “H2” are measured.
- Calculate H2/H1, the blocking ratio.

Results

If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1 = 1. Therefore the nearer this test value, the ‘blocking ratio’, is to unity, the better the flow of the concrete.

Figure 4.8 L-Box Test

- **V – Funnel Test**

The test is designed to measure flow ability of fresh Self Compacting Concrete.

Procedure

- Set the V-funnel on firm ground.
- Close the trap door and place a bucket underneath.
- Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concrete level with the top with the trowel.
- Open within 10 sec after filling the trap door and allow the concrete to flow out under gravity.
- Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (the flow time).

Results

This test measures the ease of flow of the concrete; shorter flow times indicate greater flow ability. For SCC a flow time of 10 seconds is considered appropriate.

Figure 4.9 V-Funnel Test

- **U – Box Test**

The test is used to measure the filling ability of self-compacting concrete.

Procedure

- Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.
- Fill the one compartment of the apparatus with the concrete sample.
- Leave it to stand for 1 minute.
- Lift the sliding gate and allow the concrete to flow out into the other compartment.
- After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (H1). Measure also the height in the other compartment (H2)
- Calculate H1 - H2, the filling height.

- *Results*

If the concrete flows as freely as water, at rest it will be horizontal, so H1 - H2 = 0. Therefore the nearer this test value is to zero, the better the flow and passing ability of the concrete.

Figure 4.10 U-Box Test

4.5.2 Tests for Strength Properties of SCC

- **Compressive Strength**

  All the above mentioned tests for fresh SCC were carried out in accordance with the EFNARC standards. The compressive strength of concrete was measured using AIMIL compression machine with a loading capacity of 2000 KN conforming to IS: 14858 (2000). The compressive strength test was carried out on cubes at the ages of 7 and 28 days.

  At least two hours before the compressive strength test was to occur, the concrete specimens were removed from the moist curing chamber and the moisture was removed from the ends. The specimen was then placed in the apparatus, centered, and brought to just below the upper plate.

  When the setup was complete, the specimen was loaded at the specified rate until it could no longer sustain a load and the load rate dropped to a negative value. The machine was turned off and the peak load was recorded.

The load was then divided by the cross sectional area to get the measured compressive strength in pounds per square inch. A minimum of three specimens were tested at a given test age and the results were averaged to get the final measured compressive strength.

Figure 4.11 Compressive Strength Test

- **Flexural Strength**

The specimens used for the modulus of rupture test were fabricated in accordance with ASTM C 78–10, “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).” Two specimens were fabricated for every concrete mix and the size of each specimen was 700 mm x 150 mm x 150 mm. It should be noted that the SCC was not rodded when specimens were cast. The specimens were cast in one single lift. The specimens were de-molded after 24 hours and stored in a moist curing chamber for 28 days. After 28 days they were prepared for testing.

After 28 days, the specimens were removed from the moist curing chamber. In order to align the specimen on the supports, it had to be divided into thirds.

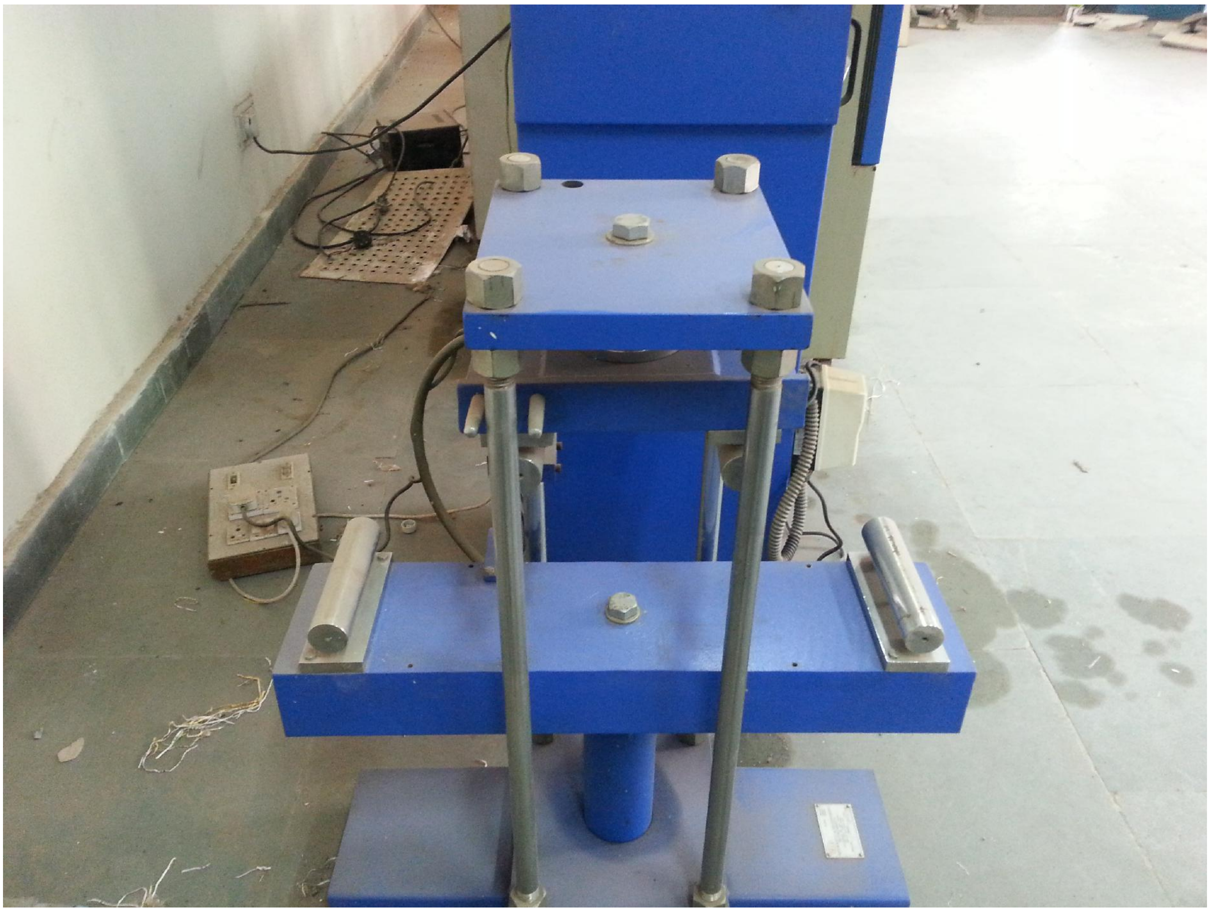


Figure 4.12 Flexural Strength Test

The load was applied at the aforementioned points. The failure load was recorded and subsequently used to calculate the modulus of rupture using Equation:

= ——

The beam was then loaded at a constant rate until failure. If the beam failed within the middle third, the test was accepted. It should be noted that all beams tested in this investigation failed in the middle third of the beam.

- **Splitting Tensile Strength**

The specimens used for the splitting tensile test were fabricated in accordance with ASTM C 496–11, “Standard Test Method for Splitting Tensile Strength.” A minimum of three specimens were made for each concrete mix. The specimens used for the splitting tensile test were the same types of specimens used for the compressive strength test. The specimens were fabricated according to ASTM C 192. After 24 hours, the specimens were de-molded and placed in a moist curing chamber for 28 days, at which time they were then tested.

After the specimens were allowed to cure for 28 days, the specimens were removed from the curing chamber for testing. The splitting test are well- known indirect tests used for determining the tensile strength of concrete. The test consisits of applying compressive line load along the middle parallel to the edges through 15mm square bars of sufficient length. In this case of side-splitting of the cubes, the tensile strength can be determined from

$$\sigma_{sp} = 0.642\ P/S^2$$

4.6 Closing Remarks

Physical properties of fresh fine and coarse aggregates, along with the recycled fine aggregates have been determined. The properties of SCC have also been found out in the laboratory by experiments.

5.1. General

This chapter comprises of fresh and hardend properties of various mixes for making self compacting concrete made from different proportions of recycled fine aggregates. The tests results are discused in this as follows

5.2 Fresh Properties

The results of fresh properties of all Self-compacting concretes are included in **Table 5.1**. The Table shows the properties such as slump flow, V-funnel flow times, L-box and U- box. SCC made with recycled fine aggregates and natural coarse aggregate typically needs more water than conventional SCC in order to obtain the same workability.

Mixture Id	Slump(mm)		V-Funnel (Seconds)		L-Box (H2/H1)		U-Box (H2-H1)mm	
	Experiment Results	EFNARC Limits	Experiment Results	EFNARC Limits	Experiment Results	EFNARC Limits	Experiment Results	EFNARC Limits
SCC-C	740	650-800	7	6-12	0.9	0.8-1	30	0-30
RFA25	720	650-800	8	6-12	0.88	0.8-1	27	0-30
RFA50	697	650-800	9	6-12	0.85	0.8-1	26	0-30
RFA75	685	650-800	10.6	6-12	0.834	0.8-1	23	0-30
RFA100	650	650-800	12	6-12	0.778	0.8-1	21	0-30

Table 5.1 Fresh concrete properties

- All SCC exhibited satisfactory slump flows in the range of 550–800 mm
- The V-funnel flow times were in the range of 7–12 seconds.
- Maximum size of coarse aggregate was kept as 20 mm in order to avoid blocking effect in the L-box. The gap between re-bars in L-box test was 35 mm. The L-box ratio H2/H1 for the mixes was above 0.8 which is as per EFNARC standards.
- U-box difference in height of concrete in two compartments was in the range of 21–30 mm. All the Fresh properties of concrete values were in good agreement to that of the values given by European guidelines.

5.3 Hardened Properties

5.3.1 Compressive Strength Test Results

The compressive strength tests results of Self Compacting Concrete are given in **Table 5.2** and shown in **Figure 5.1** and **Figure 5.2**. As the percentage of recycled fine aggregates increses, the compressive strength of the SCC decreases.

Mix	**Compressive Strength (N/mm²)**		**Average Compressive Strength (N/mm²)**	
	7 days	**28 days**	**7 days**	**28 days**
Conventional SCC	36.6	58.3	37.9	58.8
	41.3	60.9		
	35.9	57.3		
RFA 25	33.3	53.3	36.2	55.8
	38.9	56.4		
	36.6	57.8		
RFA 50	31.3	51.6	32.6	49.7
	35.6	48.3		
	30.9	49.2		
RFA 75	25.3	43.3	24.6	45.2
	27.9	46.9		
	20.8	45.5		
RFA 100	26.3	41.5	24.3	43.6
	22.1	45.6		
	24.6	43.9		

Table 5.2 Compressive Strength Test Results

- The 28 days compressive strength of conventional SCC was found to be 58.8 N/mm², where as the 28 days compressive strength decreases to 43.6 N/mm² as the fine aggregates was replaced by 100% recycled fine aggregates.

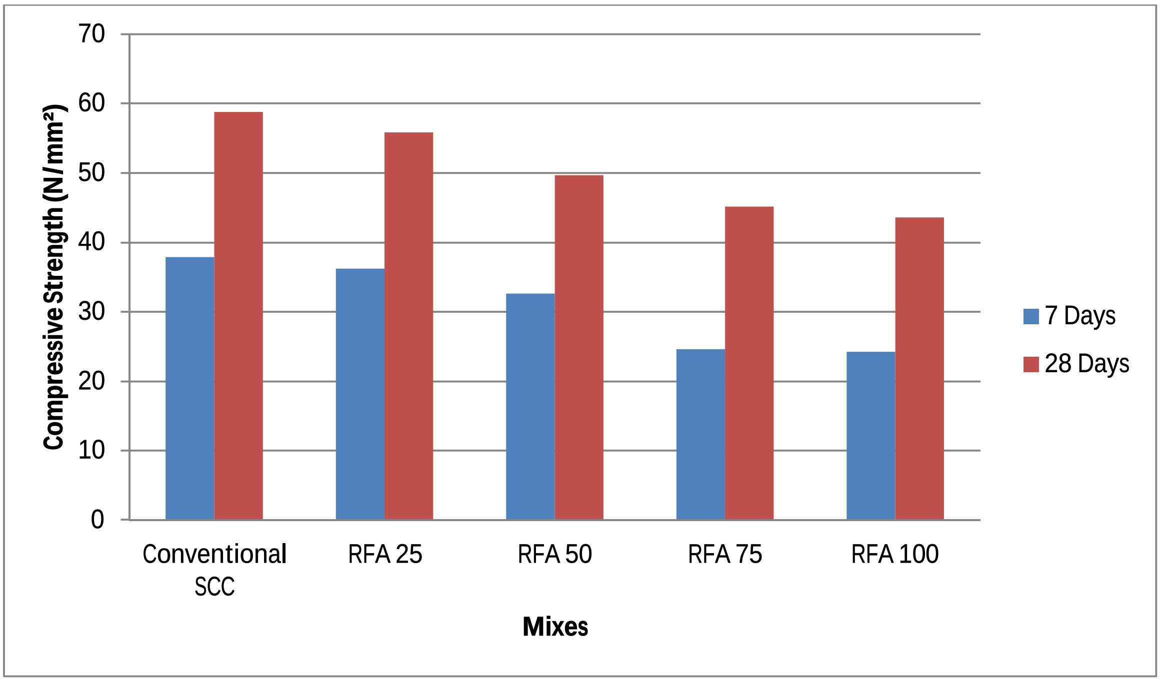


Figure 5.1 Variation of compressive strength with age of curing

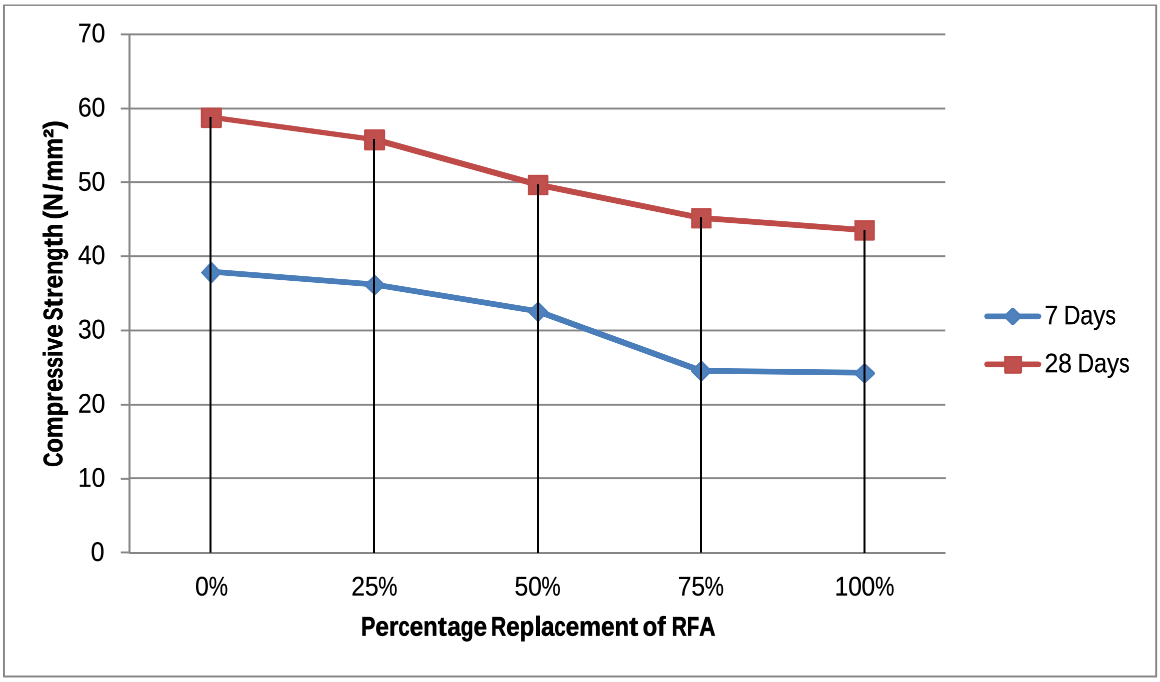


Figure 5.2 Variation of compressive strength with percentage replacement of RFA

- With the percentage replacement of 25% of recycled fine aggregates, the 28 days compressive strength decreases by a small value of 5.1 %, with replacement of 50% of recycled fine aggregates, the 28 days compressive strength decreases to 15.4 %, with replacement of 75% of recycled fine aggregates, the 28 days compressive strength decreases to 23.12 % and with replacement of 100% of recycled fine aggregates, the 28 days compressive strength decreases to 25.85 %.

- The 7 days compressive strength shows a little more differences when replacing from 0% to 100% of recycled fine aggregates. The percentage decreases are 4.4%, 13.9%, 35% and 35.8% for 25%, 50%, 75% and 100% replacement of recycled fine aggregates.
- These mixes can be comparable as the mix design adopted was of 35 N/mm² compressive strength. Further, it was concluded that, for the replacement of recycled fine aggregates upto 25 %, the decrease in compressive strength is very low as compared to the replacement by 50%, 75% and 100% of recycled fine aggregates. So the use of recycled fine aggregates shall be used up to some extent.

Therefore, efficacy of using waste concrete aggregates is justified.

5.3.2 Flexural Strength Test Results

The flexural strength tests results of Self Compacting Concrete are given in **Table 5.3** and shown in **Figure 5.3** and **Figure 5.4.**

Mix	Load (P) KN	Modulus of Rupture (N/mm²)	Average Flexural Strength (N/mm²)
Conventional SCC	36.23188	7.5	8.02
	40.57971	8.4	
RFA 25	38.16425	7.9	6.7
	27.05314	5.6	
RFA 50	32.36715	6.7	6.3
	28.50242	5.9	
RFA 75	20.77295	4.3	4.6
	23.6715	4.9	
RFA 100	20.28986	4.2	4.5
	23.18841	4.8	

Table 5.3 Test results of Flexural Strength

As the percentage of recycled fine aggregates increses, the flexural strength of the SCC decreases. The 28 days flexural strength of conventional SCC was found to be 8.02 N/mm², where as the 28 days flexural strength decreases to 6.7 N/mm².

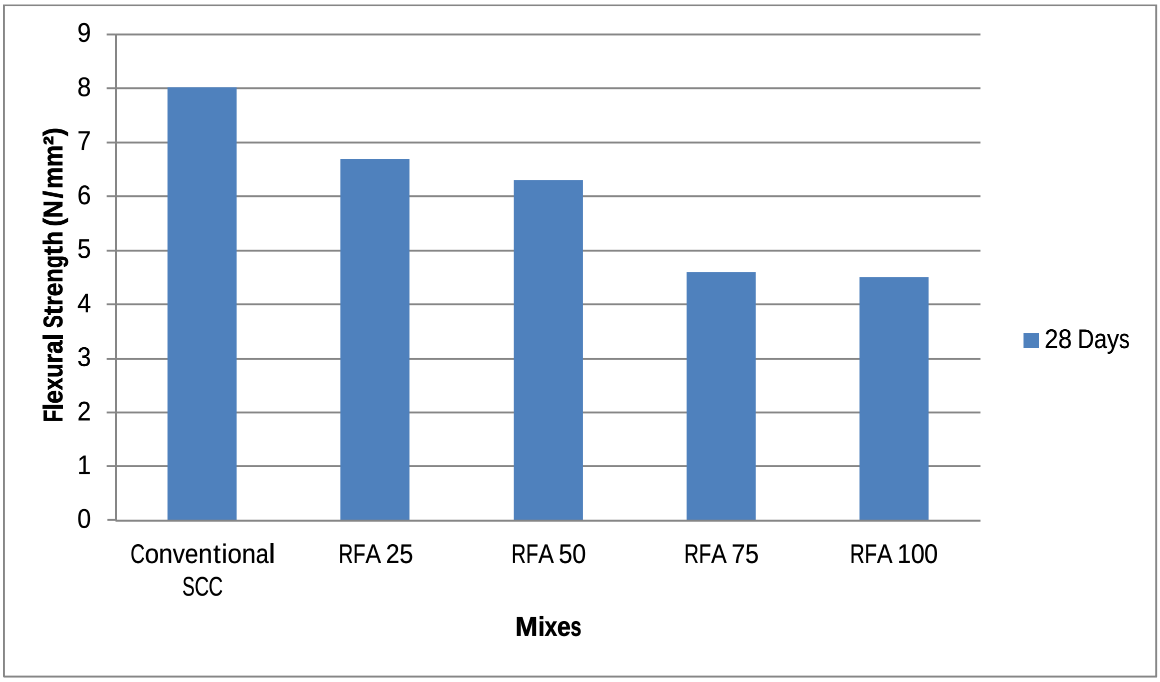


Figure 5.3 Variation of flexural strength with age of curing

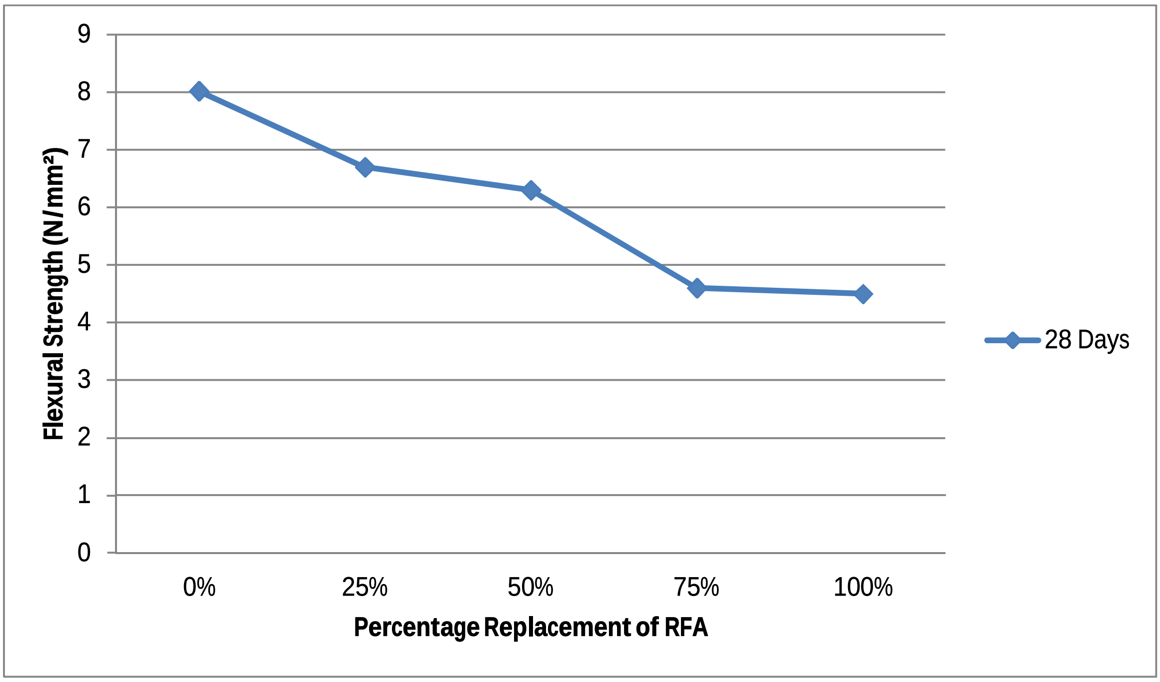


Figure 5.4 Variation of flexural strength with percentage replacement of RFA

The 28 days flexural strength decreases, when replacing from 0% to 100% of recycled fine aggregates. The percentage decreases are 16.4%, 21.4 %, 42.6% and 43.89% for 25%, 50%, 75% and 100% replacement of recycled fine aggregates.

5.3.3 Split tensile test

The split tensile strength tests results of Self Compacting Concrete are given in **Table 5.4** and shown in **Figure 5.5** and **Figure 5.6**.

	7 Days		**28 Days**		**7 Days**	**28 Days**
Mixes	**Load P (kN)**	**σ_{sp} (N/mm^2)**	**Load P (kN)**	**σ_{sp} (N/mm^2)**	**Average σ_{sp}**	**Average σ_{sp}**
Conventional SCC	683.4	19.5	1126.7	32.3	20.6	32.6
	732.4	20.9	1210.4	34.7		
	757	21.6	1077.9	30.9		
RAC 25	641.35	18.3	1039.5	29.8	18.5	30.4
	634.34	18.1	1050	30.1		
	672.89	19.2	1095.3	31.4		
RAC 50	602.80	17.2	917.4	26.3	17.3	27.9
	585.28	16.7	990.6	28.4		
	634.34	18.1	1015.1	29.1		
RAC 75	417.05	11.9	795.3	22.8	13.8	21.4
	522.19	14.9	756.9	21.7		
	515.18	14.7	690.6	19.8		
RAC 100	473.13	13.5	725.5	20.8	12.4	19.3
	385.51	11	610.4	17.5		
	445.09	12.7	683.7	19.6		

Table 5.4 Split Tensile Strength Test Results

- The 7 days split tensile strength shows the decreases in strength from 20.6 N/mm² to 12.4 N/mm² as the percentage of recycled fine aggregates increases in the mixes of SCC.
- The 28 days split tensile strength shows the decreases in strength from 32.6 N/mm² to 19.3 N/mm² as the percentage of recycled fine aggregates increases in the mixes of SCC.

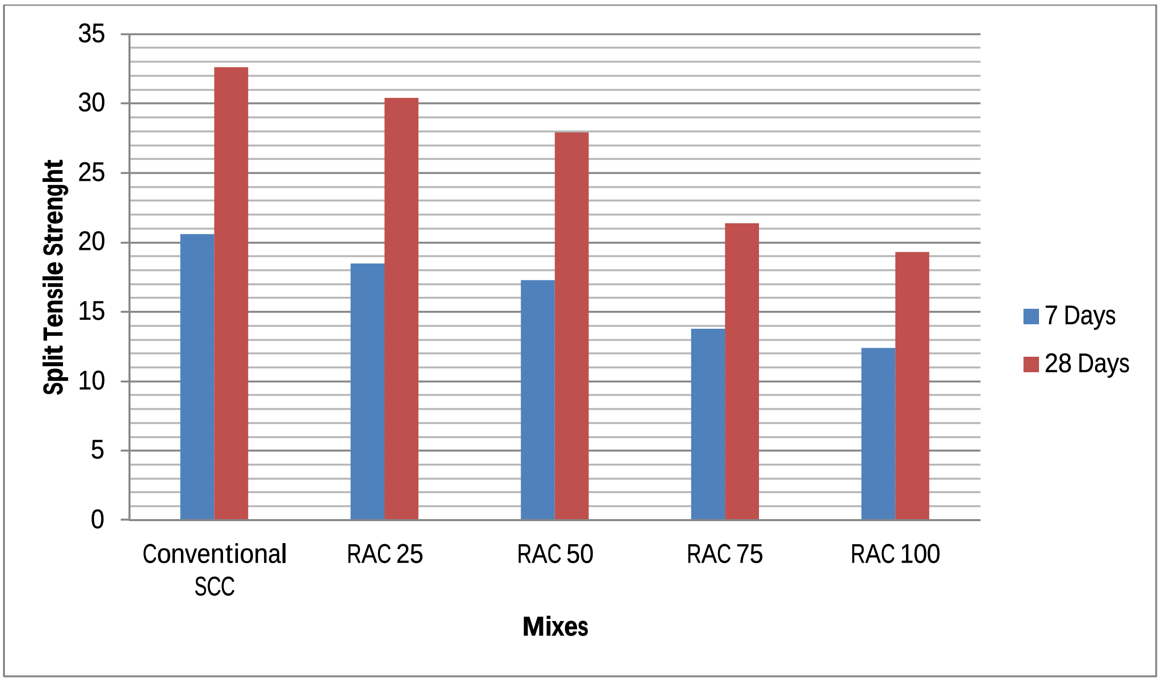


Figure 5.5 Variation of Split tensile strength with age of curing

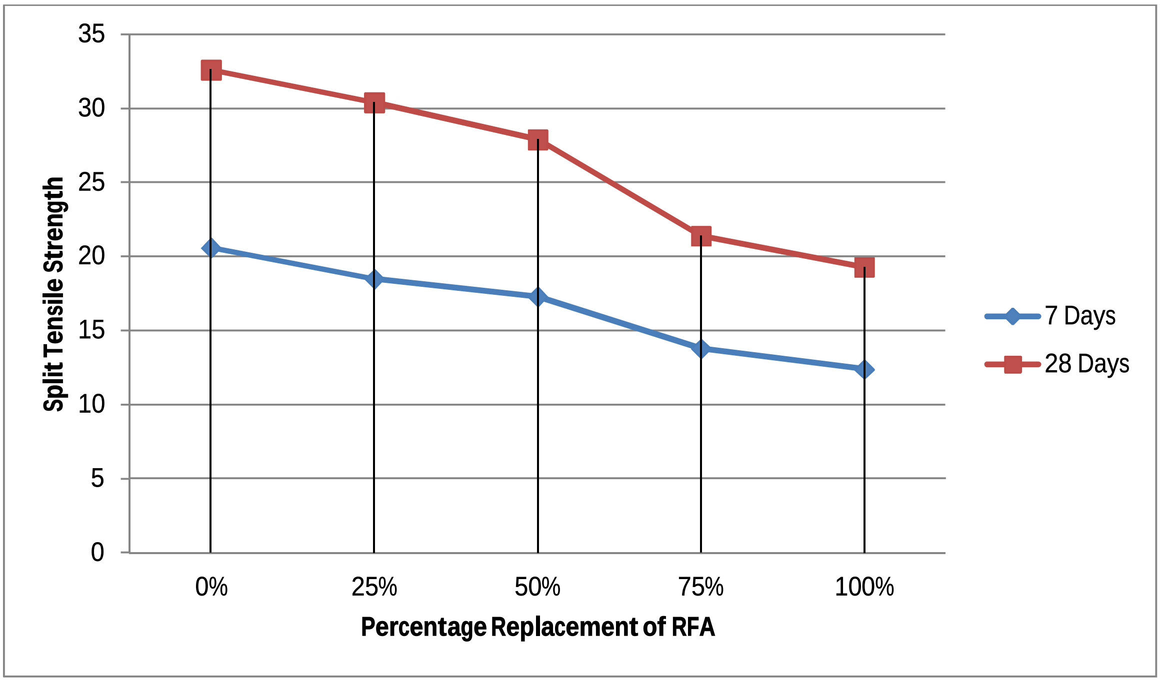


Figure 5.6 Variation of split tensile strength with percentage replacement of RFA

With the percentage replacement of 25% of recycled fine aggregates, the 28 days compressive strength decreases by a small percentage of 6.7 %, with replacement of 50% of recycled fine aggregates, the 28 days compressive strength decreases to 16.8 %, with replacement of 75% of recycled fine aggregates, the 28 days compressive strength decreases to 34.35 % and with replacement of 100% of recycled fine aggregates, the 28 days compressive strength decreases to 40.7 %.

5.4 Durability Properties

5.4.1 Water Absorption

The water absorbtion tests results of Self Compacting Concrete are given in **Table 5.5** and shown in **Figure 5.7.**

Mix	Percentage of water absorbed in 28 Days	Percentage of water absorbed in 56 Days
SCC-C	0.56	0.616
RFA 25	1.68	1.97
RFA 50	2.01	2.27
RFA 75	2.62	3.09
RFA 100	3.53	4.47

Table 5.5 Water absorbtion test results

The absorption is mainly influenced by the paste phase primarily as, it is dependent on the extent of interconnected capillary porosity in the paste. The absorption values of SCC containing the RFA are higher than that of the conventional SCC and it shows an increasing trend towards higher RFA content.

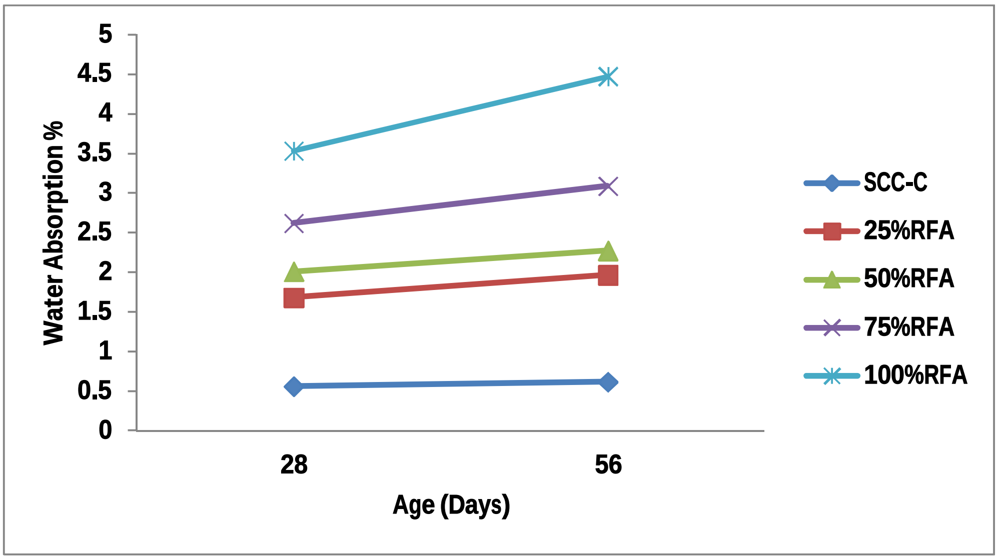


Figure 5.7 Percentage of Water absorbed at various ages

- From the results of water absorption, it is observed the water absorption values of SCC containing the RFA are higher than that of the conventional SCC .
- The SCC made with 100% RFA shows higher absorption which is 6.3 times higher than conventional SCC at the age of 28 days and 7.2 times higher than conventional SCC at the age of 56 days, that means water absorption values of all the RFA- SCC were higher than the conventional SCC.
- The absorption increased with an increase in percentage of RFA.It was due to the high absorption capacity of the RFA itself, which has created higher osmosis pressure within the concrete.

CHAPTER 6 CONCLUSION AND FURTHER SCOPE OF WORK

6.1 Conclusion

6.1.1 Fresh SCC Properties

- The present investigations shows that SCC made from recycled fine aggregates (RFA) gives satisfies workability requirements as per the desired acceptable limits.
- The slump flow test gives the value from 650 mm to 750 mm, the V-funnel time ranges from 7 seconds to 12 seconds, the L-box test value lies between 0.778 to 0.9 and the U-box test result shows the value between 21 mm to 30 mm.
- Slump test, V-funnel test, L-box test and the U-box test values all fall in the range of EFNARC limits.
- It justifies the replacement or use of RFA in SCC. Hence, recycled fine aggregates can be utilized for making SCC.

6.1.2 Hardened Properties

Compressive Strength

- In general, as the SCC is made by replacing fresh aggregates with RFA, fall in initial as well as final compressive strengths is observed.
- It is due to the reason that as the replacement of FA with RFA increases, the microstructure becomes more porous, water requirement and absorption increases and hence, drop in compressive strengths is observed.
- 28 days compressive strength of conventional SCC was found to be 58.8 N/mm², where as the 28 days compressive strength decreases to 43.6 N/mm² as the fine aggregates were replaced by 100% recycled fine aggregates.
- 7 days compressive strength shows a little more variation when percentage replacement is increased from 0% to 100% of recycled fine aggregates. The percentage drop in strengths observed are 4.4%, 13.9%, 35% and 35.8% for 25%, 50%, 75% and 100% replacement of recycled fine aggregates.
- With the percentage replacement of 25% of recycled fine aggregates, the 28 days compressive strength decreases by a small value of 5.1 %, with replacement of 50% of recycled fine aggregates, the 28 days compressive strength decreases to 15.4 %, with replacement of 75% of recycled fine aggregates, the 28 days compressive

strength decreases to 23.12 % and with replacement of 100% of recycled fine aggregates, the 28 days compressive strength decreases to 25.85 %.

- It was concluded that, for the replacement of recycled fine aggregates upto 25 %, the decrease in compressive strength is very low as compared to the replacement by 50%, 75% and 100% of recycled fine aggregates.
- Hence, it is justified to replace FA with RFA upto 25-50% for cost reduction and waste management prespective.

1. Flexural Strength

- As the percentage of recycled fine aggregates increses, the flexural strength of the SCC decreases. The 28 days flexural strength of conventional SCC was found to be 8.02 N/mm², where as the 28 days flexural strength decreases to 6.7 N/mm².
- The 28 days flexural strength decreases, when replacing from 0% to 100% of recycled fine aggregates. The percentage decreases are 16.4%, 21.4 %, 42.6% and 43.89% for 25%, 50%, 75% and 100% replacement of recycled fine aggregates.

2. Split Tensile Strength

- With the percentage replacement of 25% of recycled fine aggregates, the 28 days compressive strength decreases by a small percentage of 6.7 %, with replacement of 50% of recycled fine aggregates, the 28 days compressive strength decreases to 16.8 %, with replacement of 75% of recycled fine aggregates, the 28 days compressive strength decreases to 34.35 % and with replacement of 100% of recycled fine aggregates, the 28 days compressive strength decreases to 40.7 %.
- The 7 days split tensile strength shows the decreases in strength from 20.6 N/mm² to 12.4 N/mm² as the percentage of recycled fine aggregates increases in the mixes of SCC.

6.3 Durability Properties

- From the results of water absorption, it is observed the water absorption values of SCC containing the RFA are higher than that of the conventional SCC .
- The SCC made with 100% RFA shows higher absorption which is 6.3 times higher than conventional SCC at the age of 28 days and 7.2 times higher than conventional

SCC at the age of 56 days, that means water absorption values of all the RFA- SCC were higher than the conventional SCC.

- The absorption increased with an increase in percentage of RFA.It was due to the high absorption capacity of the RFA itself, which has created higher osmosis pressure within the concrete.

6.4 Overall Conclusions

- Further, the fresh properties for the SCC made with recycled fine aggregates gives satisfactory results for their use in SCC.
- The hardened and durability charcteristeics of SCC modified with variable replacement of FA with RFA shows marginal fall in strengths as well as duarability characteristics.
- Upto 50% replacement of recycled fine aggregates to modify SCC, it shows very small marginal fall in compressive, flexural as well as split tensile strength values as compared to conventional SCC.
- Some admixture like alccofine, silicafume etc. can be used to retrieve the loss in strengths.
- But the falls in strengths and durability parameters is not so large and hence, it justifies the use of waste fine aggregates in SCC from environmental and waste management issues.

6.5 Further scope of work

- Detailed investigation on optimal replacement of RFA in SCC without compromising on strength and durability.
- Study on the use of admixtures like alccofine, silica fumes, nano silica etc can be made in SCC modified by waste concrete aggregates to improve the strength and durability.

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