

STUDY OF DURABILITY CHARACTERISTICS OF SCC MADE FROM RECYCLED FINE AGGREGATES

A thesis submitted

In partial fulfillment of the requirements for

the award of the degree of

MASTERS OF ENGINEERING

IN

STRUCTURAL ENGINEERING

Submitted by

YOGESH BHASIN

(ROLL NO.820922005)

UNDER THE GUIDANCE OF:

Dr. Mehtab Alam

Prof. and Head, CED, JMI, New-Delhi

Dr. Shruti Sharma

Assistant Professor, CED



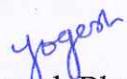
THAPAR UNIVERSITY, PATIALA
JULY 2013

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.

Date: 15/7/13

Place: Patiala


Yogesh Bhasin

Roll No. 820922005

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 **Yogesh Bhasin, Roll No.820922005** 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.



Dr. Mehtab Alam

Prof. and Head, CED, JMI, New-Delhi



Dr. Shruti Sharma

Assistant Professor, CED
Department of Civil, Engineering

Countersigned by:



(Dr. Naveen Kwatra)

Head,

Department of Civil Engineering

Thapar University, Patiala.


(Dr. S. K. Mohapatra)

Dean, Academics Affairs

Thapar University, Patiala

ACKNOWLEDGEMENTS

I express my sincere gratitude to my supervisors **Dr. Mehtab Alam, Prof. and Head, CED, JMI university, New-Delhi** and **Dr. Shruti Sharma Assistant Professor, Department of civil Engineering, Thapar University, Patiala** for acting as supervisors and giving their valuable guidance during the course of this Thesis.

I do not find enough words with which I express my feelings of thanks to entire faculty and staff of **Department of Civil Engineering, Thapar University, Patiala**, for their help, inspiration and moral support, which went a long way in successful completion of my seminar.

I also owe my thanks to my wife Neha, Friends- Charush, Pinchu & TU Library for providing necessary material. My heart brims with gratitude for my family for their perpetual blessing, inspiration & love.

Yogesh Bhasin

ABSTRACT

“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”.

The primary aim of this 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 were measured at the age of 7 and 28 days, and testing them for, water absorption, sulfate resistance sorptivity and chloride penetration resistance. The significance of this work lies in its attempt to provide Durability performance of SCC made with recycled concrete so as to draw attention to the possible use of SCC made with recycled fine aggregate(RFA).

TABLE OF CONTENTS

Declaration	i
Certificate	i
Acknowledgement	iii
Abstract	iv
Table of content	v
List of Tables	vi
List of Figures	vii

CHAPTER 1 INTRODUCTION

1.1 General	1
1.2 Objectives of Thesis	2
1.3 Brief Methodology	2
1.4 Background of SCC	3
1.5 Properties of SCC	7
1.6 Recycled Concrete	10
1.7 Closing Remark	18

CHAPTER 2 DURABILITY OF SCC

2.1 General	19
2.1 Durability of SCC	19
2.3 Various test for Durability	23

2.4Closing Remarks	30
--------------------	----

CHAPTER 3 LITERATURE REVIEW

3.1 General	28
3.2 Recent Works	28
3.3Closing Remark	63

CHAPTER 4 EXPERIMENTAL PROGRAM

4.1General	64
4.2 Experimental Programme & Test Results	64
4.3 Material used for making SCC	68
4.4 Mix design Detail	69
4.5 Casting	71
4.6 Test Method	72

CHAPTER 5 RESULTS AND DISCUSSIONS

5.1General	84
5.2Fresh Properties of SCC and Modified SCC	84
5.3 Hardened Property	85
5.4 Durability Property	87

CHAPTER 6 CONCLUSION AND FURTHER SCOPE OF WORK

6.1 Fresh SCC properties	95
6.2Compressive strength	95
6.3 Durability Property	96
6.4 Further scope of Work	

REFERENCES

LIST OF TABLES

Table No	Description	Page No
1.1	Test methods to evaluate the workability properties of SCC	8
1.2	Typical acceptance criteria for SCC	8
2.1	RCPT ratings	25
3.1	Mix proportions of the S.C.C mixtures investigated	28
3.2	Properties of Binders per cubic meter of concrete	32
3.3	Mix proportion of SCC	35
3.4	Mix proportion of SCC	38
3.5	Durability Properties of the Concretes investigated	40
3.6.1	Mix proportion of RA-SCC mixtures in Series I	43
3.6.2	Mix proportion of RA-SCC mixtures in Series II and III	44
3.7	Mix Proportion of SCC for 1 Cu.m	47
3.8	Ultrasound pulse velocity and density of SCC mixtures	49
3.9	Mix proportion of SCC	50
3.10	Depth of Water Penetration	51
3.11	Freeze residence in terms of the loss of mass(kg/m ²)	51
3.12.1	Mix Proportions of SCC	53
3.12.2	Carbonation depth and pH for SCC mixes Siddique (2012)	54
3.12.3	Weight loss for SCC mixes Siddique (2012)	55
3.12.4	Charge assessed and rating for SCC mixes Siddique (2012)	56
3.12.5	Mix proportions and fresh concrete properties of SCC mix	57
3.13	Mass loss for scc mixes	59
3.14	Porosity for SCC mixes	59
3.15	Mix design proportions (kg/m ³) self compacting concrete	60
3.16	Sorptivity coefficients of all mixtures	61
4.1	Composition Limit of Portland cement	65
4.2	Physical properties of cement used	65
4.3	Physical properties of Fine Aggregate	65

4.4	Physical properties of Recycled Fine Aggregate	66
4.5	Sieve analysis of recycled Fine aggregate	67
4.6	Physical properties of Coarse aggregate	67
4.7	Seive analysis of Recycled fine aggregate	67
4.8	Trial with Fresh Coarse & Fine aggregate	70
4.9	Trial with Fresh Coarse & 100% recycled aggregate	70
4.10	Final mix design details	70
5.1	Fresh concrete Properties	84
5.2	Compressive strength test result	85
5.3	Percentage of water absorbed	87
5.4	Evolution of water absorption by capillary	89
5.5	Percentage of water loss with age	90
5.6	Criteria to rate the concrete (RCPT)	92
5.7	Test result of chloride penetration resistance.	92
5.8	Test Results	93

LIST OF FIGURES

<i>Figure</i>	<i>Description</i>	<i>Page No</i>
1.1	Basic principles for the production of SCC	6
2.1	Rapid chloride permeability test	25
2.2	RCPT Rating test setup	29
3.1	Decing salt surface scaling	30
3.2	Cumulative mass scaled off versus member of freeze	32
3.3	xpansion of bar specimens of mortar extracted from SCC mixtures submerged in a 5%Na ₂ SO ₄ solution for 9 months	33
3.4.1	Rate of mass loss for group A	33
3.6	Rate of mass loss for group B	34
3.7	Rate of mass loss for group C	36
3.8	Water and Mercury porosity of concrete study	36
3.9	Effective coefficient of chloride diffusion of concrete studied	36
3.10	Oxygen Permeability of concrete studied	37
3.11	Capillary absorption coefficient at (24h) studied	38
3.12	Carbonation depth of concrete studied	39
3.13	Initial absorption values of the concretes investigated	39
3.14	Variation of Final Absorption with Permeable voids	40
3.15	Weight Loss with fly ash replacement	41
3.16	Chloride Permeability values	42
3.17	Initial current VS Total charge	42
3.18	Variation of charge with Alumina	43
3.19	Total charge passed (coulombs) of RA-SCC mixtures in Series I, II, and III	44
3.20	Drying shrinkage development of RA-SCC mixtures in Series I	45
3.21	Drying shrinkage development of RA-SCC mixtures in Series II	46
3.22	Drying shrinkage development of RA-SCC mixtures in Series. III	46
3.23	The best case (GBFS40 specimen) and (b) the worst case of specimens in 10% magnesium sulphate solution after 400 days exposure	48

3.24	The best case (GBFS40 specimen) and (b) the worst case of specimens in 10% Sodium sulphate solution after 400 days exposure	50
3.25	Pore Distribution curve	52
3.26	Moisture content [5% kgkg ⁻¹]	54
3.27	Carbonation depth	55
3.29	Chloride penetration for SCC mixes at various fly ash content	56
3.30	Rapid Chloride Permeability of Fly Ash concrete (28 days)	58
3.31	Rapid Chloride Permeability of Fly Ash concrete (91 days)	58
3.32	Carbonation coefficients for various w/c ratios for SCC and CC mixtures	62
3.33	Chloride diffusion coefficient of SCC and CC.	63
4.4	Superplasticizer	68
4.5	Magnesium Sulphate	69
4.6	Specimen casting	71
4.7	SCC made with Fresh concrete	72
4.8	SCC made with 100%RFA	72
4.9	Specimen curing	72
4.10	L-Box	73
4.11	V-Funnel	75
4.12	Slump Flow test	78
4.13	Slump Flow test SCC-C	78
4.14	Slump Flow test SCC-100RFA	78
4.15	U-Box Test	78
4.16	Compressive Test	80
4.17	Specimen dipped in sodium solution	81
4.18	Specimen immersed with water seal	82
4.19	water seal	82
4.20	Typical cell arrangement	83
4.21	Appratus for measuring curreny	84
4.22	Core cutter	83
5.1	Variation of compressive strength	86
5.2	%age of water absorbed	87

5.3	Evaluation of sorptivity	89
5.4	%age of weight loss with ages	91
5.5	Chroride permeability test	91

1.1 General

Cement-based materials are the most abundant of all man-made materials and are among the most important construction materials, and it is most likely that they will continue to have the same importance in the future. However, these construction and engineering materials must meet new and higher demands. When facing issues of productivity, economy, quality and environment, they have to compete with other construction materials such as plastic, steel and wood. One direction in this evolution is towards self-compacting concrete (SCC), a modified product that, without additional compaction energy, flows and consolidates under the influence of its own weight.

Self compacting concrete is a concrete which compacts itself, there is no further compaction required for self compacting concrete. Development of self-compacting concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. Self compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure and, due to its high-fluidity and resistance to segregation it can be pumped longer distances (Bartos, 2000).

The concept of self-compacting concrete was proposed in 1986 by Professor Hajime Okamura (1997), but the prototype was first developed in 1988 in Japan, by Professor Ozawa (1989) at the University of Tokyo. Self-compacting concrete was developed at that time to improve the durability of concrete structures. Since then, various investigations have been carried out and SCC has been used in practical structures in Japan, mainly by large construction companies. Investigations for establishing a rational mix-design method and self-compactability testing methods have been carried out from the viewpoint of making it a standard concrete. Self-compacting concrete is cast so that no additional inner or outer vibration is necessary for the compaction. It flows like “honey” and has a very smooth surface level after placing. With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated concrete, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in different proportions.

Self compacting concrete has been described as “the most revolutionary development in concrete construction for several decades”. Originally developed in Japan to offset a growing shortage of skilled labour, it has proved to be beneficial from the following points,

1. Faster construction,
2. Improved durability,
3. Reduction in site manpower,
4. Better surface finish
5. Easier placing,
6. Safer working environment.

Usually, the chemical admixtures used are high-range water reducers (super plasticizers). Mineral admixtures are used as an extra fine material, besides cement, and in some cases, they replace cement.

1.2 Objective of Thesis

- To prepare self compacting concrete of desired strength made with `Conventional & Recycled waste concrete used as fine aggregate.
- To evaluate durability properties of Self Compacting Concrete made with Recycled Fine Aggregates in various proportions and compare with SCC made with normal aggregate.

1.3 Brief Methodology

- Five SCC mixes were prepared by replacing 0%,25%,50%,75%&100% fine aggregate with recycled fine aggregate.
- Trial mixes were prepared to check the required strength.
- Durability characteristics evaluates for conventional SCC and SCC prepared by replacing FA in varying proportions.

- Comparison of durability characteristics of SCC made by replacing FA with recycled FA was done.
- Efficiency of using RFA is established and studied in this study.

1.4 Background of SCC

1.4.1 History

Making concrete structures without vibration have been done in the past. For examples, placement of concrete under water is done by the use of tremie without vibration. Mass concrete, and shaft concrete can be successfully placed without vibration. But the above examples of concrete are generally of lower strength and difficult to obtain consistent quality. Modern application of self-compacting concrete (SCC) is focussed on high performance, better and more reliable and uniform quality. Self-compacting concrete, in principle, is not new. Early self-compacting concretes relied on very high contents of cement paste and, once superplasticizers became available, they were added in the concrete mixes. The mixes required specialized and well-controlled placing methods in order to avoid segregation, and the high contents of cement paste made them prone to shrinkage. The overall costs were very high and applications remained very limited.

The introduction of “modern” self-levelling concrete or self-compacting concrete (SCC) is associated with the drive towards better quality concrete pursued in Japan around 1983, where the lack of uniform and complete compaction had been identified as the primary factor responsible for poor performance of concrete structures (Dehn et al., 2000). Due to the fact that there were no practical means by which full compaction of concrete on a site was ever to be fully guaranteed, the focus therefore turned onto the elimination of the need to compact, by vibration or any other means. This led to the development of the first practicable SCC by researchers Okamura and Ozawa, around 1986, at the University of Tokyo and the large Japanese contractors (e.g. Kajima Co., Maeda Co., Taisei Group Co., etc.) quickly took up the idea. The contractors used their large in-house research and development facilities to develop their own SCC technologies. Each company developed their own mix designs and trained their own staff to act as technicians for testing on sites their SCC mixes. A very important aspect was that each of the large contractors also developed their own testing devices and test methods (Bartos, 2000).

1.4.2 Motive

Recognising the lack of uniformity and complete compaction of concrete by vibration, researchers at the University of Tokyo, Japan, started in late 1980's to develop Self compacting concrete. By the early 1990's, Japan has developed and used SCC that does not require vibration to achieve full compaction. By the year 2000, the SCC has become popular in Japan for prefabricated products and ready mixed concrete. The utilisation of self compacting concrete started growing rapidly.

The other motive for development of self-compacting concrete was the social problem on durability of concrete structures that arose around 1983 in Japan. Due to a gradual reduction in the number of skilled workers in Japan's construction industry, a similar reduction in the quality of construction work took place. As a result of this fact, one solution for the achievement of durable concrete structures independent of the quality of construction work was the employment of self-compacting concrete, which could be compacted into every corner of a formwork, purely by means of its own weight. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were carried out by researchers Ozawa and Maekawa (Bartos, 2000) at the University of Tokyo.

During their studies, they found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, they eliminated the main cause for the poor durability performance of the concrete. By 1988, the concept was developed and ready for the first real-scale tests and at the same time the first prototype of self-compacting concrete was completed using materials already on the market. The prototype performed satisfactorily with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties and was named "High Performance Concrete."

At almost the same time, "High Performance Concrete" was defined as a concrete with high durability due to low water-cement ratio by professor Aitcin (Ouchi et al., 1996). Since then, the term high performance concrete has been used around the world to refer to high durability concrete. Therefore, Okamura (1997) has changed the term for the proposed concrete to "Self-Compacting High Performance Concrete."

1.4.3 More about self compacting concrete

Self compacting concrete can be described as a high performance material which flows under its own weight without requiring vibrators to achieve consolidation by complete filling of formworks even when access is hindered by narrow gaps between reinforcement bars (Zhu et al., 2001). SCC can also be used in situations where it is difficult or impossible to use mechanical compaction for fresh concrete, such as underwater concreting, cast in-situ pile foundations, machine bases and columns or walls with congested reinforcement. The high flowability of SCC makes it possible to fill the formwork without vibration (Khayat et al., 2004).

The method for achieving self-compactability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone of reinforcing bars (Okamura et al., 2003). Homogeneity of SCC is its ability to remain unsegregated during transport and placing. High flowability and high segregation resistance of SCC are obtained by:

1. A larger quantity of fine particles, i.e., a limited coarse aggregate content,
2. A low water/powder ratio, (powder is defined as cement plus the filler such as fly ash, silica fume etc.),
3. The use of superplasticizer (Okamura et al., 2003).

Because of the addition of a high quantity of fine particles, the internal material structure of SCC shows some resemblance with high performance concrete having self compactability in fresh stage, no initial defects in early stage and protection against external factors after hardening. Due to the lower content of coarse aggregate, however, there is some concern that: (1) SCC may have a lower modulus of elasticity, which may affect deformation characteristics of prestressed concrete members and (2) creep and shrinkage will be higher, affecting prestress loss and long-term deflection (Mata, 2004).

Self compacting concrete can be produced using standard cements and additives. It consists mainly of cement, coarse and fine aggregates, and a filler, such as fly ash or Super-pozz®, water, super plasticizer and stabilizer. The composition of SCC is similar to that of normal concrete but to attain self flow ability admixtures, such as fly ash, glass filler, limestone powder, silica fume, Super-pozz®, etc; with some superplasticizer is mixed.

Three basic characteristics that are required to obtain SCC are: high deformability, restrained flowability and a high resistance to segregation (Khayat et al., 2004). High deformability is related to the capacity of the concrete to deform and spread freely in order to fill all the space in the formwork. It is usually a function of the form, size, and quantity of the aggregates, and the friction between the solid particles, which can be reduced by adding a high range water-reducing admixture (HRWR) to the mixture.

Restrained flowability represents how easily the concrete can flow around obstacles, such as reinforcement, and is related to the member geometry and the shape of the formwork. Segregation is usually related to the cohesiveness of the fresh concrete, which can be enhanced by adding a viscosity-modifying admixture (VMA) along with a HRWR, by reducing the free-water content, by increasing the volume of paste, or by some combination of these constituents.

Fig 1.1 explains the basic principles for the production of SCC, the major work involves designing an appropriate mix proportion and evaluating the properties of the concrete thus obtained. In practice, SCC in its fresh state shows high fluidity, self-compacting ability and segregation resistance, with these good properties, the SCC produced can greatly improve the reliability and durability of the reinforced concrete structures. In addition, SCC shows good performance in compression and can fulfil other construction needs because its production has taken into consideration the requirements in the structural design.

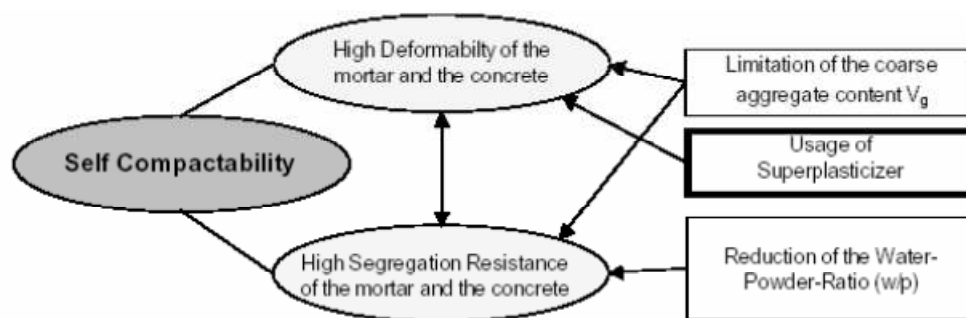


Fig. 1.1: Basic principles for the production of SCC (Dehn et al., 2000).

1.5 Properties of SCC

1.5.1 Fresh Concrete Properties

Workability

SCC has the characteristics of filling ability, passing ability, segregation resistance, robustness and consistence retention and these characteristics should remain during transport and placing.

- **Filling ability** reflects the deformability of SCC, i.e. the ability of fresh concrete to change its shape under its own weight (Khayat, 1999b; Okamura and Ozawa, 1995). 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 (RILEM TC 174 SCC, 2000).

- **Passing ability** is unique to SCC. It determines how well the mix can flow through confined and constricted spaces and narrow openings, which ensures its particular applications in densely reinforced structures such as bridge decks, abutments, tunnel linings or tubing segments. It depends on the risk of blocking which results from the interaction between constituent materials and obstacles.

- **Segregation resistance** is sometimes called ‘stability’. Since SCC is composed of materials of different sizes and specific gravities, it is susceptible to segregation. Segregation includes that between water and solid or between paste and aggregate or between mortar and coarse aggregate in both stationary and flowing states (RILEM TC 174 SCC, 2000).

- **Robustness** is the ability of the concrete to maintain its properties with such variations. The fewer changes in the properties, the more robust SCC is.

- **Consistence retention** is sometimes called ‘open time’ during which SCC retains its properties, which is important for transportation and placing, particularly of in-situ concrete.

1.5.2 Tests for Measuring Workability of SCC

Following are the important tests conducted on fresh SCC to evaluate its workability are summarized under in a table and are briefly explained later in experimental programme.

Table 1.1: Test methods to evaluate the workability properties of SCC (EFNARC, 2002).

Property	Test Methods	
	Laboratory (Mix Design)	Field (Quality Control)
Filling Ability	Slump Flow Test T50cm Flow Test V-Funnel Test Orimet Test	Slump Flow Test T50cm Flow Test V-Funnel Test Orimet Test
Passing Ability	L- Box Test U- Box Test Fill Box Test	J-Ring Test
Segregation Resistance	GTM Test V-Funnel At T5mins	GTM Test V-Funnel At T5mins

Typical acceptance criteria for SCC with a maximum aggregate size of up to 20 mm are presented in Table 1.2

Table 1.2 Limits for Workability (EFNARC, 2002)

Method	Unit	Minimum Value	Maximum Value
Slump flow	mm	650	800
J –Ring	mm	0	10
V- Funnel	sec	6	12
L-Box	(H2/H1)	0,8	1,0
U- Box	(H2-H1)mm	0	30
Orimet	sec	0	5
Fill Box	%	90	100

1.5.3 Advantages and Disadvantages of SCC

It can also be regarded as "the most revolutionary development in concrete construction for several decades". Originally developed to offset a growing shortage of skilled labour, it is now proved beneficial economically because of a number of factors as noted below (Krieg, 2003 and ENFARC, 2002).

- i. Faster construction,
- ii. Reduction in site manpower,
- iii. Easier placing,
- iv. Uniform and complete consolidation,
- v. Better surface finishes,
- vi. Improved durability,
- vii. Increased bond strength,
- viii. Greater freedom in design,
- ix. Reduced noise levels, due to absence of vibration, and
- x. Safe working environment.

Because compaction is eliminated, the internal segregation between solid particles and the surrounding liquid is avoided which results in less porous transition zones between paste and aggregate and a more even colour of the concrete . Improved strength, durability and finish of SCC can therefore be anticipated

Very good finish effect can be achieved of pure SCC cement placed in a steel mould, de-moulded after 24h after casting. The surface is so smooth and dense that it can reflect light.

For much concrete construction, the structural performance is improved by increasing reinforcement volumes, limiting cracking by using smaller bar diameters and using complex formwork, all of which increase the difficulty of compaction (Okamura et al., 2003). Self compacting concrete meets the above developments by making casting homogeneous concrete in congested structures possible; it also improves efficiency and effectiveness on site by reducing the construction time and labour cost.

SCC requires higher powder and admixture (particularly super plasticisers) contents than NVC and so the material cost is higher (The Concrete Society and BRE, 2005). It was reported that in most cases, the cost increase ranged from 20% to 60% compared to similar

grade NVC (Nehdi et al., 2004 ;). However, in very large structures, increased material cost by using SCC was outweighed by savings in labour costs and construction time.

1.6 Recycled concrete

1.6.1 Issues of disposal of waste concrete aggregates

One of the major challenges of our present society is the protection of environment. There is a continuous deterioration of the environment owing to the indiscriminate exploitation of natural resources for obtaining raw materials for development practises. Construction is the backbone of infrastructural development and it derives its basic ingredients which are sand and stone aggregate from nature. The various environmental hazards imposed by this industry may be summarized as follows

1.6.2 Pollution caused by quarrying

Quarrying has very serious implications on the environment. It is known to cause both air and noise pollution. The heavy machinery involved to extract the stone aggregates operates on fuels releasing obnoxious gases and fumes. The pollution is caused also by release of suspended particulate matter into the atmosphere which is dangerous for the working staff and the adjoining population. The particulate matter also runs off to the nearby rivers or water bodies to cause their undue silting. It settles on the vegetation leading to their destruction. It has harmful implications on the wildlife because of the destruction of its natural habitat. Also a lot of land is rendered waste and useless after quarrying procedures. In addition noise of operation is very annoying and distributing worsening the scenario.

1.6.3 Pollution caused by Transportation of aggregate

A 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 . Usually aggregate are transported to long distances through trucks in many cycles adding to the pollution problem.

1.6.4 Dearth of Landfill Sites

According to Mehta, 2010 the global concrete industry consumes close to 10 billion tons of sand and rocks, and produces over 1 billion tons of construction and demolition waste annually .About 300 million tons of construction and demolition waste is generated in the Us each year. The main reasons for increase of volume of demolition concrete /masonry waste which are as follows:-

1. Many old buildings, concrete pavements, bridges and other structures have overcome their age limit of use due to structural deterioration beyond repairs and need to be demolished ;
2. The structures even adequate to use are under demolition because they are not serving the needs in present scenario ;
3. New construction for better economic growth ;
4. Structures are turned into debris resulting from natural disasters like earthquake , cyclone , and floods etc
5. Creation of building waste resulting from manmade disaster/war

All this calls for the proper disposal of the debris of the demolished concrete structures which is a serious concern in mega cities due to insufficiency of landfill sites and the increasing landfill costs .The construction and demolition waste is thus another serious issue that needs an immediate solution .

These environmental problems are a driving force in developing an urgent and thoughtful sustainable approach towards our natural resources to which the recycling of the waste concrete aggregates seems to be a legitimate remedy.

Concept of use of recycled aggregate in concrete is not new, researches have been carried out all over the world. However all most all fthe researches have stated that the recycled aggregate concrete is not fit for high strength construction. M C Limbachiya(2011), indicating the inferiority of recycled aggregate concrete, reported that often this concrete is used in as road construction, backfill for retaining walls, low grade concrete production , drainage and brick work and block work for low cost housing . A similar pattern is presented by Vivian in 2011, that the use of recycled aggregate is confined to low grade applications such as unbounded road base, fill and hard core although he accepts that recycling rate is high in many countries

1.6.5 Recycling of waste concrete Aggregates

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 option in this age of greater environmental awareness , more environmental laws , and the desire to keep construction costs down .

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

Crushing at the actual construction site using portable crushers reduces construction costs and the pollution generated when compared with transporting material to and from a quarry .

Large road portable plants can crush concrete and asphalt rubble at upto 600 tons per hour or more . These systems normally consists of a rubble crusher , side discharge conveyor , screening plant , and a return conveyor from the screen to the crusher inlet for reprocessing oversize materials . Compact , self contained mini crushers are also available that can handle upto 150 tons per hour and fit into tighter areas . With the advent of crusher attachments- those connected to various construction equipment , such as excavators – the trend towards recycling onsite smaller volumes of material is growing rapidly . These attachments encompass volumes of 100 tons /hour and less

1.6.6 Advantages of Recycling of Aggregate

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 coarse aggregate portion of RCA has no significant adverse effects on desirable mixture

proportions or workability . Recycled fines , when used , are generally limited to about 30 percent of the fine aggregate portion of the mixture . There are many advantages through using the recycled aggregate . The advantages that occur through usage of recycled aggregate are listed below .

- *Performance*

Angularity of RCA:

1. Helps to increased structural strength in the base , resulting in improved load carrying capacity :
2. Building pads (residual cementation) , provides a strong , durable platform for which to build upon .
3. Better control over gradation , in this RCA is able to meet gradation and angularity requirements .
4. Potential to minimize cracking and ASR

Cracking is caused by the freeze-thaw expansive pressures of certain types of aggregate , whereas Alkali Silica Reaction (ASR) is caused by the detrimental reaction between silica found in certain aggregates and the alkali paste . These forms of distress are material related and studies show that the inclusion of RCA in the concrete mix and a suitably fly ash has the potential to reduce these distresses . Freeze thaw testing of concrete in Minnesota made with recycled cracking aggregate indicated a greatly reduced potential for cracking when fly ash was used in the mixture

- *Resource Conservation*

1. Reduced land disposal and dumping : The use of recycled concrete pavement eliminates the development of waste stockpiles of concrete . Also , since recycled material can be used within the same metropolitan area , this can lead to a decrease in energy consumption from hauling and producing aggregate , can help improve air quality through reduced transportation source emissions .
2. Conservation of virgin aggregate : The supply of virgin aggregate in many areas of the United States is or becoming limited . In such areas , the use of recycled aggregate is beginning to serve as as an environmentally friendly and economically viable solution . Many European countries have placed a

tax on the use of virgin aggregates . This process is being used as an incentive to recycle aggregates . It is noted that several states have high tipping fees for disposal of RCA , this is done to control landfill usage thus increasing the reuse of RCA

3. Reduce impacts to the landscape : The reuse of concrete demolition debris reduces unsightly stockpiles of concrete rubble , animal infestation of stockpiles, and an overall environmental improvement when re-used .
4. Metal Recovery : The removal of metal , steel reinforcement is an important step in the recycling process and can take place in several stages . Contractors usually remove continuous reinforcement on the grade , whereas dowel and tie bar removal is typically done at the plant . Most crushing plants have an electro magnet to catch steel moving along the conveyor belt between the primary and secondary crushers . Salvaged steel usually becomes the property of the crushing plant and is sold as scrap metal . Wire mesh steel generally found in reinforced concrete pipes retains a large quantity of bonded concrete and usually becomes waste .
5. Defined as inert material in Solid Waste Regulations : Generally in the states that use RCA the environment regulatory agencies have reviewed the material , where it is to be used , and have deemed it inert . After all it really is just broken up concrete pavement being reused as aggregate base or PCC aggregate .

- *Economic Benefits*

1. Limit haul distance : Recycled concrete is crushed and the entire aggregate product can be used as a base material according to specifications , therefore generating no waste . This can be done on the project site or at nearby recycling plants , eliminating the transportation to distant disposal sites and the hauling in of virgin aggregates . In an urban environment concrete debris is hauled to a crushing site that is generally closer to the centre of urban area than the virgin aggregate quarry . In some cases the two operations cohabitate . Industry comments were that the RCA stockpile is usually closer to the job sites in an urban environment , thus less haul distance is less fuel burnt in delivery . Production of virgin aggregates can

- use more fuel to crush due to larger initial size of rock needing to be crushed to the desired grade .
2. Reduce Disposal Costs : Disposal of concrete rubble and other waste consumption materials by dumping or burial is a less attractive and more expensive option . Reconstruction of urban streets and expressways results in an enormous amount of waste concrete being generated and creating a massive disposal problem . Recycling can therefore alleviate some of these problems and offer savings to the owner agencies in terms of material acquisition and disposal costs .
 3. 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 contractor , who can sell as scrap material. There is also potential for cost savings in many areas where aggregates 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 govt. due to increased recycling of RCA.
 4. Minimize impacts to existing roads with reduced hauling : Using the existing concrete on grade as the source of base aggregate eliminates the importation of large volume of virgin material for reconstruction . This reduces the heavy vehicle loading carried by current highway system , an economic and public interest advantage to the owner agency . For instance in the VA I-66 REHABILITATION contract the contractor setup a crushing plant at a visitor centre that was within the project limits and crushed the old pavement for use as a aggregate base material , with very little truck impacting the large numbers of daily commuters .
 5. Maintaining grade on highways : The process of reusing the existing pavement as a base material or concrete aggregate allows the owner agency to redesign the new pavement structure at the existing grade . This allows the continued use of many of existing feature outside the roadways ; such as at guiderails , traffic signs and bridge clearance can be maintained . Rubblization and Crack and Seal operations usually require

extensive grade increases that make relocation of the highway features mandatory .

- *Cost*

1. Reduction in transportation costs : Substitution of new aggregate with recycled concrete aggregate can provide savings in the final costs of the project .It is a common practise in Minnesota and many other staes to crush the material on site .This process eliminates the transportation costs to import virgin aggregates , lessens trucktraffic on already congested highways
2. Reduction in disposal costs : Disposal of concrete , rubble and other waste construction materials by dumping or burial is a less attractive and more expensive option .Reconstruction of urban streets and expressways results in an enormous amount of waste concrete , creating a massive disposal problem . Recycling can therefore alleviate some of these problems by saving in terms of material acquisition and disposal costs . States with active recycling of RCA virtually use all that being removed .
3. Overall project savings :There may be considered project savings by using less virgin aggregates and base materials .Savings are induced from decreased hauling and disposal costs . n additional bebenefits is the recovery of steel from recycling process . Usually it becomes property of contractor , who may sell it as a scrap metal . There is also a potential for cost savings in many areas where aggregates are not locally available and have to be hauled long distances .

- *Environmental Benefits*

1. Reduced land disposal and dumping : The use of recycled concrete pavements eliminates the development of waste stockpiles of concrete . Also , as recycled material can be used within the same suburban area , this can lead to a decrease in energy consumption and can help improve air quality through reduced mobile source emissions .
2. Reconstruction of urban streets and expressways results in a enormous waste concrete , creating a massive disposal problem . Recycling can eliminate many of these issues
3. Currently , the demand for disposal space for concrete debris is high in the Detroit Metro Area . The recycling plants are reaching their stocks capacity

and disposal costs are increasing . This demand is considerably diminished when RCA has an engineered use in projects around this area .

4. In Minnesota , RCA will be considered a standing beneficial use and not subject to review or permitting by pollution control Agency . Beneficial use of solid waste , where RCA will be considered a Tpollution control agency.

- *Job opportunities*

There will be many people involved this new technology , such as specialized and skilled persons , general workers etc . According to Scottish executive (2004) , a Scottish Market Development Program is developed . The purpose of this program is to recycle the materials arising in Scotland . This program will provide 150 new jobs in the Scottish industry .

- *Sustainability*

Comprehensive method of estimating the degree of impurity in the recycled aggregate sample in comparison to the virgin aggregate sample 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

- *Market is wide*

The markets for recycled concrete aggregate are wide. According to Environmental council of Concrete Organization, recycled concrete aggregate can be used in sub bases and support layers such as unstabilized base and permeable bases .

1.6.7 Disadvantages

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

- *Higher water absorption (3-9%)*

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 .

- *Lower Density (2000-2500 Kg/m³)*

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

- *Higher contents of Impurities*

Since recycled aggregates are obtained from rubble , construction and demolition waste and unwanted materials is expected to be higher .This Calls for a more effective means of aggregates extraction and a highly

Comprehensive method of estimating the degree of impurity in the recycled aggregate sample in comparison to virgin aggregate sample .

- *Hard to have permit*

Jacobsen stated that it is hard to get the permit for machinery that needed air permit or permit to operate during the recycling process . These has to depend on local or state regulations whether this technology is implemented or not .

- *Lack of Specification and Guidelines*

According to Kawano (n.d) , there is no specification or 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 sources would have different properties . Thus mix design will be different in every case that too without any specific guidelines and codal provisions .

- *Lower Freeze Thawing Resistance*

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

- *Increased Shrinkage*

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

1.7 Closing Remarks

This chapter provides the basic details about the Self compacting concrete and its advantages over normal vibrated concrete, various types of tests used for measuring its properties. Further it focuses on utilizing waste concrete aggregates in SCC as FA highlighting the problems associated with waste concrete aggregates and their various recycling issues.

2.1 General

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.

2.2 Durability of SCC

It is essential for concrete structures to perform well not only within their specified mechanical requirements but also within their durability expectations. Very often the issue of durability is being overlooked since engineers make the assumption that strong concrete is also durable. It is worth noting that concrete structures are vulnerable to attack both from physical and chemical deterioration mechanisms, many of which still require a lot of research in order to be fully explained and understood. All deterioration mechanisms involve complex processes that take place in the pore skeleton of SCC and the vast majority of durability problems are due to synergistic actions between two or more different processes. It is widely acceptable that all deterioration mechanisms are triggered by movement of fluids through pores existing within the microstructure of concrete. It is therefore very important to know the nature and characteristics of the pore system within the bulk of the hardened cement paste. Various durability measures of SCC are

- Oxygen permeability
- water sorptivity
- chloride conductivity

have often been defined as three durability indexes of SCC in addition to following parameters

Chloride-induced reinforcement corrosion: Parts of structures which are in contact with seawater, splash, spray, salty-dust, or other chloride sources (e.g. industrial process water, or irrigation water), are at risk from chloride penetration leading to reinforcement corrosion.

Carbonation-induced reinforcement corrosion: Parts of structures which are not regularly wet are subject to carbonation, the rate of penetration of which is subject to humidity and concrete mix. Good quality concretes which are durable against chloride-induced corrosion are also unlikely to be vulnerable to carbonation, subject to concrete mix details.

Sulphate attack: Severity of sulphate exposure should be checked on a structure-by-structure basis, following systematic methodology such as that provided by BRE Special Digest 1: 2005 Concrete in Aggressive Ground.

Salt-scaling: Spalling of thin layers from concrete surfaces due to splitting pressures arising from crystallization of salts in concrete pores within the surfaces.

2.2.1 Principle mechanisms by which water, ions; gases may be transported through concrete.

- Transport is driven by pressure difference, for example water permeation through soil or concrete driven by hydrostatic pressure.
- This typically applies to underwater zones of marine structures, or underground zones of structures built in the water-table such as foundations, bridge piers, basements or tunnels.
- The combination of ground-water permeation into concrete basements or tunnels, plus water evaporation on the inside of these “hollow” structures, can result in more rapid transport of water and salts into such concrete than by permeation alone.
- Permeability measurement techniques and durability modeling are based on the Darcy equation for permeability based on measurement of flow rate, and the Valetta equation for permeability based on measurement of penetration depth and time.
- Transport is driven by concentration difference, for example chloride ion diffusion through water, or carbon dioxide or water vapor diffusion through air.
- Diffusion is also used for representing the overall effect of wetting and drying by salt-water which leads to chloride ingress, and is termed “effective diffusion”.
- Transport is driven by capillary suction, for example water absorption into concrete or masonry.

- This typically occurs in concrete structures around and just above the ground-water table. Absorption is also the mechanism by which a splashing wave penetrates into concrete, the cumulative effect of which is often termed effective diffusion, as above.
- The combination of absorption due to capillary suction, plus evaporation of the rising moisture, is often responsible for vertical transport of salts from ground water leading to salt-scaling and/or reinforcement corrosion above the water-table.
- Some forms of durability test involve measuring voltage-induced chloride ion flow through water, in which the voltage is provided in order to shorten the test duration.

2.2.2 Sulphate Resistance of SCC

Solution of sulphate can attack the hardened cement paste in the concrete causing deterioration. The precise chemical reaction will depend on the nature of the sulphate present and the type of cement. In some clay soils the ground water is solution of magnesium and calcium sulphates. These salts react with the $\text{Ca}(\text{OH})_2$ and the calcium aluminate hydrate in the concrete to produce gypsum and calcium sulphoaluminate. These products have considerably greater volume than the compounds they replace, leading to expansion and disruption of the concrete. Sea water and de-icing salt also contain appreciable concentrations of sulphates. The rate and extent of sulphate attack depend upon the ease with which sulphate ions are able to penetrate the concrete and upon the chemical resistance of cement paste.

There have been numerous field studies on the distress caused to concrete structures generated by sulphate attack. In particular, volume of cementitious paste (34–40%) and the larger powder content (400–600 kg/m^3) of SCC can make it particularly vulnerable to chemical attack, for example by sulphate solutions. Since the last decade, SCC has been widely used in areas vulnerable to sulphate attack such as substructures, infrastructure and industrial floors. Sulphate attack has often been discussed in terms of the reaction between the hydrates in cement pastes and dissolved compounds, such as sodium sulphate or magnesium sulphate, in the attacking solution (Taylor 1997).

The classical form of sulphate attack involves alkali sulphates such as sodium sulphate which reacts with calcium hydroxide and calcium aluminate hydrate to form gypsum and

ettringite. The gypsum and ettringite formed as a result of sulphate attack is significantly more voluminous (1.2–2.2 times) than the initial reactants, which can cause expansion, cracking, and deterioration of concrete by the reaction of SO₂ ions (Bonen, 1993). A magnesium sulphate solution may cause the deterioration of concrete due to the formation of Mg-containing hydrates (e.g. M–S–H gel), as well as gypsum and thaumasite. Some researchers have reported on the sulphate resistance imparted by mineral admixtures, which is generally incorporated in concrete to improve its engineering properties and durability.

2.2.3 Water transport in concrete and other durability aspects of SCC

1. **Sorption:** is the water movement driven by capillary action in short-term exposure in partially dry concrete. The rate of water uptake by a porous material is defined as sorptivity. It has been considered as an important criterion to assess the durability of concrete (Ho and Chirgwin, 1996). The pore system of the paste and the interfacial zone has a great influence on sorptivity. The interfacial zone is porous but it is the hardened paste, the only continuous phase in concrete that controls the ingress and transportation of water (Sabir et al., 1998). Sorptivity of SCC was only 30~40% of those of NVC with the same strength grade C40 (Zhu and Bartos, 2003).
2. **Diffusion:** is the water movement driven by a concentration gradient in long term exposure. For example, the durability of concrete in the sea is largely determined by the diffusivity of the chloride solution entering and moving through the matrix. Chloride diffusivity depends on the tortuosity of the pores instead of the total porosity. Since fly ash particles made concrete dense, concrete incorporating fly ash was reported to have a lower chloride diffusivity (Zhu and Bartos, 2003). On the other hand, Tang et al (1999) reported a higher chloride diffusivity than NVC because of the poor dispersion of powders. It is interesting to note that the diffusivity of SCC with VMA is higher than NVC and powder-type SCC (Zhu and Bartos, 2003). This confirms that the powders used in SCC improve packing density leading to a denser structure. Diffusion and capillary action are the primary mechanisms of ingress of water. Diffusion was a very slow process and it accounted for about 30% of the overall water intake whereas sorption accounts for about 70% (Neithalath, 2006).

3. **Capillary porosity:** has a very important influence on hardened properties and is useful for predicting the durability (Yaman et al., 2002). The capillary transport especially near concrete surface is the dominant invasion mechanism. An increase in the porosity of the cover concrete leads to more water and more dissolved chemical flowing through the surface, and thus, more durability problems. The relationships between water absorption and some durability such as the resistance of concrete to carbonation and chloride (De Schutter and Audenaert, 2004), freezing/thawing cycling and wet/dry cycles (Martys and Ferraris, 1997) were investigated. Capillary suction was influenced by the moisture state of the specimen, the ambient conditions, curing conditions and testing procedures (Hall, 1989).
4. **Permeability:** is a process in which water is transported under a hydrostatic pressure differential. The main influences on permeation include the paste volume, the pore structure and the interfacial zone between the mortar and aggregates. The overall porosity of SCC was lower than that of NVC of equivalent strength because of the higher powder content, lower w/p ratio and improved microstructure (Tragardh, 1999; Zhu et al., 2004; Zhu and Bartos, 2003). Zhu and Bartos, 2003 reported that the oxygen permeability for SCC was only 30~40% of that of NVC with the same strength grade C40.

2.3 Various Tests for Durability

The basic explanation of transport mechanisms should enable the relevance of each test to be considered when concrete durability tests are selected for specific projects. Various types of tests conducted for measuring durability can be summarised as follow.

2.3.1 Absorption tests

In Absorption concrete takes in liquid by capillary suction to fill the pore space available. Absorption tests should measure the property mentioned and the sorptivity. However, due to the difficulty in achieving a unidirectional penetration of water and problems of determining the water penetration depth without actually splitting open the concrete sample, the absorption characteristics of concrete are usually measured indirectly. The most common of these tests are:

- Standpipe tests

- Initial Surface Absorption Test
- Autoclave sorptivity test
- Water-absorption test

2.3.2 Permeability tests

Permeability is where a fluid passes into concrete under the action of pressure gradient. Experimental evidence of permeability/durability correlation was well established from experiments. Permeability tests measure the transfer of a liquid or gas into the concrete under the action of a pressure gradient. They can be either steady state or non-steady state depending on the condition of flow established within the pore system of the concrete. The most common air permeability tests are:

- Water permeability
- Air Permeability

2.3.3 Diffusion tests

Diffusion is where a liquid, gas or ion migrates through concrete; due to a concentration gradient. There is interest in ionic diffusion tests because the rate at which chloride ions diffuse through concrete is closely related to the corrosion of reinforcement. There are tests which require cores to be extracted, while others can be carried out in-situ. The most common diffusion tests are:

- The Rapid Chloride permeability test (RCPT)
- Steady state migration tests
- In-situ chloride migration test

2.3.4 Details of Test Methods

2.3.4.1 Rapid Chloride Permeability Test (RCPT)

According to ASTM C1202 test, water saturated, 50 mm thick, 100 mm thick diameter concrete specimen is subjected to a 60 V applied DC voltage for 6 hours using the apparatus and the cell arrangement is shown in Figure-1. In one reservoir is a 3.0% NaCl solution and in the other reservoir is a 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete according to the criteria included as Table-2.1

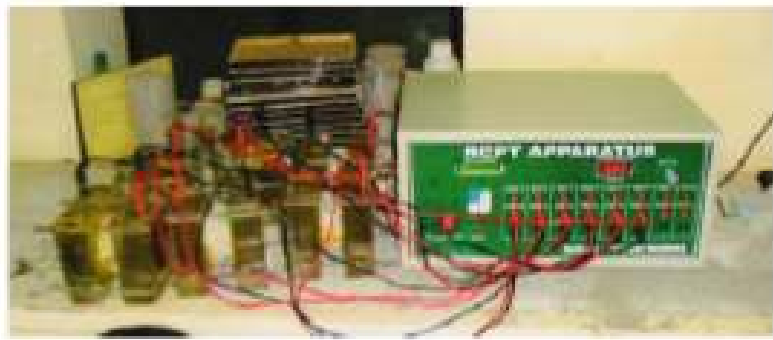


Fig.2.2: RCPT ratings Test Setup

Table:-2.1 RCPT ratings (As per ASTM C1202)

Charge passed (coulombs)	Chloride Ion penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

2.3.4.2 Water porosity measurements of SCC

Water porosity test is normally carried out according to the Vacuum Saturation method. The cylindrical samples of $\text{Ø}50 \text{ mm} \times 100 \text{ mm}$ height cure in a humidity room at a temperature of 20°C with a relative humidity of $90 \pm 5\%$, the water porosity test to be conduct at curing periods of 3, 7, 28 days. The test samples prepare by cutting cylindrical samples into two halves and cutting $40 \pm 2 \text{ mm}$ thick slice, $\text{Ø} 50 \text{ mm} \times 40 \text{ mm}$ cylindrical samples to be dry at $100 \pm 5^{\circ} \text{C}$ until constant weight, then self compacting concrete samples are place in desiccators under vacuum negative pressure of 1 bar for 3 h, de-aired water introduce to submerge samples of SCC and maintaining negative pressure for a further 3 h, finally, the pressure is released to atmospheric level and samples are left submerged overnight to ensure full saturation. The water porosity of samples to be calculate using to the following equation

$$P = (W_{\text{sat}} - W_{\text{dry}}) / (W_{\text{sat}} - W_{\text{wat}}) \times 100 \quad (2.1)$$

Where: P is the water porosity (%), W_{sat} is the weight of saturated Sample in air, W_{dry} is the weight of sample in oven at 100 ± 5 °C, and W_{wat} is the weight of saturated sample in water.

2.3.4.3 Carbonation test:

The test consist of three 100 mm x100 mm x300 mm prismatic samples of SCC curing 26 days are dry at 48 h at 60°C temperature according to GBJ 82-85 standards, the accelerated carbonation test of SCC samples is perform in a chamber with a perticular concentration at a particular temperature $T = 20 \pm 3$ °C, the half face of SCC samples seal with heating the paraffin, leaving the other face exposed to carbonation, then, SCC samples were put into the accelerated carbonation chamber. The accelerated carbonation test carries out at 3, 7, 14, 28 day exposure durations.

2.3.4.4 Acid attack test:

In this test chemical resistance of the concrete study through chemical attack by immersing them in an acid solution. After 90days period of curing the specimens are remove from the curing tank and their surfaces are clean with a soft nylon brush to remove weak reaction products and loose materials from the specimen. The initial weight is measure and the specimens are identifying with numbered plastic tokens that are tie around them. The specimens are immersed in 3% H_2SO_4 solution and the pH is maintained constant throughout. The solution will replace at regular intervals to maintain constant concentration throughout the test period. The mass of specimens will be measure at regular intervals up to 90 days, and the mass losses will be determine.

2.3.4.5 Oxygen permeability test:

This test will Conduct using a CEMBUREAU experimental device. The flow of oxygen through concrete samples is measure at steady state against the test pressure and the material saturation rate. The apparent coefficient of permeability (k_A) calculates for laminar flow of a compressible viscous fluid through a porous material from the Hagen–Poiseuille relationship.

$$k_A = \frac{2Q\mu LP_{atm}}{A(P_i^2 - P_{atm}^2)} \quad (2.2)$$

Where Q is the measured oxygen flow (m³/s), μ dynamic viscosity of oxygen (N s/m²), L the thickness of the sample (m), P_{atm} atmospheric pressure (Pa), A the cross-sectional area of the sample (m²) and P_i the absolute pressure applied (Pa).

2.4 Closing Remarks

This chapter provides the basic details about the durability properties, of self compacting concrete, its necessity and various types of tests used for measuring durability properties of self compacting concrete.

3.1 General

In this chapter the research work carried out for testing of Self compacting concrete made 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 focussing mainly on durability aspects of SCC.

3.2 Recent Works

Nehdi et al. (2004) investigated the rapid chloride ion penetrability, sulfate expansion and deicing salt surface scaling resistance of SCC mixtures made with high-volume replacement binary, ternary, and quaternary cements. Rapid chloride ion penetrability was investigated for the various SCC mixtures at 28 and 91 days, while the deicing salt surface scaling under 50 freezing–thawing cycles and sulfate expansion after up to 9 months of immersion in a 5% Na₂SO₄ solution were investigated as per the ASTM C-672 and ASTM C1012 guidelines, respectively.

Mix proportion:-

Mixture proportions of the self-consolidating concrete mixtures investigated shown in Table-3.1 (constant water/binder = 0.38)

Table 3.1: Mix Proportion (Nehdi et al., 2004)

Mixture		Portland cement (kg/m ³)	Fly ash (kg/m ³)	Slag (kg/m ³)	RHA (kg/m ³)	Silica fume (kg/m ³)	Gravel (kg/m ³)	Sand (kg/m ³)	VMA (kg/m ³)	HRWR (l/m ³)	Density (kg/m ³)
Reference	1	425					900	930		1.9	2255
Binary a	2	215	215				905	925		1.5	2260
Binary b	3	215	215				905	925	0.1	3.3	2260
Ternary a	4	215	105	105			905	920		1.3	2255
Ternary b	5	215	105	105			905	920	0.2	4.9	2250
Quaternary a	6	215	100	85		25	910	915		3	2260
Quaternary b	7	215	100	85	25		910	915		3.2	2250

VMA= viscosity-modifying admixture; HRWR= high-range water reducer.

For rapid chloride ion penetrability (ASTM C1202) at 28 and 91 days (four specimens at each age) were prepared in plastic moulds (no vibration or other means of consolidation was used). In addition, concrete slabs (200x230x75 mm), for the determination of the resistance to deicing salt surface scaling of concrete (ASTM C672), were made.

Results:

Rapid chloride ion penetrability:

The rapid chloride ion penetrability measured at 28 and 91 days for all SCC mixtures is illustrated in Fig 3.1. The pure OPC SCC mixture achieved rapid chloride ion penetrability in the high range at 28 days (>4000 C). At 28 days, binary mixtures incorporating 50% class F fly ash decreased the rapid chloride penetrability from a high to a moderate range. In SCC made with high volume replacement ternary and quaternary cementitious blends, the 28-day rapid chloride ion penetrability was decreased from a high range for the reference 100% OPC mixture to a low range (less than 2000 C). The most efficient mixtures in decreasing the 28-day chloride ion penetrability were quaternary mixtures incorporating either 6% silica fume or 6% RHA. At 91 days All SCC mixtures made with high-volume binary, ternary and quaternary cementitious blends reduced the rapid chloride ion penetrability to the very low range (less than 1000 C).

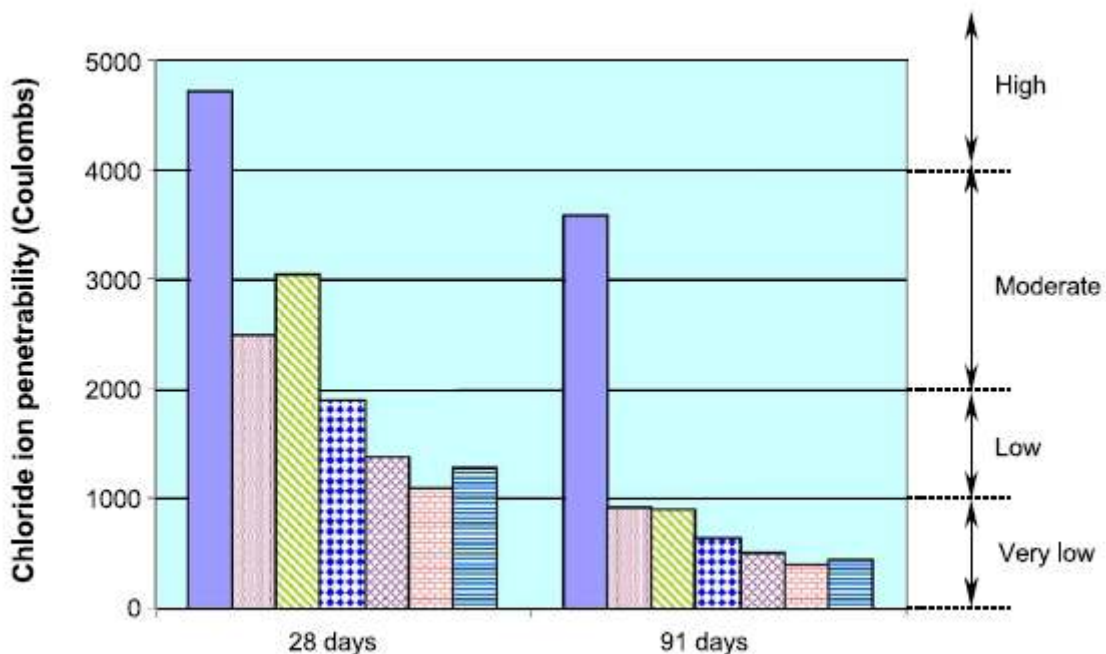


Figure.3.1: Deicing salt surface scaling (Nehdi et al., 2004)

The average cumulative mass of scaled-off material versus number of freezing–thawing cycles for each SCC mixture is shown in Fig.3.2. It can be observed that the 50% OPC–50% class F fly ash SCC mixture had the largest mass of scaled-off material and the worst visual scaling rating among all other SCC mixtures made with high-volume replacement composite cements.

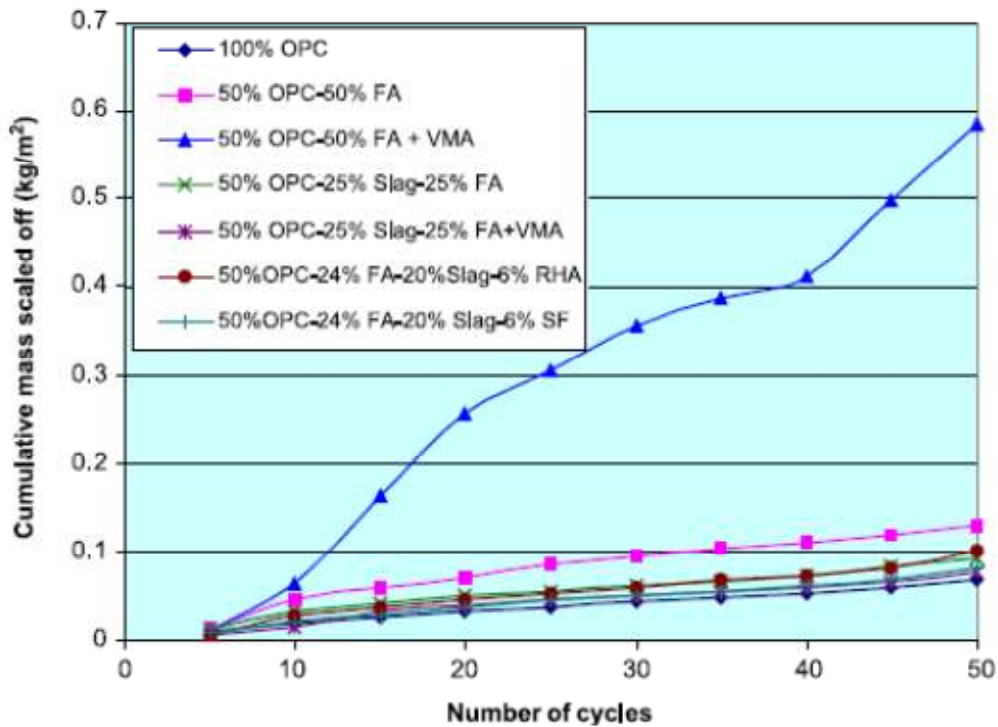


Figure: - 3.2: Cumulative mass scaled off versus number of freezing –thawing cycles. (Nehdi et al., 2004)

Resistance to sulfate expansion:-

The sulfate expansion after 9 months of immersion in a 5% solution of Na₂SO₄ for bar specimens made of mortar extracted from the various SCC mixtures is illustrated in Fig. 3.3. When 50% of the cement was replaced with class F fly ash, the sulfate expansion at 9 months was decreased substantially. However, bars made of a mortar extracted from a SCC mixture incorporating a ternary 50% OPC–25% fly ash–25% slag cement achieved lower sulfate expansion after 9 month immersion in a 5% solution of Na₂SO₄ compared to that of the binary 50% OPC–50% flyash bar specimens described above. This result was unexpected because slag was much richer in calcium compared to fly ash.

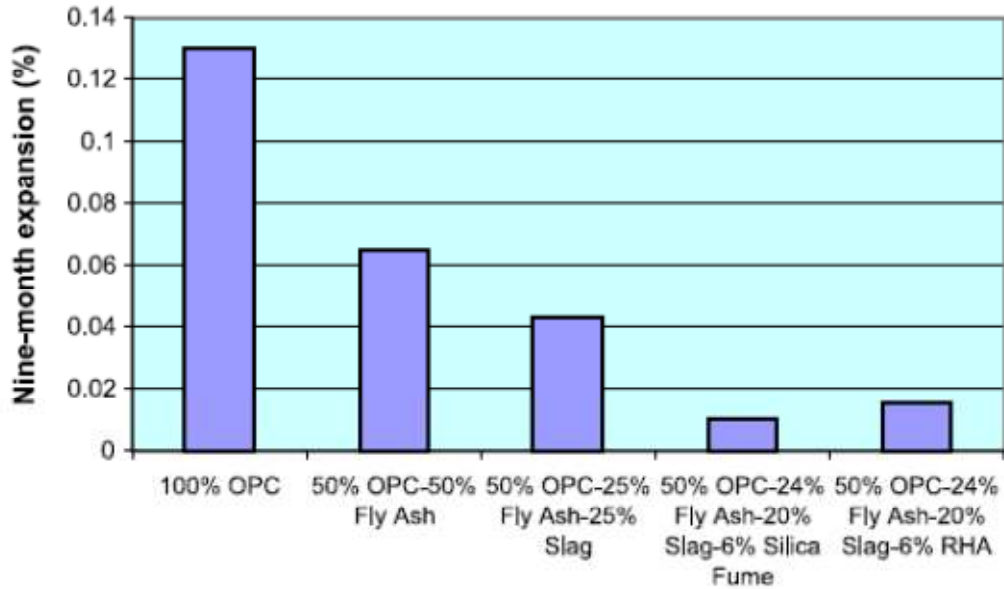


Fig-3.3: Expansion of bar specimens of mortar extracted from SCC mixtures submerged in a 5% Na₂SO₄ solution for 9 months (Nehdi et al.,2004)

Bassuoni et al. (2007) investigated the resistance of a variable range of SCC mixture designs to sulfuric acid attack. The main test variables include the cementitious materials type (single, binary, ternary and quaternary binders), the sand-to-total aggregates mass ratio, and the inclusion of fibre reinforcement (single and hybrid). The investigation comprised two consecutive 6-week phases of immersion of test specimens in sulfuric acid solutions with a maximum pH threshold of 2.5 and 1.0, respectively. In total 24 SCC mixtures were tested. The study reveals that the rate of attack is controlled by different factors at each exposure phase. The advantages of blended binders and hybrid (steel+polypropylene) fibres in improving the resistance of SCC to sulfuric acid attack are highlighted.

Twenty four SCC mixtures with a w/cm of 0.38 (180 kg/m³) were prepared. The mixtures were divided into three groups as shown in Table 3.2

Table:-3.2: Properties of Binders per cubic meter of concrete (Bassuoni et al.,2007)

Proportions of binders per cubic meter of concrete

Binder description	Binder code	Cement (kg)	Silica fume (kg)	Slag (kg)	Fly ash (kg)	Limestone (kg)
100% SRPC	SRPC	470	–	–	–	–
100% OPC, OCI	OCI	470	–	–	–	–
100% OPC	B1	470	–	–	–	–
92% OPC, 8% SF	B2	430	40	–	–	–
50% OPC, 5% SF, 45% S	B3	235	25	210	–	–
50% OPC, 15% LF, 20% S, 15% FA	B4	235	–	95	70	70
50% OPC, 5% SF, 25% S, 20% FA	B5	235	25	120	90	–

Proportions of groups A, B and C mixtures per cubic meter of concrete

Binder code	Mix. ID	Steel fibres (kg)	Poly-propylene fibres (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Air-entraining agent (ml/100 kg of binder)	f _l loss (%)
<i>Group A</i>							
SRPC	SRPC	–	–	870	870	–	18.4
OCI	OCI	–	–	860	865	–	6.1
B1	B1-N-50	–	–	870	870	–	3.3
B2	B2-N-50	–	–	860	860	–	5.8
B3	B3-N-50	–	–	855	855	–	-15.9 ^a
B4	B4-N-50	–	–	845	845	–	3.8
B5	B5-N-50	–	–	840	840	–	16.7
<i>Group B</i>							
B1	B1-A-40	–	–	655	1015	45	21.2
	B1-A-60	–	–	1015	655	35	23.8
B2	B2-A-40	–	–	640	990	70	22.5
	B2-A-60	–	–	990	640	50	14.3
B3	B3-A-40	–	–	640	985	70	-4.9
	B3-A-60	–	–	985	640	60	3.1
B4	B4-A-40	–	–	625	970	110	6.2
	B4-A-60	–	–	970	625	95	22.0
B5	B5-A-40	–	–	625	965	120	8.5
	B5-A-60	–	–	965	625	100	16.1
<i>Group C</i>							
B1	B1-A-S	40	–	830	805	35	26.9
	B1-A-P	–	1	825	820	40	9.5
	B1-A-H	30	1	830	805	40	12.2
B2	B2-A-H	30	1	825	795	60	34.0
B3	B3-A-H	30	1	820	790	65	15.3
B4	B4-A-H	30	1	805	780	100	4.4
B5	B5-A-H	30	1	800	775	105	8.9

For each specimen, the cumulative mass loss at each week (ML_t) was calculated by:

$$ML_t = \left(\frac{M_t - M_i}{M_i} \right) \times 100$$

Where

Mt Mass at time t (kg)

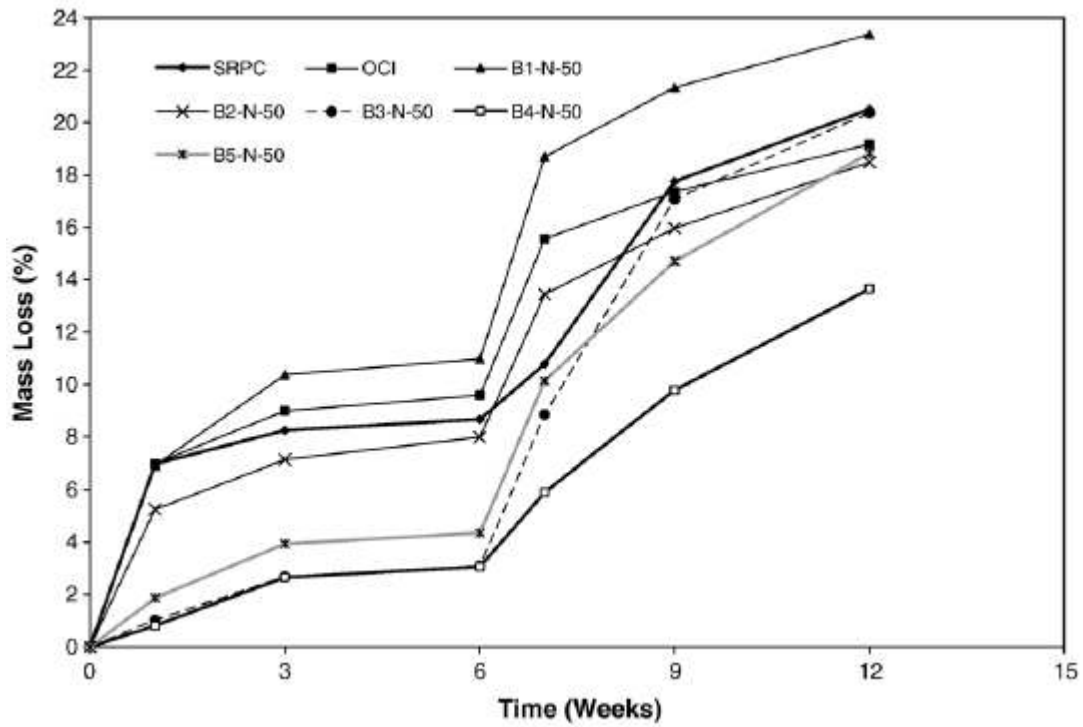
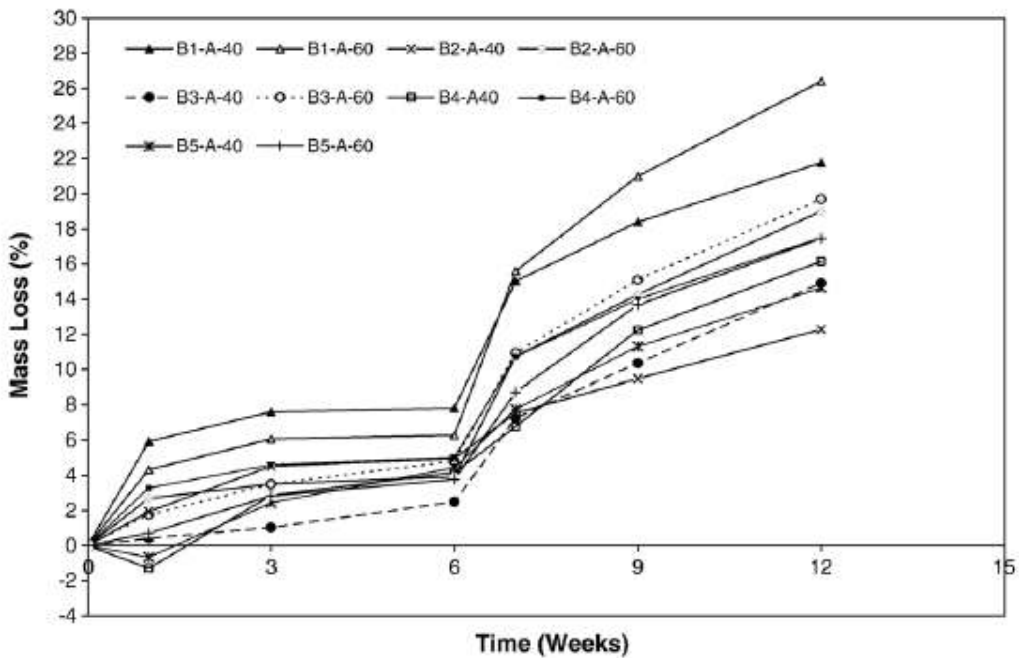


Fig 3.5: Rate of mass loss for group A (Bassuoni et al., 2007)



Notes
A: air-entrained.
40: S/A is 40%; 60: S/A is 60%.

Fig 3.6: Rate of mass loss for group B (Bassuoni et al., 2007)

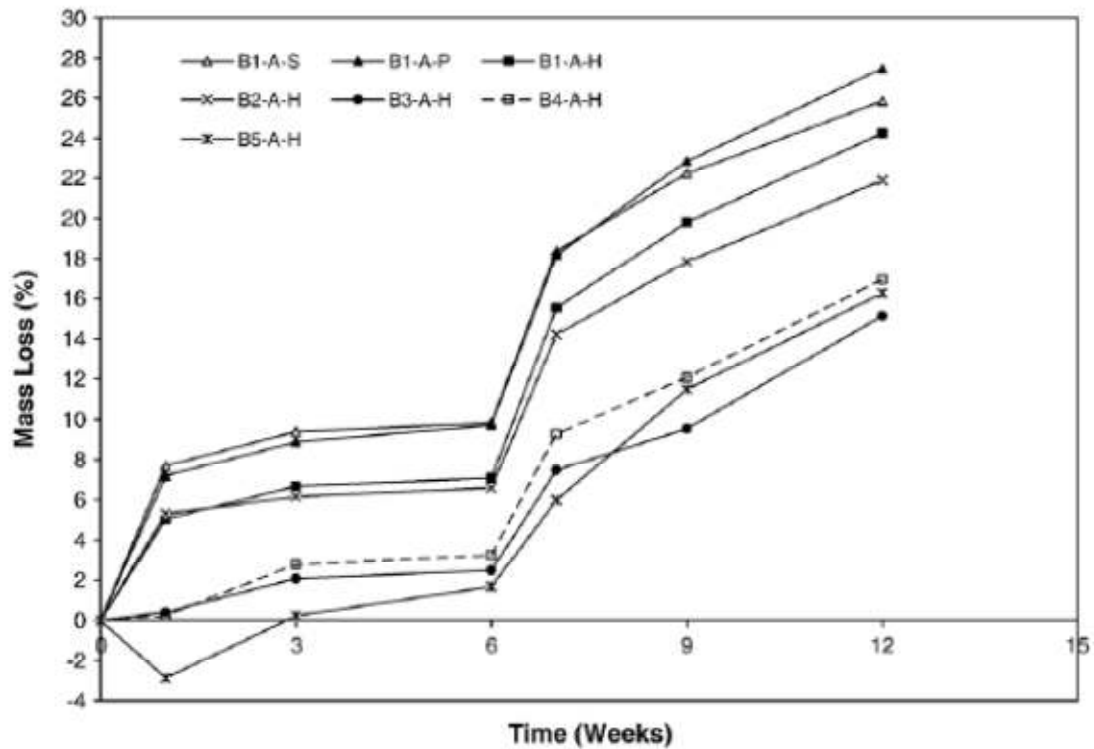


Fig: 3.7: Rate of mass loss for group C (Bassuoni et al., 2007)

From Fig 3.5, the quaternary mixture B4-N-50 prepared with 50% OPC, 15%limestone filler, 20% slag and 15% fly ash had the highest mass loss reduction of 42% at the end of phase II.This may be due to incorporation of limestone in this blended binder. acid solutions.

At the end of phases I and II, shown in Fig 3.6, mass loss ranged from 2.48to 7.82% and from 12.28 to 26.41%, respectively. Some mixtures exhibited mass gain during the first week of immersion due to solution absorption, which is customary at early ages of chemical immersion tests.

From Fig.3.5 it can be observed that the incorporation of hybrid fibres generally led to better performance than using each fibre type individually. The rational behind incorporating hybrid fibres is the combination of the advantageous effects of polymer micro-fibres and steel macro-fibres. The control SCCmixture (B1-A-H) prepared with 100%OPC had the highestmassloss compared to that of the binary, ternary and quaternary binder mixtures with hybrid fibre reinforcement. As discussed earlier, this can be mainly ascribed to the limited calcium hydroxide content and the formation of a protective zone in specimens from blended binders relative to the control specimens.

Stephan et al. (2007):- studied the ‘potential’ durability of self-compacting concrete and reference vibrated concrete (VC) with similar compressive strength. To do this, general indicators of durability (water porosity, chloride diffusion, oxygen permeability) and additional properties necessary for a better understanding (mercury porosity, water absorption by capillarity, carbonation and ammonium nitrate leaching) were examined.

Research program was therefore set up to study concrete with a compressive strength of about 20–70 MPa. The main goal of the project was to compare the durability properties of SCC and VC with equivalent compressive strength. SCC and VC mixes were cast with the same granular components in identical proportions. The use of limestone filler and a greater quantity of super plasticizer in the SCC mixes were the only differences.

Two cements were used a CEM II/A-LL 32.5 R shown in Table 3.3, containing 15.8% limestone filler, with a 28-day compressive strength of 45 MPa and a CEM I 52.5 N, whose 28-day compressive strength was 63 MPa. A polycarboxylate modified super plasticizer was used as a water reducer in SCC and VC.

Table 3:3: Mix proportion chosen (Stephan et al., 2007)

Mix proportions (kg/m ³)		Composition (kg/m ³)					
		Mix					
		VC 20	SCC 20	VC 40	SCC 40	VC 60	SCC 60
Cement	CEM II/A-LL 32.5 R CEM I 52.5 N	315	315	350	350	450	450
Limestone filler		–	150	–	140	–	70
Sand		981	900	962	888	751	884
Gravel	4/12 mm 4/20 mm	841	771	857	791	1088	793
Superplasticizer		1.4	8.0	6.9	12.6	5.9	13.5
Water		189	205	175	191	164	189

Mix characteristics		Properties					
		Mix					
		VC 20	SCC 20	VC 40	SCC 40	VC 60	SCC 60
Water/Cement ratio		0.60	0.65	0.50	0.55	0.36	0.42
Water/Binder ratio		0.60	0.65	0.50	0.50	0.36	0.40
G/S ratio (by mass)		0.86	0.86	0.89	0.89	1.45	0.90
Volume of paste (l/m ³)		317	380	305	374	318	377

Results

Water & Mercury Porosity

The results of water and mercury porosity are presented in figure 3.8 for SCC and VC mixes.

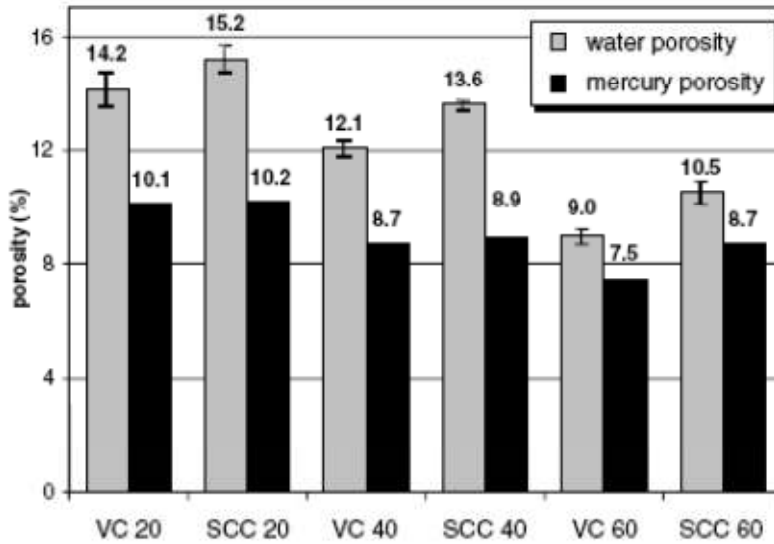


Fig 3.8: Water and Mercury porosity of concrete study (Stephan et al., 2007)

As shown in Fig 3.8 Water porosity is slightly higher (from +1% to +1.5%) for the SCC mixes than the corresponding VC whatever the strength class. The results of mercury porosity lead to a similar conclusion: SCC presents slightly higher mercury porosity (+0.1% to +1.2%) than VC.

Chloride Diffusion:-

Results from Fig 3.6 indicate that SCC and VC have an equivalent effective coefficient of diffusion and that it is of the same order of magnitude (even for concrete C20 which is not recommended for this type of exposure).

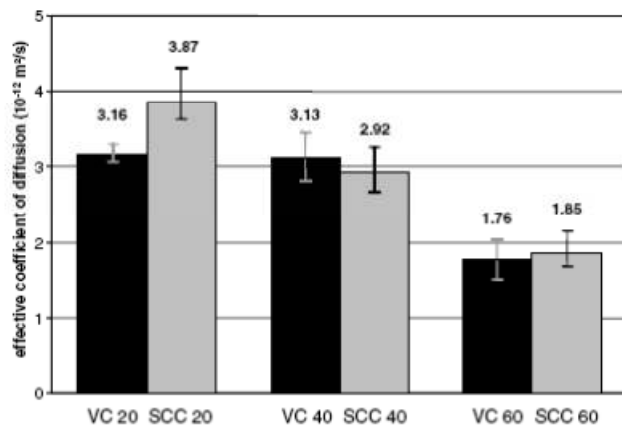


Fig 3.9: Effective coefficient of chloride diffusion of concrete (Stephan et al.,2007)

Oxygen Permeability:-

The results of the oxygen permeability test were obtained for a 0.2 MPa test pressure and in dry material. Although this does not represent concrete in normal conditions of use. Fig. 3.10 reveals that the oxygen permeability of SCC is lower than that of VC (especially for C20 class).

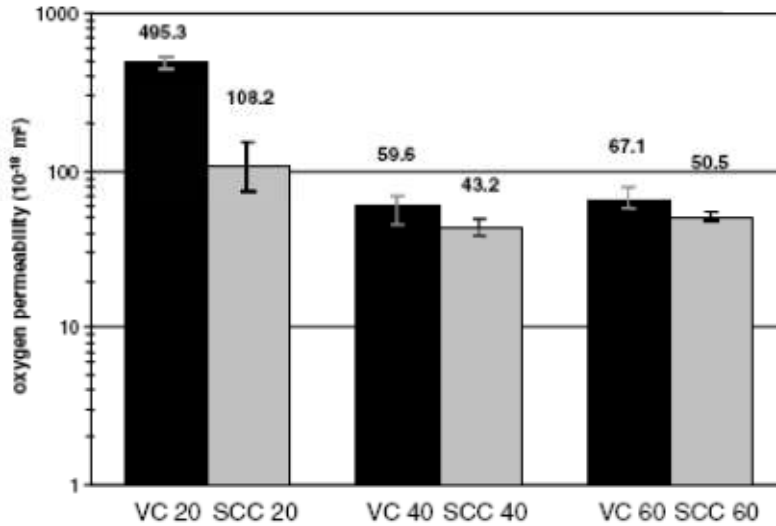


Fig 3.10: Oxygen Permeability of concrete (Stephanet et al., 2007)

Water Absorption: -

The results of water absorption by capillarity (at 24 h) are presented in Fig. 3.11, for SCC and VC mixes. According to these results, the capillary absorption of SCC is higher than that of VC with a similar order of magnitude.

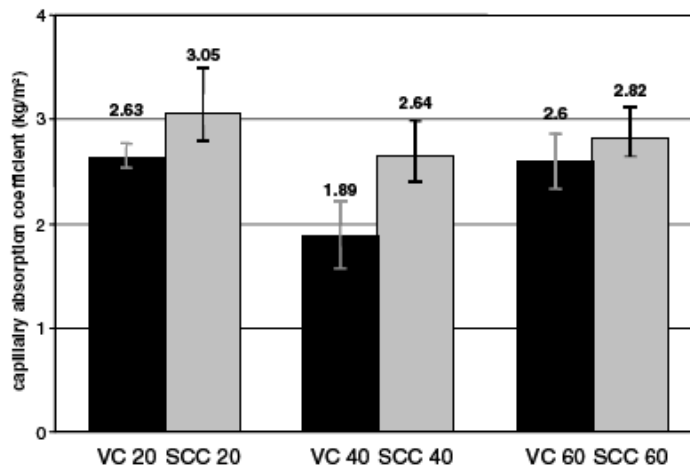
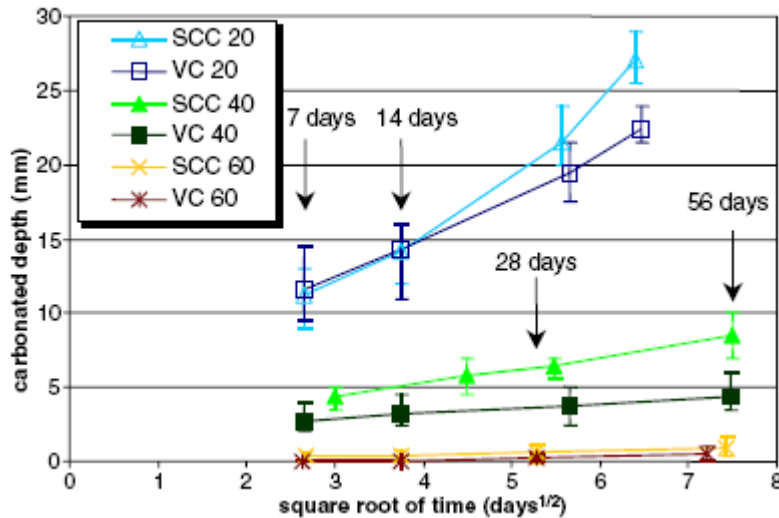


Fig 3.11: Capillary absorption coefficient at 24h (Stephan et al. -2007)

Carbonation: -

The graph for the carbonation accelerated test shown in Fig.3.11, proves that the degradation of SCC increases as quickly as for the corresponding VC. Moreover, for these concretes and in such conditions, these carbonated depths remain small, i.e. less than 25 mm after 28 days of testing (which would be reached after 40 years in natural conditions for ordinary concrete and less than 10 mm at 56 days for structural concrete (Which would be reached after 200 years in natural conditions))



Fig; 3.12: Carbonation depth of concrete studied (Stephan et al., 2007)

Dinakar et al. (2008) studied on the durability properties of self compacting concretes (SCCs) with high volume replacements of fly ash. Eight fly ash self compacting concretes of various strength grades were designed at desired fly ash percentages of 0, 10, 30, 50, 70 and 85%, in comparison with five different mixtures of normal vibrated concretes (NCs) at equivalent strength grades. The durability properties were studied through the measurement of permeable voids, water absorption, acid attack and chloride permeation. The details of concretes of different strengths with the different percentages of replacement are given in Table 3.4.

Table3.4: Mix proportion (Dinakar et al.-2008)

No	Concrete Grade(Mpa)	Concrete name	TCM(p)kg/m ³	Fly Ash (%)	Cement kg/m ³	Total Aggregate Kg/m ³	w/P ratio	HRWR Liquid Weight %
1	20	NC20	234	0	234	1874	0.79	0
2		SCC558	550	85	83	1418	0.41	2
3	30	NC30	319	0	319	1681	0.58	0
4		SCC557	550	70	165	1491	0.34	2
5		SCC757	750	70	225	1107	0.33	2
6	60	NC60	500	0	500	1462	0.37	0
7		SCC555	550	50	275	1571	0.34	2.5
8		SCC655	650	50	325	1388	0.34	2
9	90	NC90	552	0	552	1465	0.29	1
10		SCC553	550	30	385	1663	0.31	2.5
11		SCC530	500	30	350	1608	0.36	1.75
12	100	NC100	659	0	659	1334	0.22	1
13		SCC551	550	10	495	1718	0.29	3

Water Absorption:-

The results of water absorption in 30 min (initial surface absorption) as well as the absorption after 96 h (final absorption) and the permeable voids for all the concretes are presented in Table3.5

Table 3.5;-Durability Properties of the Concretes investigated (Dinakar et al., 2008)

No	Name	30MinAbs. (%)	Final Abs(96h)(%)	Permeable Voids (%)	Weight Loss in acis attack (90 days)	chloride Permeability results		
						initial Current (mA)	Resistivity at 60v (Ω m)	Total Charge (coulombs)
1	NC20	0.86	4.92	12.7	-25.73	1212	77.76	3413
2	SCC558	2.51	8.84	16.7	-4.31	43.5	216.67	1424
3	NC30	1.23	4.93	13.3	-15.19	102.4	91.89	2983
4	SCC557	0.83	4.91	17.1	-1.37	16.5	569.91	352
5	SCC757	1.49	4.12	15.8	-11.09	20.5	458.91	500
6	NC60	0.86	2.98	11.1	-23.12	71.7	130.31	1688
7	SCC555	1.3	4.61	15.5	-23.26	29.4	320.28	659
8	SCC655	1.19	4.06	15.8	-38.9	28.5	329.7	740
9	NC90	0.55	1.68	8.5	-24.16	42.5	221.37	1008
10	SCC553	1.21	4.69	12.6	-37.86	20.8	452.16	737
11	SCC530	0.78	4.33	12.8	-57.29	27.7	339.12	629
12	NC120	0.69	2.15	7.6	-23.35	52.1	180.55	1115

From these results it can be seen that the low strength concretes were showing higher absorption than high strength concretes.

Fig. 3.13 presents the values of 30 min (initial) absorption of all the concretes. The initial absorption values of all the self compacting fly ash concretes were slightly higher than the normal vibrated concretes and the absorption increased with an increase in percentage of fly ash replacement. This shows that all the self compacting fly ash concretes as well as normal vibrated concretes had lower absorption than the limit specified for “good” concretes.

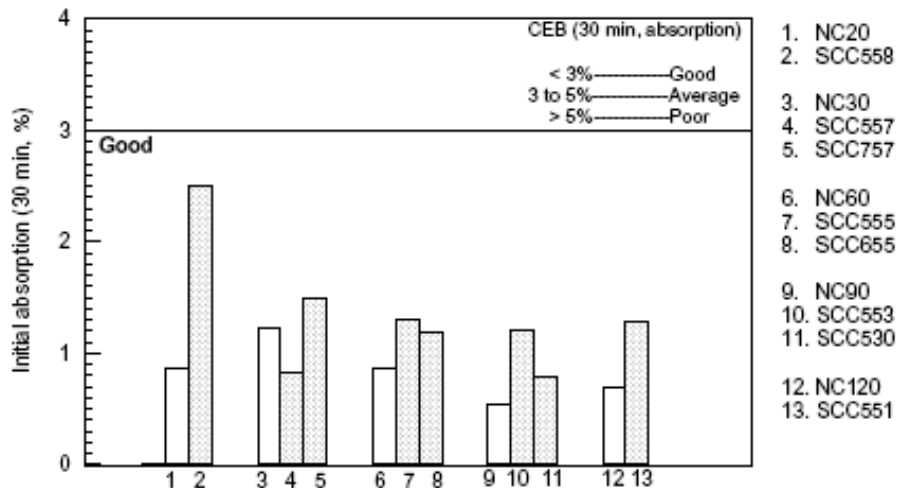


Fig 3.13: Initial absorption values of the concretes investigated (Dinakar et al.,2008)

It can be observed from Fig.3.13 that similar to absorption, the percentage permeable voids are also higher for self compacting fly ash concretes than normal vibrated concretes. For all the SCCs, which were developed with high volume replacements of fly ash, the corresponding permeable voids were also found to be higher.

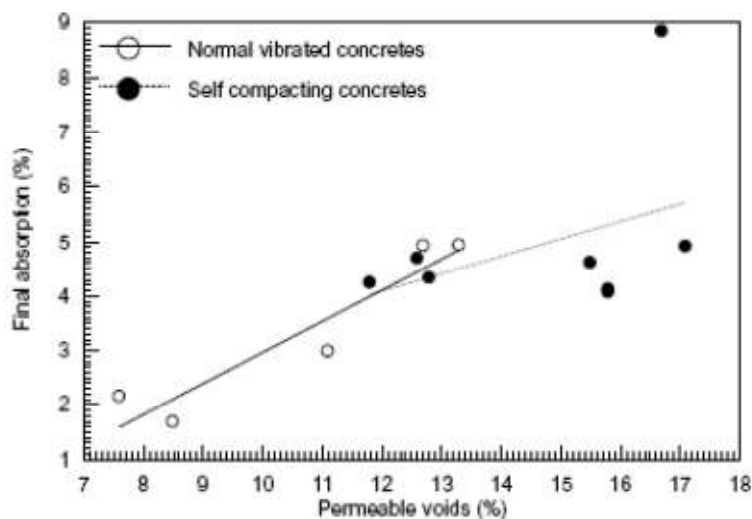


Fig 3.14: Variation of Final Absorption with Permeable voids (Dinakar et al.--2008)

Acid Attack:

It can be seen that in the concretes of lower strength (20 and 30 MPa) the weight loss decreased with increasing percentage of fly ash replacement. The 90 days weight loss with fly ash replacement percentage was also shown in Fig. 3.14 Evidently, the weight loss of self-compacting concrete decreased as the fly ash percentage increased (for levels of replacement >30%). At low replacement level, the behaviour was similar to normal concrete (without fly ash). This suggests that, at higher replacement levels of fly ash self-compacting concretes will result in superior concretes with higher resistance.

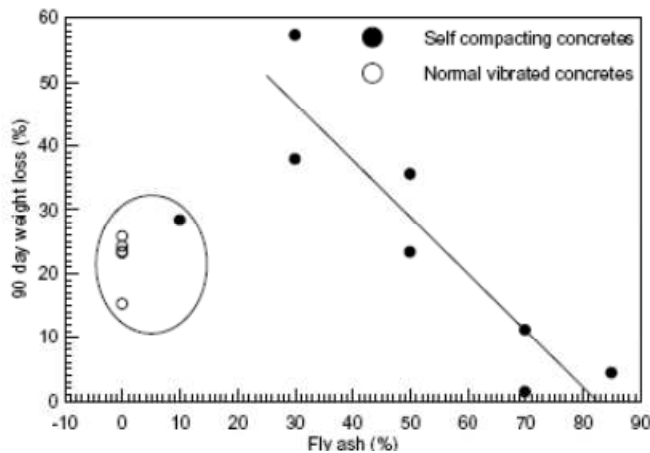


Fig 3.15: Weight Loss with fly ash replacement (P. Dinakar-2008)

Chloride Permeability:

The total charge passing in 6 h as a measure of the chloride permeability is presented in Fig.3.15. It can be seen that(except 20 MPa SCC) all self compacting fly ash concretes showed less than 1000 Coulombs total charge passing and these were assessed as “very low” chloride permeability concretes as per ASTM C 1202–94 assessment criteria. The corresponding normal concretes showed values in the range ‘low’ to ‘moderate’ according to the assessment criteria. The chloride diffusion values obtained for self compacting concretes of grades 20, 30 and 60 MPa, which had high volumes of fly ash (85, 70 and 50%), were about 2 to 8times less than the corresponding normal vibrated concretes. The higher grades 90 and 100 MPa which had fly ash replacements at 30 and 10% performed almost similar to normal vibrated concretes. This clearly indicates that the high volume fly ash self compacting concrete mixes performed much better with respect to chloride penetrability.

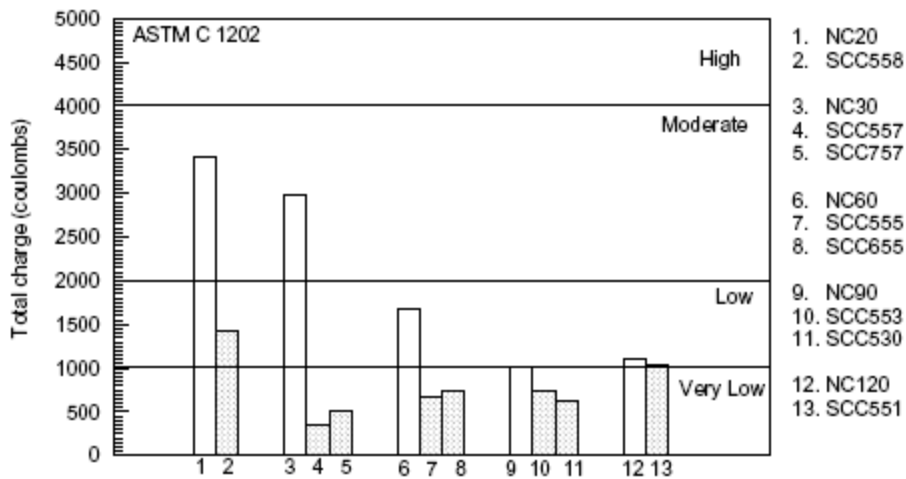


Fig 3.16; Chloride Permeability values (Dinakar et al., 2008)

It can be seen from Fig.3.16 that as initial current increases the total charge increases and with increased resistivity the total charge decreases. The self compacting fly ash concretes showed higher resistance compared to normal vibrated concrete and also the resistance increased with an increase in replacement percentage of flyash.

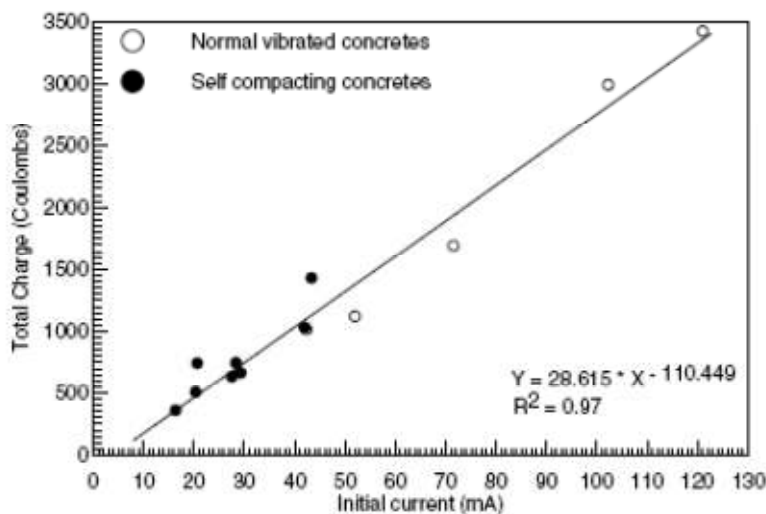


Fig 3.17; Initial current Vs total charge (Dinakar et al., 2008)

It can be clearly observed from figure 3.17, that the alumina content has a significant influence on the total charge of the concrete. As the alumina (Al_2O_3) content increases the total charge decreases. Self-compacting concretes with high volume replacements of fly ash (with high amounts of alumina contents) result in increased resistance against chloride ion penetration.

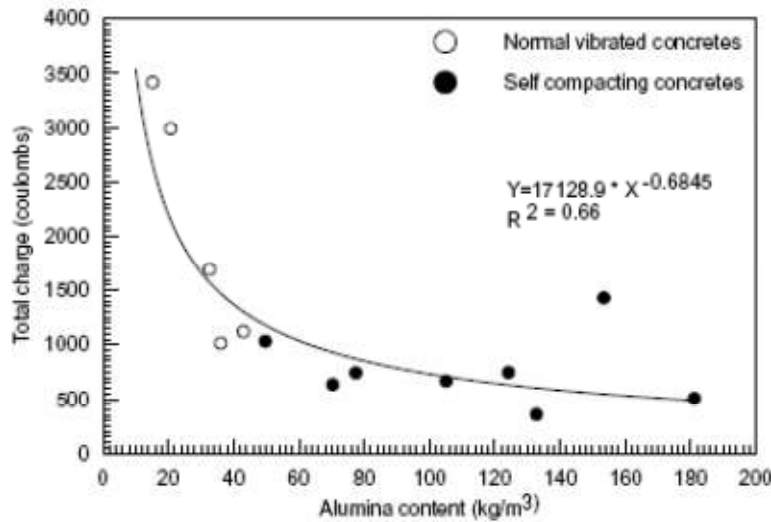


Fig 3.18; Variation of charge with Alumina (Dinakar et al., 2008)

Poon et al. (2009):- studied the properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates. The SCC mixtures shown in Table 3.6.1 & 3.6.2 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.

Table 3.6.1: Mix proportion of RA-SCC mixtures in Series I. (Poon et al., 2009)

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				
							10mm	20mm			
Control-1		0				695	0		1		
RF25		25				521	153		1.5		
RF50	0.53	50	180	340	200	348	305	560	335	8.5	1.5
RF75		75				174	458				1.5
RF100		100				0	610				1.5

Table 3.6.2: Mix proportion of RA-SCC mixtures in Series II and III. (Poon et al., 2009)

Mix code	W/B	Recycled fine agg.(%)	Proportions (kg/m ³)								SP
			Water	Cement	f-FA	r-FA	Sand	RF	Recycled agg. Coarse		ADVA-109
											(l/m ³)
									10mm	20mm	
Series ii											
Control-2		0					662	0			
RF25		25					497	145			
RF50	0.44	50	180	340	70	200	331	291	530	320	8.5
RF75		75					166	436			
RF100		100					0	581			
Series iii											
RF100A	0.44		180	340			0	581			8.5
RF100B	0.4	100	165	340	70	200	0	616	530	320	9
RF100C	0.35		145	340			0	662			9.5

Results:

Resistance to chloride ion penetration:

It can be seen from Fig.3.18, that the chloride-ion penetrability of the RA-SCC mixtures in Series I can be classified as moderate or low. Contrary to compressive strength, the resistance to chloride ion penetration increased with fine recycled aggregate content. This can likely be attributed the filler effect of the fine recycled aggregate as it was comprised of a higher percentage of small particles (<0.30 mm) than the river sand.

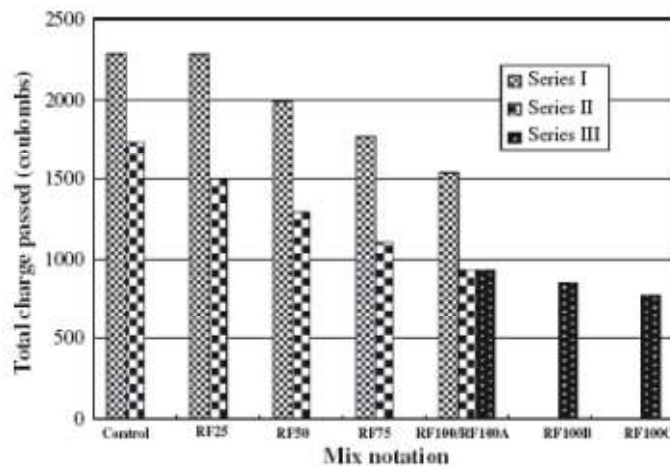


Fig 3.19; Total charge passed (coulombs) of RA-SCC mixtures (Poon et al., 2009)

Total charge passed (coulombs) of RA-SCC mixtures in Series I, II, and III at 28days
 Similarly, it was found that the resistance to chloride ion penetration of the Series II mixes increased as the fine recycled aggregate content increased. As expected, the resistance to chloride ion penetration increased as the W/B ratio decreased from 0.44 to 0.35 (Series III).

Drying Shrinkage:

It can be seen from Figures.3.20, 3.21, 3.22, that at all the test ages, the drying shrinkage values increased with an increase in fine recycled aggregate content. This can be explained by the mortar adhering to the fine recycled aggregates which contributed to an increase in the volume of paste(old + new) as the fine recycled aggregate content increased, thus increasing the drying shrinkage. But the results of Series III mixes show that the drying shrinkage can be controlled by decreasing the W/B ratio.

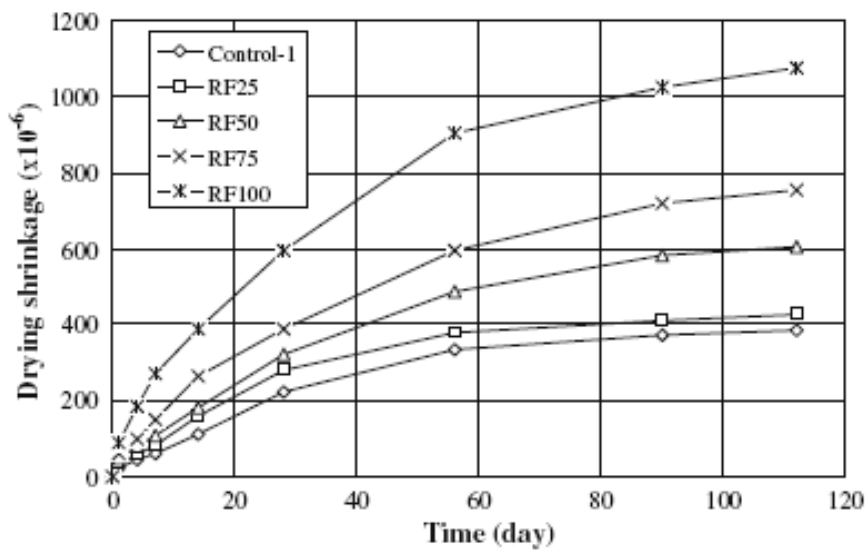


Fig 3.20; Drying shrinkage development of RA-SCC mixtures in Series I. (Poon et al., 2009)

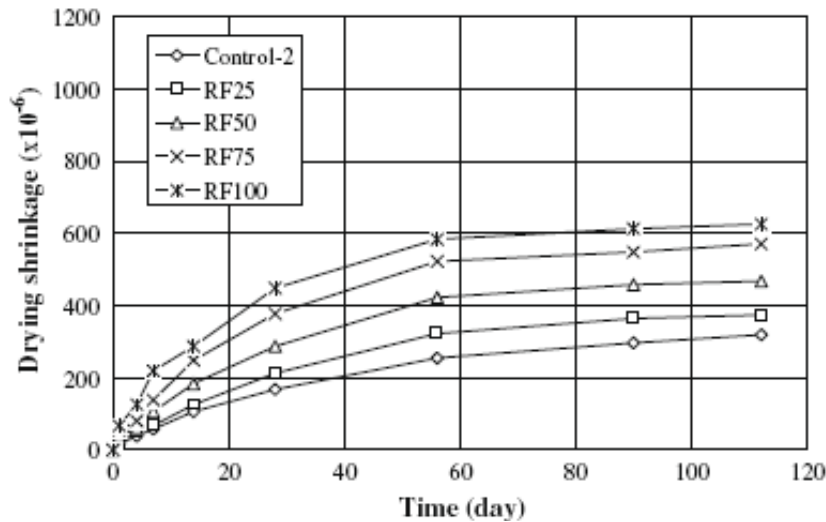


Fig 3.21: Drying shrinkage development of RA-SCC mixtures in Series II (Poon et al., 2009)

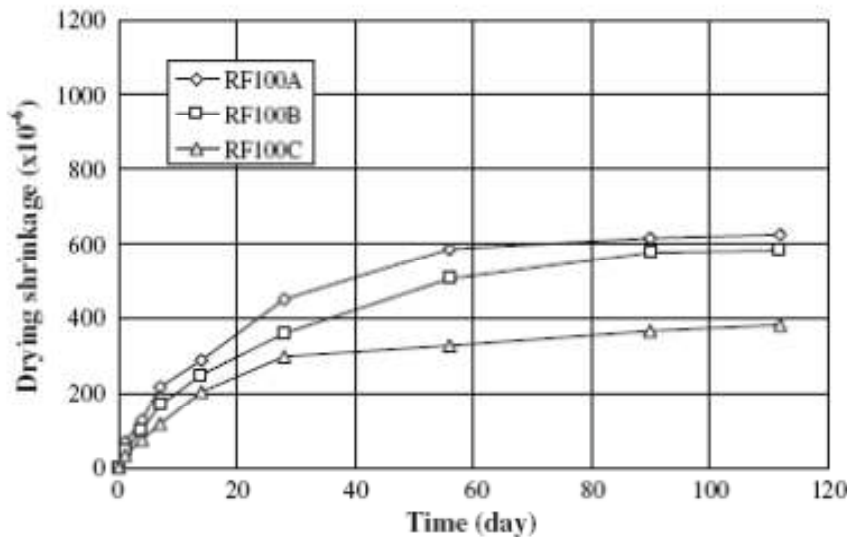


Fig 3.22: Drying shrinkage development of RA-SCC mixtures in Series III (Poon et al., 2009)

Uysal et al. (2011) investigated effect of different mineral admixtures on the sulphate resistance of self compacting concrete. They prepared sixteen series of mix proportions shown in Table3.7, of which one is control, and fifteen were prepared by replacing Portland cement with fly ash (FA)(15%, 25% and 35%) (proportion used is 83, 138, 193 kg/m³ respectively) granulated blast furnace slag (GBFS)(20%, 40% and 60%) (110, 220, 330 kg/m³ respectively) limestone powder (LP)(10%, 20% and 30%) (55, 110 165 kg/m³ respectively), basalt powder (BP)(10%, 20% and 30%) (55, 110, 165 kg/m³ respectively)

and marble powder (MP)(10%, 20% and 30%) (55,110,165 kg/m³ respectively). A natural river sand and crushed limestone with a maximum size of 16 mm was used as fine and coarse aggregates respectively. The total powder content was fixed to 550 kg/m³ and the water–powder ratio (w/p) was selected as 0.33. Experimental results of sulphate resistance include reduction in compressive strength loss and visual examination which have been subjected to 10% sodium and 10% magnesium sulphate solutions for 400 days.

Table 3.7; Mix Proportion of SCC for 1 Cu.m (Uysal et al., 2011)

Materials (kg/m ³)	Cement	FA	GBFS	BP	MP	LP	Water	w/p	w/c	Sand	CSI	CSII
Control	550	–	–	–	–	–	182	0.33	0.33	869	467	311
FA15	467	83	–	–	–	–	182	0.33	0.39	865	457	305
FA25	412	138	–	–	–	–	182	0.33	0.44	887	451	301
FA35	357	193	–	–	–	–	182	0.33	0.51	878	445	297
GBFS20	440	–	110	–	–	–	182	0.33	0.41	866	465	310
GBFS40	330	–	220	–	–	–	182	0.33	0.55	863	463	309
GBFS60	220	–	330	–	–	–	0.33	0.83	861	461	308	
BP10	495	–	–	55	–	–	182	0.33	0.37	866	465	310
BP20	440	–	–	110	–	–	182	0.33	0.41	863	463	309
BP30	385	–	–	165	–	–	182	0.33	0.47	861	462	307
MP10	495	–	–	–	55	–	182	0.33	0.37	867	466	311
MP20	440	–	–	–	110	–	182	0.33	0.41	865	465	309
MP30	385	–	–	–	165	–	182	0.33	0.47	863	463	312
LP10	495	–	–	–	–	55	182	0.33	0.37	866	464	311
LP20	440	–	–	–	–	110	182	0.33	0.41	863	463	308
LP30	385	–	–	–	–	165	182	0.33	0.47	860	461	307

Compressive strength, density, ultrasonic pulse velocity and sulphate resistance measurements were made on 100 mm cube SCC specimens. All specimens, with or without mineral admixtures, were demoulded in a controlled chamber at 20 ± 2 °C after 1 day of casting, and cured in water at 20 °C and 60% RH. Specimens were then cast in steel moulds and were not subjected to any compaction other than their own self-weights.

Results:

Resistance to sulphate attack of concrete:

Visual examination:

It was observed from (Fig.3.17.1) that a small amount of spalling at edges and corners of the GBFS40 specimen which showed the best performance exposed to 10% magnesium sulphate solution for 400 days. In addition white substance was deposited on the face of

the control specimen it was affected the worst in this solution exhibited relatively severe spalling at edges and corners.

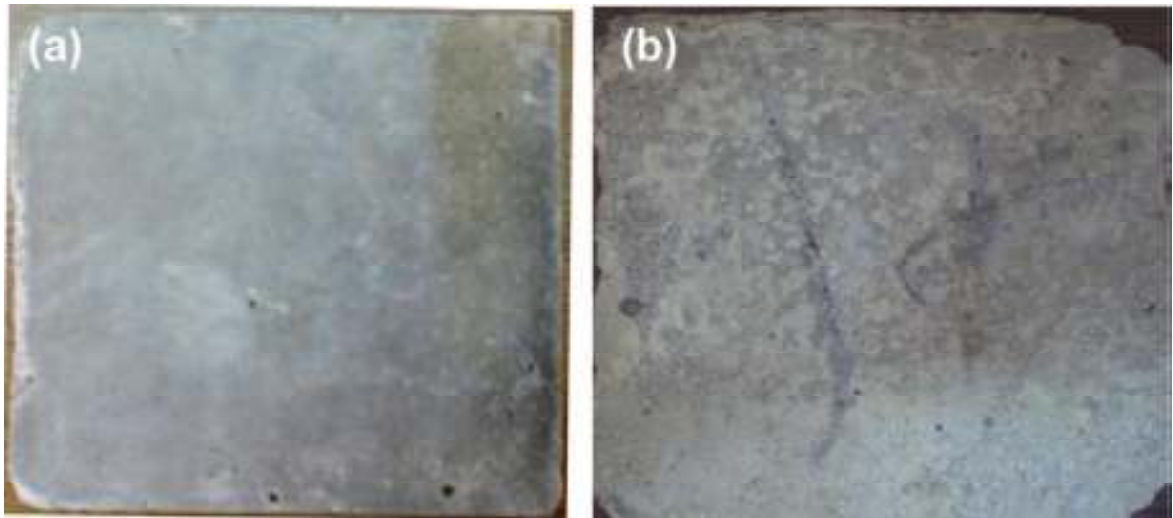


Fig:-3.23 (a) The best case (GBFS40 specimen) and (b) the worst case (control specimen) of specimens in 10% magnesium sulphate solution after 400 days exposure. (Uysal et al., 2011)

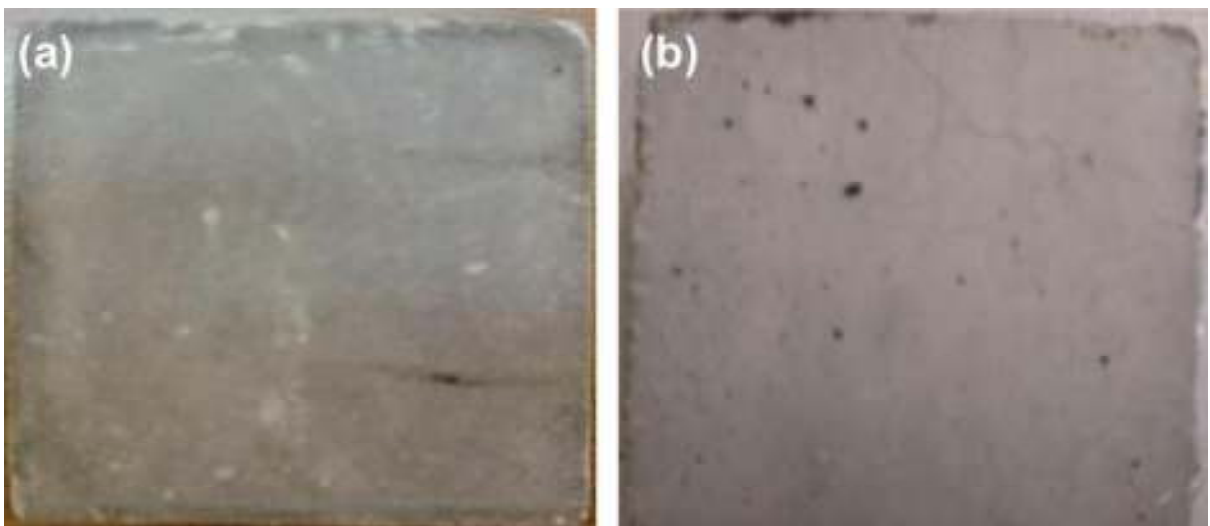


Fig. 3.24 : (a) The best case (GBFS40 specimen) and (b) the worst case (MP10 specimen) of specimens in 10% sodium sulphate solution after 400 days exposure. (Uysal et al- 2011)

Control specimen it was affected the worst in this solution exhibited relatively severe spalling at edges and corners.

After 400 days of immersion in sodium sulphate solution (Fig. 3.22&3.23), the visual examination of the GBFS40 specimen showed no visible deterioration with no detectable weight loss. Furthermore, the MP10 specimen exhibited visible deterioration spalling concrete especially at the corners and edges and some cracking. The visual examination of SCC specimens stored in the magnesium and sodium sulphate solutions for 400 days, indicated that the intensity of the damage by magnesium sulphate attack was greater than sodium sulphate attack.

Table 3.8 presents the UPV values for all mixtures at different ages. The UPV value is related to the density of constituent materials and can be used to assess strength of concrete for a given aggregate and a given moisture condition. Table 4 also presents the density values for all SCC mixtures at 28 days and each density values represents the average density. Generally, GBFS series have shown the highest density values. This can be attributed to the better compaction and reduction in voids in concrete containing GBFS.

Table 3.8: Ultrasound pulse velocity and density of SCC mixtures (Uysal et al., 2011)

Code	Ultrasound Pulse vel. (m/s)				Density (kg/m ³)
	7 Days	28 Days	90 Days	400 Days	28 Days
Control	4416	4650	4796	4995	2.43
FA15	4375	4621	4750	4992	2.41
FA25	4286	4593	4808	5014	2.39
FA35	4210	4535	4702	4935	2.38
GBFS20	4292	4680	4823	4989	2.44
GBFS40	4399	4620	4886	4960	2.43
GBFS60	4284	4551	4715	4797	2.41
LP10	4195	4506	4702	4812	2.43
LP20	4280	4440	4630	4698	2.43
LP30	4193	4222	4502	4611	2.42
BP10	4425	4600	4755	4891	2.44
BP20	4233	4462	4688	4729	2.42
BP30	4161	4380	4587	4693	2.43
MP10	4446	4679	4808	4998	2.42
MP20	4527	4694	4735	4969	2.43
MP30	4230	4550	4709	4948	2.42

Incorporation of mineral admixtures substantially improved the resistance of SCCs against sulphate attack. Test results show that GBFS series showed superior resistance against sulphate attack. Replacing cement with 40% GBFS can reduce magnesium sulphate attack by one third when compared to control mixture. SCC specimens exposed to sulphate solutions and their compressive strength reduction showed that attack by magnesium sulphate was more aggressive in its action on SCC mixtures than sodium sulphate attack.

Vejmelkova, et al. (2011):- studied Rheological, mechanical and durability properties of self-compacting concrete (SCC) mixes produced using blended binders containing metakaolin and blast furnace slag.

Metallurgical cement CEM III/A 32.5 containing blast furnace slag in the amount of 56% by mass was used as the first blended binder. Its specific surface area was 400 m²/kg (Blaine). The second blended binder was prepared using 60% of Portland cement CEM I 32.5R and 40% of metakaolin. The specific surface area of the binder was 974 m²/kg (Blaine).

Therefore, in the preparation of the SCC-M mixture containing metakaolin the demand for water and superplasticizer was higher than in the case of SCC-S containing blast furnace slag. This was to be respected in the mix design as the main factor. The composition of final SCC mixes is summarized in Table 3.9.

Table 3.9; Mix Proportion (Vejmelkova, et al.,2011)

<u>SCC mixtures composition.</u>			
Component	Unit	Quantity	
		SCC-S	SCC-M
Cement CEMIII/A32.5N	kg/m ³	570	–
Cement CEMI32.5R	kg/m ³	–	364
Metakaolin	kg/m ³	–	243
Water	kg/m ³	146	192
w/c	–	0.26	0.32
Superplasticizer	%mass	1.2	1.5
Aggregates 0/2mm	kg/m ³	750	750
Aggregates 2/8mm	kg/m ³	375	375
Aggregates 8/16mm	kg/m ³	375	375
Air content (assumed)	dm ³ /m ³	40	40

Results:*Water penetration:*

As shown in Table 3.10, the water penetration depth h of SCC-S was after 28 days about 40% higher than SCC-M but after 90 days the situation was reversed and SCC-S exhibited only about 40% of h value obtained for SCC-M. The h values of the above mentioned mixes after 90 days were in the range of 13–14 mm which was about two times higher than SCC-M and five times higher than SCC-S. This confirmed the good prerequisites of the mixes designed in this paper for increased durability.

Table 3.10: Depth of Water Penetration (Vejmelkova et al., 2011)

Depth of water penetration.

Material (mm)	Time (days after mixing)	Depth of water penetration
SCC-S	28	37.7
	90	2.8
SCC-M	28	22.3
	90	7.0

Freeze resistance:

Freeze resistance of SCC-M was excellent (Table 3.11) not any mass loss was observed up to 56 freeze/thaw cycles, within the accuracy of 0.001 kg/m². However, also the freeze resistance of SCC-S was satisfactory. The mass loss of 0.396 kg/m² after 56 cycles placed it into the category “good” according to the Swedish Standard 13 72 44. This was in a reasonable agreement with pore distribution measurements

Table 3.11: Freeze residence in terms of the loss of mass-kg/m² (Vejmelkova et al., 2011)Freeze resistance in terms of the loss of mass (kg/m²).

Material	Number of cycles			
	14	28	42	56
SCC-S	0.205	0.323	0.356	0.396
SCC-M	0	0	0	0

The worse performance of SCC-S as compared to SCC-M could be attributed to the presence of pores in the range of 10–100 μm (Fig. 3.24) which enabled the salt solution penetration deeper under the material's surface. The results obtained by mercury intrusion porosimetry (Fig. 3.25) showed that SCC-S had much less homogeneous pore distribution than SCC-M and contained also large pores. These pores in the range of 10–100 μm might present key to the higher thermal conductivity of SCC-S because they could facilitate the formation of thermal bridges in the pore structure of SCC-S.

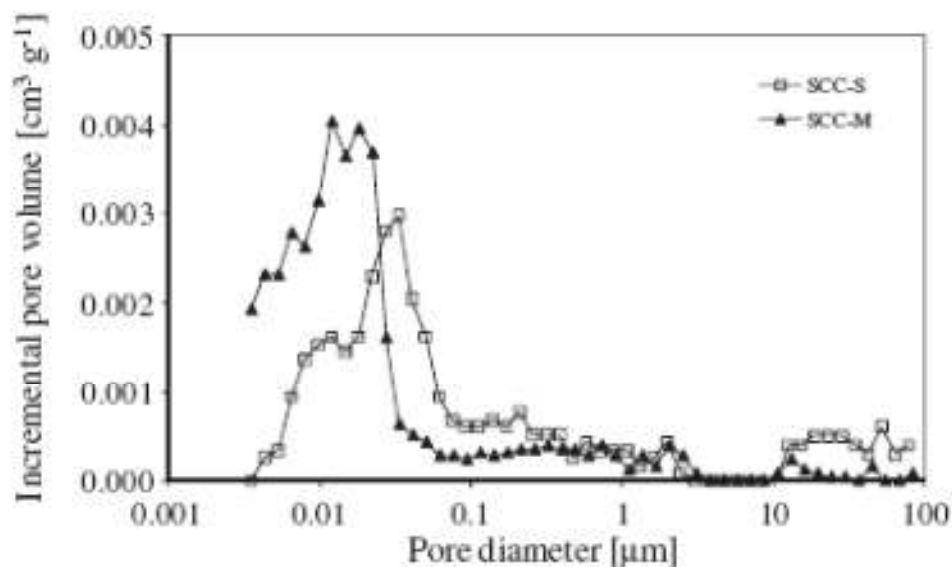


Figure 3.25: Pore Distribution curve (Vejmelkova et al., 2011)

Thermal parameters:-

From Fig.3.26, thermal conductivity of SCC-M was in the whole range of moisture content about 40% lower than SCC-S which was in disagreement with the total open porosity values.

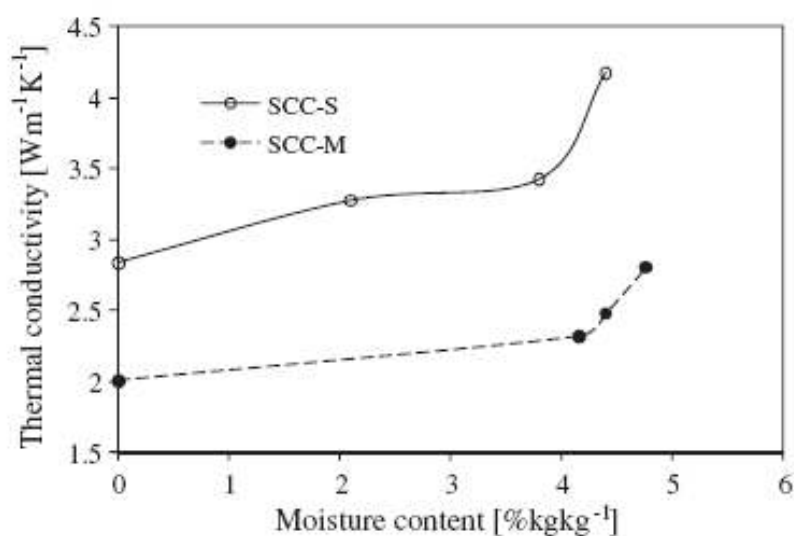


Fig 3.26: Moisture content (Vejmelkova et al., 2011)

Siddique (2011):-

Studied the properties of self-compacting concrete (SCC) made with Class F fly ash. The mixes were prepared with five percentages of class F fly ash ranging from 15% to 35%. Properties investigated were self-compactability parameters (slump flow, J-ring, V-funnel, L-box and U-box), strength properties (compressive and splitting tensile strength), and durability properties (deicing salt surface scaling, carbonation and rapid chloride penetration resistance).

Five concrete mixes were made shown in Table 3.12.1, 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 flyash has 15%, 20%, 25%, 30% and 35% by weight of total powder content were developed, and their mix proportions.

Table 3.12.1: Mix Proportions of SCC (Rafat Siddique,2012)

Mix	Cement(kg/m ³)	Flyash (kg/m ³)	Flyash %	CA (kg/m ³)	FA (kg/m ³)	Water(kg/m ³)	SP (kg/m ³)	SP (%)	w/p
SCC1	465	85	15	590	910	227.7	10.73	1.95	0.41
SCC2	440	110	20	590	910	228.6	11.01	2	0.41
SCC3	415	135	25	590	910	233.3	9.91	1.8	0.42
SCC4	385	165	30	590	910	234.4	9.91	1.8	0.43
SCC5	355	195	35	590	910	241.6	9.91	1.8	0.44

Results:

Carbonation:

Phenolphthalein indicator, which is used conventionally to determine the depth of carbonation in concrete, has a pH of approximately 9.0. When the pH of the pore solution is less than 7.5, the degree of carbonation of the specimen is 100%. When the pH value of the pore solution is between 7.5 and 9.0, the degree of carbonation is 50–100%. When the pH of the pore solution is 9.0–11.5, the degree of carbonation is 0–50%. However, when the pH of the pore solution exceeds 11.5, the specimen is not carbonated. The pH of all the samples tested was greater than 11.

According to the square root of time (T, in months). The rate of carbonation (D) is determined by the diffusion of carbon dioxide into concrete and carbonated depth (X) can be expressed from Flick's first law of diffusion as follows:

$$X = DT^{0.5}$$

As shown in Table.3.12.2, carbonation depth increased with the increase in age from 90 days to 365 days. For SCC 2 (20% fly ash), increase in carbonation depth was observed in comparison to SCC 1 (15% fly ash). With further increase in fly ash content to 25% (SCC3), decrease in carbonation depth was noticed. For SCC 3 (25% fly ash) to SCC 5 (35% fly ash), carbonation depth was almost constant.

Table 3.12.2: Carbonation depth and pH for SCC mixes (Siddique,2011)

Carbonation depth and pH for SCC mixes.

Mix	90 Day			365 Day		
	Xp (mm)	Coefficient (Xp/age ^{0.5})	pH value	Xp (mm)	Coefficient (Xp/age ^{0.5})	pH value
SCC1	0.83	0.472	11.70	1.33	0.384	11.27
SCC2	1.67	0.964	11.71	1.85	0.534	11.67
SCC3	1.33	0.768	11.34	1.65	0.476	11.72
SCC4	1.33	0.768	11.79	1.75	0.505	11.29
SCC5	1.33	0.768	11.36	1.78	0.514	11.69

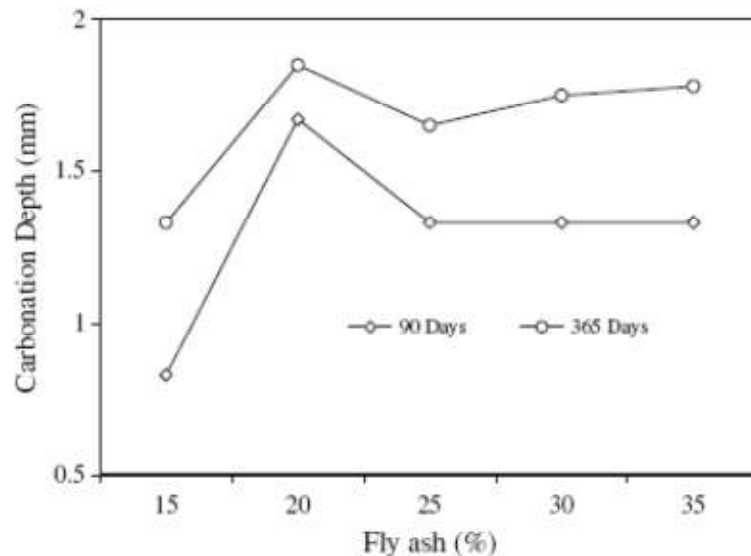


Fig 3.27: Carbonation depth (Siddique, 2011)

Deicing salt surface scaling resistance:-

For SCC mixes shown in Table 3.12.3, weight loss increased with the increase in fly ash content except with mix Containing 15% fly ash (SCC1). At 90 days, the maximum weight loss was observed with SCC1 (15% fly ash). On increasing the flyash content to 20% (SCC2), a considerable decrease in mass loss was observed. Further, the weight loss

increased with the increase in fly ash content to 35% but was still considerably less than that observed at 15%. For 365 days age, the weight loss was almost consistent for all percentages of fly ash varying between 0.525 and 0.750 kg/m² as indicated in Fig. 3.27

Table 3.12.3: Weight loss for SCC mixes (Siddique,2011)

Weight loss for SCC mixes.

Mix	90 Day		365 Day	
	Weight loss (kg/m ²)	Visual rating	Weight loss (kg/m ²)	Visual rating
SCC1	3.70	1	0.525	0
SCC2	1.00	0	0.375	0
SCC3	1.75	2	0.625	1
SCC4	1.95	1	0.650	0
SCC5	2.25	1	0.750	0

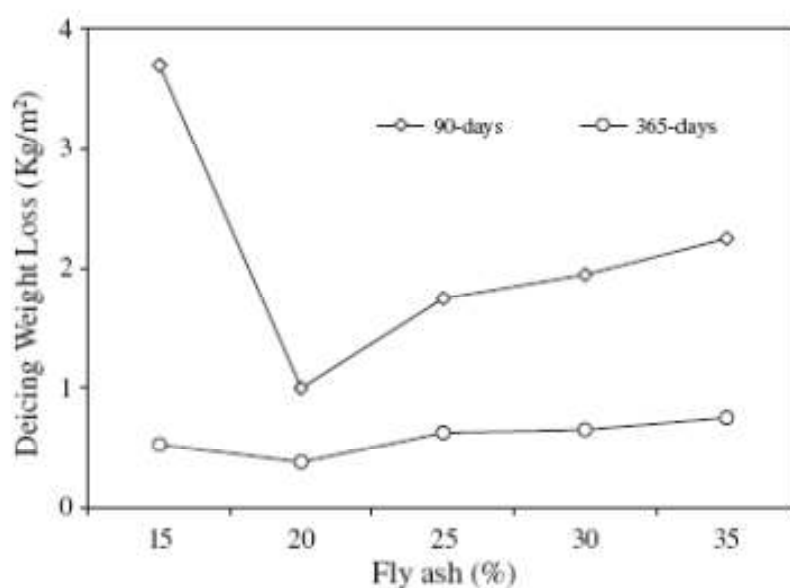


Fig 3.28; Deicing weight loss for SCC mixes at various fly ash content (Siddique,2011)

Chloride penetration resistance:-

It is evident from results shown in Table 3.12.4, that all SCC mixes made with fly ash reduced the rapid chloride ion penetrability to the very low range (less than 400 and 700 Coulomb) at the age of 90 and 365 days respectively.

The incorporation of fly ash resulted in a reduction in Coulomb Charges. The Coulomb charge of SCC 5 (35% fly ash) was 310 Coulomb at 365 days, indicating high chloride penetration resistance. In the study, the charge in the mixes varied with the increase in fly ash content. For SCC 3 (25% fly ash) penetration is least. With the increase in fly ash content above 30%, decrease in chloride penetration was observed (Fig 3.29).

The significant reduction in chloride ion penetration may be due to incorporation of flyash whose spherical particles could improve particle-packing density in the matrix.

Table 3.12.4: Charge assed and rating for SCC mixes (Siddique, 2011)

Charge passed and rating for SCC mixes.

Mix	90 Day		365 Day	
	Charge passed in Coulomb C	Chloride ion penetrability	Charge passed in Coulomb C	Chloride ion penetrability
SCC1	662	Very low	381	Very low
SCC2	649	Very low	373	Very low
SCC3	594	Very low	303	Very low
SCC4	634	Very low	350	Very low
SCC5	610	Very low	310	Very low

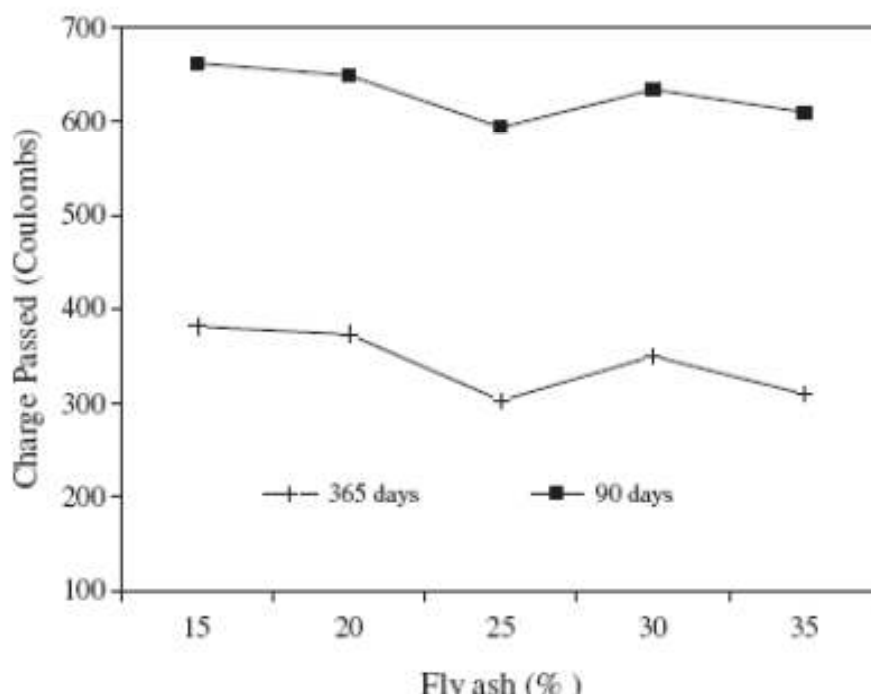


Fig: 3.29: Chloride penetration for SCC mixes at various fly ash content (Siddique,2011)

Pathak & Siddique (2012) studied the properties of Self-Compacting-Concrete (SCC) such as compressive strength, splitting tensile strength, rapid chloride permeability, porosity, and mass loss when exposed to elevated temperatures. Mixes were prepared shown in Table 3.12.5 with three percentages of class F fly ash ranging from 30% to 50% and for comparison; one controlled mixture without fly ash was also produced. The variables included were the temperature effects (20 °C, 100 °C, 200 °C, and 300 °C) using Ordinary Portland Cement. SCC mixes developed 28 days compressive strength ranging from 21.43 to 40.68 MPa and splitting tensile strength ranging from 1.35 to 3.60 MPa.

The objective of the present research was to evaluate the behavior of SCC subjected to elevated temperature, by using locally available materials. The effect of elevated temperature ranging from 100 to 300 °C on compressive strength, splitting tensile strength and rapid chloride permeability, porosity, and mass loss was investigated.

Table 3.12.5: Mix proportions and fresh concrete properties of SCC mixes (Pathak & Siddique, 2012)

Mix proportions and fresh concrete properties of SCC mixes.

Mix	Cement (kg/m ³)	Fly Ash (%)	FA (kg/m ³)	CA (kg/m ³)	W/b	SP (%)
SCC 1	500	–	830	876	0.38	2.00
SCC 2	500	30	830	876	0.38	1.82
SCC 3	500	40	845	860	0.40	1.80
SCC 4	500	50	856	856	0.42	1.72

Results:

Chloride Penetrate Resistance :

Chloride permeability test was conducted on all the concrete specimens. The total charge passed in 6 h as a measure of the chloride permeability is presented in Fig.3.29. Showed that the use of fly ash significantly reduced the chloride permeability of hardened SCC mixtures when compared to the control concretes. It is evident from the results that SCC mixes (SCC2–SCC4) made with fly ash reduced the rapid chloride ion penetrability to the low range (1000–2000 Coulomb) at the age of 28 days, between low range to very low range (<1000 Coulomb) at the age of 91 days. The incorporation of fly ash resulted in a reduction. In Coulomb charges.

The significant reduction in chloride ion penetration may be due to incorporation of fly ash whose spherical particles could improve particle-packing density in the matrix.

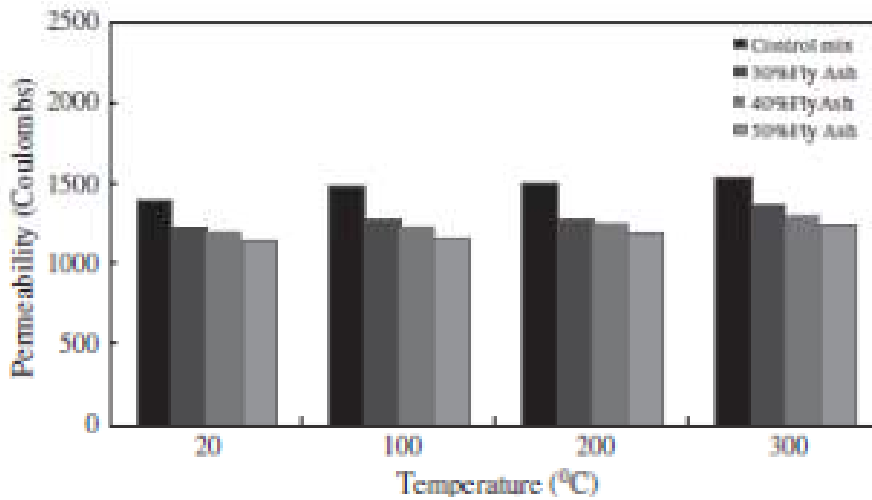


Figure 3.29; Rapid Chloride Permeability of Fly Ash concrete-28 days (Pathak &Siddique,2012)

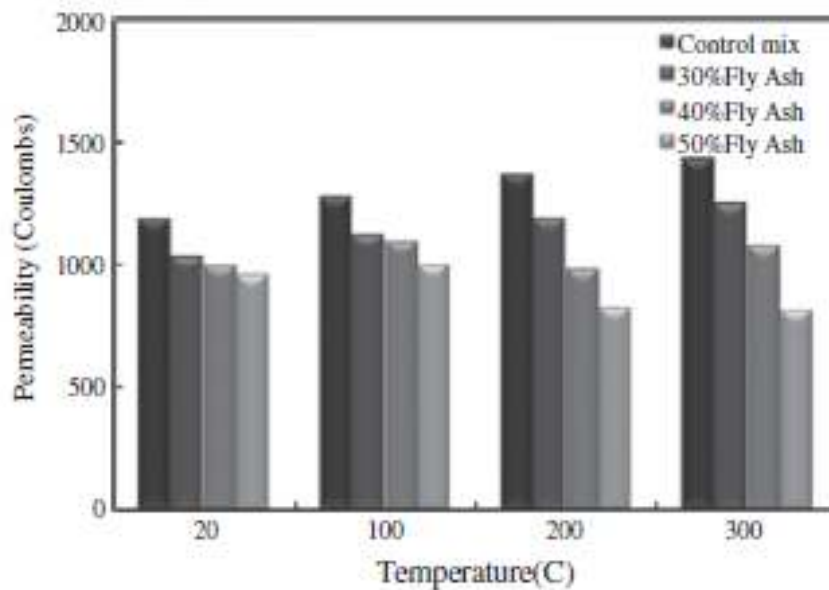


Figure 3.30: Rapid Chloride Permeability of Fly Ash concrete (91 days) (Pathak&Siddique,2012)

One of the most important factor affecting the permeability of concrete was the internal pore structure, which in turn was dependent on the extent of hydration of the cementitious materials. The curing conditions and the age of concrete thus largely determine the ease with which chloride ions can move into a concrete. From the test results shown in Fig

3.30, it is observed that most concretes become significantly less permeable with increase in curing time.

Concrete Mass Loss:-

Table 3.13: Mass loss for SCC mixes (Siddique-2012)

Mass loss for SCC mixes.

Mix	Temperature (°C)	Fly ash (%)	Mass loss (gm)	
			28 days	91 days
SCC 1	100	0	225	124
SCC 1	200	0	242	130
SCC 1	300	0	285	139
SCC 2	100	30	179	120
SCC 2	200	30	196	135
SCC 2	300	30	230	142
SCC 3	100	40	182	154
SCC 3	200	40	216	175
SCC 3	300	40	234	205
SCC 4	100	50	190	156
SCC 4	200	50	225	178
SCC 4	300	50	245	195

It was observed from Table 3.13, that the evolution of mass loss was less between the room temperature and 200 C. between 200 and 300 C, noticeable increase in mass loss was observed for all concretes. This is because of loss of chemically bound water from the decomposition of the C-S-H, the carboaluminate hydrates and the dehydration of calcium silicate hydroxide.

Porosity:-

Table 3.14: Porosity for SCC mixes (Pathak & Siddique-2012)

Porosity for SCC mixes.

Mix	Temperature (°C)	Fly ash (%)	Porosity (%)	
			28 days	91 days
SCC 1	100	0	0.77	0.55
SCC 1	200	0	0.86	0.64
SCC 1	300	0	0.95	0.79
SCC 2	100	30	1.20	1.00
SCC 2	200	30	1.46	1.35
SCC 2	300	30	1.57	1.39
SCC 3	100	40	1.53	1.42
SCC 3	200	40	1.68	1.55
SCC 3	300	40	1.75	1.64
SCC 4	100	50	1.90	1.68
SCC 4	200	50	2.25	1.75
SCC 4	300	50	2.42	1.95

For the initial stage of heating, the porosity was nearly stable up to 100 C. By increasing the temperature from 100 to 200 C or from 200 to 300 C porosity increased shown in Table 3.14. When the percentage of fly ash increased porosity also increased. The increase

in porosity values was attributed to change SCC from impermeable to permeable material due to losses and pruned of fine, super fine and organic materials.

Kosmas et al. (2013):- evaluated the durability properties of medium strength self-compacting concretes and their comparison with those measured on reference normally vibrated concretes. Eight different self-compacting mixtures were produced using different types of cements and aggregates. The durability properties assessed were the water absorption, the carbonation resistance and the chloride induced corrosion resistance. These were compared with the relevant properties measured on normally vibrated concretes of the same strength class. The coefficients calculated were used to estimate the service life of reinforced concrete structures.

Mix design proportion

Table 3.15: Mix design proportions -kg/m³ S.C.C (Kosmas et al., 2013)

Self Compacting concrete									
	Limestone					Siliceous			
	SCC1	SCC2	SCC3	SCC4		SCC5	SCC6	SCC7	SCC8
	C20/25	C25/30	C30/37	C35/45		C20/25	C25/30	C30/37	C35/45
	Mix 1	Mix 2	Mix 3	Mix 4		Mix 5	Mix 6	Mix 7	Mix 8
Cement	302	336	374	436		338	354	432	436
L.filler	185	136	104	100		206	144	120	100
Silicafume	–	–	–	20		–	–	–	20
Limestone sand	862	916	897	808		–	–	–	–
River sand	–	–	–	–		808	897	808	808
Coarse aggregates	800	800	800	800		800	800	800	800
Water	187	173.4	180.6	192		188	172	190	192
Super/sizer	1.27	1.64	1.56	1.65		1.61	1.84	1.88	1.57
W/C	0.62	0.52	0.48	0.42		0.56	0.49	0.44	0.42
W/P	0.38	0.37	0.38	0.35		0.35	0.34	0.34	0.35

Conventional concrete

	Limestone				Siliceous			
	SCC1	SCC2	SCC3	SCC4	SCC5	SCC6	SCC7	SCC8
	C20/25	C25/30	C30/37	C35/45	C20/25	C25/30	C30/37	C35/45
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Cement	300	330	370	450	335	350	430	435
Silicafume	–	–	–	–	–	–	–	20
Limestone sand	1000	925	868	762				
River sand	–	–	–	–	1060	985	948	910
Coarse aggregates	845	925	930	940	760	852	780	800
Water	186	173	180	190	186	173	190	192
Super/sizer	1	1	1	1	1	1	1	1
W/C	0.62	0.52	0.49	0.42	0.56	0.49	0.44	0.44
W/P	0.62	0.52	0.49	0.42	0.56	0.49	0.44	0.42
Slump flow D (cm)	19	19	20	20	20	19	18	18
fc28 (MPa) ^b	31.1	41	52.7	56.7	32.1	42.6	51.2	57.3

Results:-

Sorptivity:-

An improved durability is observed in all SCC mixtures against the conventional Concretes of the same strength class indicated by marginally lower values. This difference in sorptivity coefficient among SCC and CC in general is decreasing as the w/c also decreases (Table 3.16).

Table 3.16: Sorptivity coefficients of all mixtures (Kosmas et al., 2013)

Sorptivity coefficients of all mixtures.

Sorptivity coefficient (kg/m ² /min ^{0.5})							
SCC1	SCC2	SCC3	SCC4	SCC5	SCC6	SCC7	SCC8
0.182	0.115	0.094	0.091	0.158	0.122	0.109	0.082
CC1	CC2	CC3	CC4	CC5	CC6	CC7	CC8
0.221	0.134	0.119	0.101	0.186	0.137	0.126	0.099

Carbonation Coefficient:-

By examination of the results of carbonation test from Fig 3.31, it can be concluded that the rate of carbonation (expressed by the carbonation coefficient) is lower in SCC mixtures in all studied cases. Limestone filler produce a better particle packing, resulting in lower

porosity and a finer pore structure which also makes the pore network more intricate. SCC mixes that include limestone sand in their composition, due to their finer gradation, presented lower carbonation rate as compared with limestone sand CC mixtures of the same strength class.

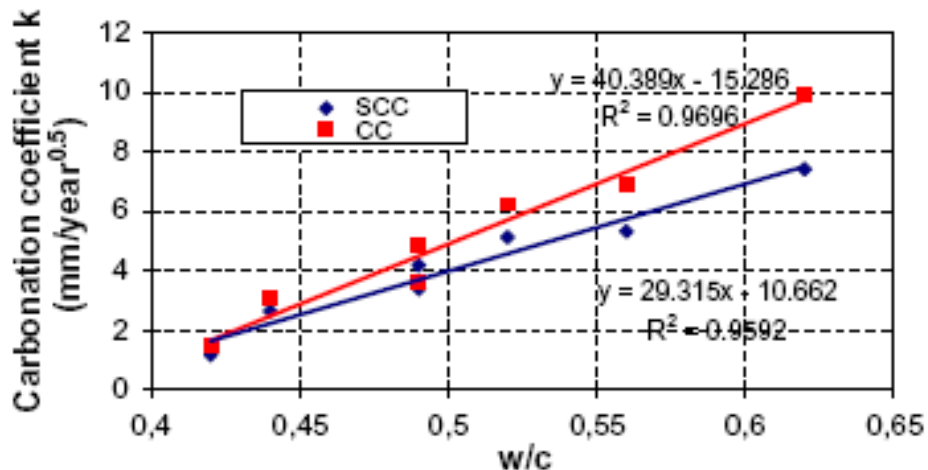


Fig-3.31: Carbonation coefficients for various w/c ratios for SCC and CC mixtures (Kosmas et al., 2013)

Improved carbonation coefficients determined in SCC mixtures had a positive effect on extending the service life of reinforced concrete structures. When self-compacting concrete is used instead of conventional concrete of the same grade, service life of reinforced concrete structures against carbonation induced corrosion is in any case extended.

Chloride diffusion coefficient:-

Permeability of SCC mixtures is lower than CC mixtures because of the absence of vibration that reduces the volume of water accumulating around aggregates and leads to lower ITZ porosity in SCC mixtures. It can be concluded from Fig.3.32, that the values of chloride coefficients are close comparing the two kinds of concrete, especially for the higher strength grade tested. The difference of chloride diffusion coefficients significant for mixtures produced with w/c ratio greater than 0.55. The w/c ratio had the more significant effect on the chloride diffusion, but not in the same way for SCC and CC mixtures.

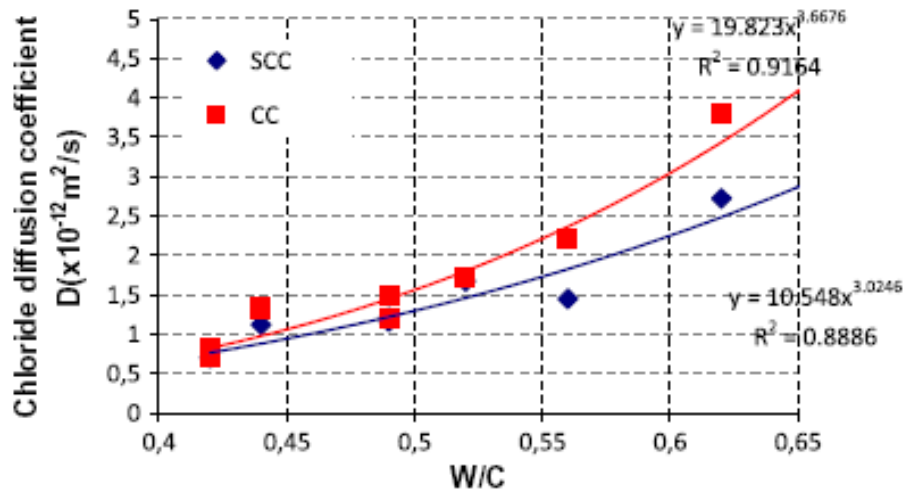


Fig- 3.32; Chloride diffusion coefficient of SCC and CC. (Kosmas et al. -2013)

3.3 Closing Remarks

This chapter gives brief review and description of the experiments studied by different authors to find the durability properties of self compacting concrete and their results.

4.1 General

The aim of the research program is to compare durability properties of self Compacting concrete made with Fresh & Recycled concrete aggregate.. In the end various tests conducted on the SCC are discussed.

4.2 Experimental Programme & Test Matrix

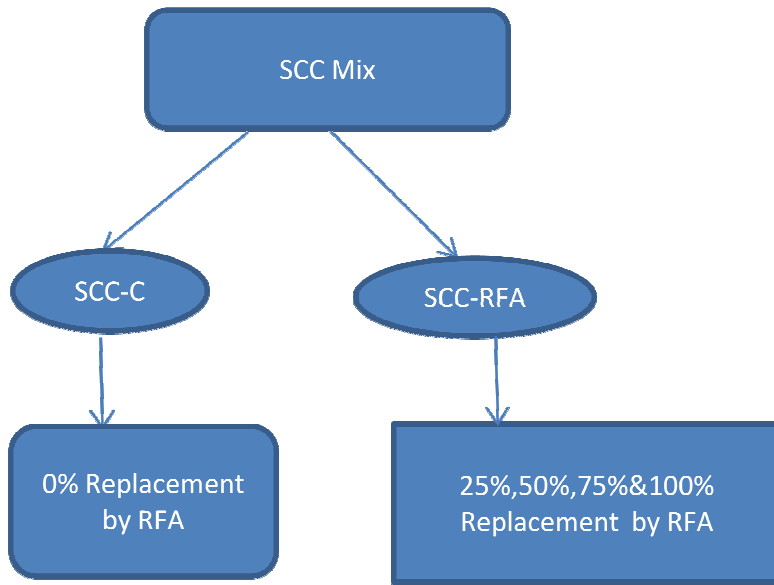


Fig 4.1: Mix Details

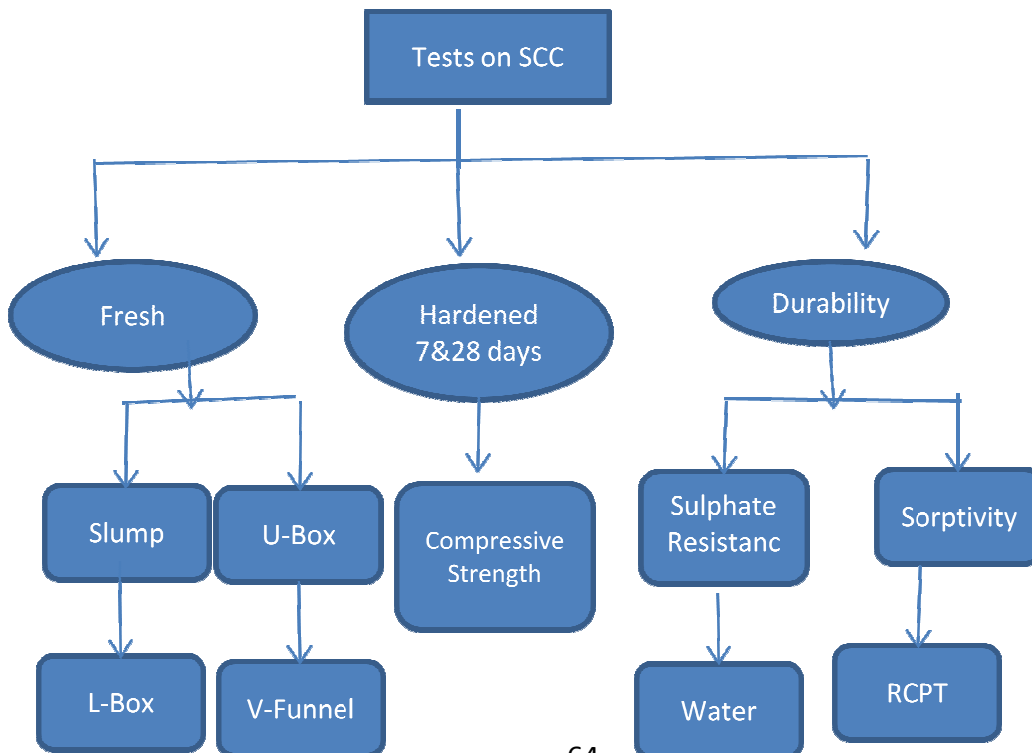


Fig 4.2: Tests on SCC

4.3 Materials used for making SCC

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

4.3.1 Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials clay predominates and in calcareous materials calcium carbonate predominates. Basic composition of the cement is shown in Table 4.1

Table 4.1 Composition limits of Portland cement.

Ingredient	%Content
Cao(Lime)	60-67
SiO ₂ (Silica)	17-25
Al ₂ O ₃ (Alumina)	3-8
Fe ₂ O ₃ (Iron Oxide)	0.5-6
Mgo(Magnesia)	0.1-4
Alkalies	0.4-1.3
Sulphur	1-3

Ordinary Portland Cement of Grade 43 has been used. Properties of Cement are tabulated below.

Table 4.2 Physical properties of Cement used

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

4.3.2. Fine Aggregates

Fine aggregates were procured from Kotputli source whereas the recycled fine aggregate were obtained by crushing demolished concrete waste in a laboratory jaw crusher. The fine sand & recycled fine sand were first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then washed to remove the dust. Properties of the fine aggregate & recycled fines used in the experimental work are tabulated in Table 4.3&4.4. The fine aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in Table 4.5 .



Fig 4.3 Recycled Fine Aggregate Natural Fine aggregate from Kotputli

Table 4.3 Physical properties of Fine Aggregate

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

Table 4.4 Physical properties of Recycled 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 4.5 Sieve Analysis of Recycled Fine Aggregates

Total weight of Sand Sample = 1000gm

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	600 μ m	220.0g	22	47.7	52.3
5	300 μ m	274.0g	27.4	75.1	24.9
6	150 μ m	246.5g	24.65	99.75	0.25
				$\Sigma=256.55$	

Fine modulus of Sand = 2.56

Zone = II

4.3.3 Coarse aggregate

The material which is retained on IS sieve no. 4.75 is termed as a coarse aggregate. The crushed stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 10 mm was used in our work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. The results of various tests conducted on coarse aggregate are given in Table 4.6 and Table 4.7 shows the sieve analysis results.

Table 4.6 Physical Properties of Coarse aggregate (10mm)

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

Table 4.7 Sieve Analysis of Coarse Aggregate (10mm)

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	$\Sigma=183.54$	

Total Weight taken = 3Kg

Fineness Modulus = $(183.54 + 500)/100 = 6.83$

4.3.4 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting.

4.3.5 Fly Ash

Class F Fly ash obtained from —NTPC Thermal Power Station, Faridabad Delhi was used.

4.3.6 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 a 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.



Fig 4.4 : Superplasticizer (Ultracon)

4.3.7 Magnesium Sulphate

Powder form of magnesium sulphate was obtained from New Delhi. It was white in color. Its solution of strength 5% by adding it to water was made and used for sulphate resistance test.



Fig. 4.5: Magnesium Sulphate

4.4 Mix Design Details

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 $< 150\mu$)
2. Optimal dosage of superplasticizer.

Initially two types of SCC were prepared- one SCC-C 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 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.

Further the mix designs were prepared with the replacement of 25%, 50% and 75% of fine aggregates with recycled waste of concrete aggregates for the comparison of fresh, hardened & Durability properties

Table 4.8 Trial with fresh coarse and fine aggregates

SCC trial mix details			
Date:		Time:	Trial 1
Ingredients	Source/ Type	SCC 1	Remarks
		(Kg/m ³)	
Cement		400	
Fly Ash		150	
Fine Aggregate	Fresh	800	0% replacement
Aggregate 1 (20 mm)	Fresh	270	
Aggregate 2 (10 mm)	Fresh	500	
Water		180	
Admixture		5	

Table 4.9: Trial with fresh coarse and 100% Recycled fine aggregates

SCC trial mix details			
Date:		Time:	Trial 1
Ingredients	Source/ Type	SCC 5	Remarks
		(Kg/m ³)	
Cement		400	
Fly Ash		150	
Fine Aggregate	Recycled	800	100% replacement
Aggregate 1 (20 mm)	Fresh	270	
Aggregate 2 (10 mm)	Fresh	500	
Water		280	
Admixture		14	

Table 4.10 Final Mix design details of SCC made by RFA

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
SCC-C	400	150	270	500	800	-	5	180	0.45
RFA 25	400	150	270	500	600	200	8	184	0.46
RFA50	400	150	270	500	400	400	10	192	0.48
RFA75	400	150	270	500	200	600	12	200	0.5
RFA100	400	150	270	500	-	800	14	208	0.52

Where SCC-C –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

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.

4.5 Casting

Before casting, the entire test specimen 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. The coarse aggregates and fine aggregates were weighed first with accuracy. The concrete mixture was prepared by hand mixing on a non-absorbing platform. On the non-absorbing platform, the coarse and fine aggregates were mixed thoroughly. To this mixture, the cement was added. These were mixed to uniform color. Then 70 to 80 % water was added by making space in the center and rest was sprinkled on the mix. For each mix 22 samples were casted, 6 cubes for compressive strength at 7&28 days while 4 cylinders for sulphate resistance ,4cubes for water absorption,4 cubes for sorptivity & 4 cubes were casted for chloride penetration resistance.



Fig 4.6 Specimen Casting



Fig 4.7 SCC made with Fresh Aggregate



Fig 4.8 SCC made with 100% Recycled Fine Aggregate



Fig 4.9 Specimen Curing (Recycled & Fresh)

4.6 Test methods

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).

4.6.1 Fresh properties & details

Fresh properties of conventional and modified SCC (with varying %age of RFA) were measured using standard tests as below

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

- **L- Box Test Method**

The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. The apparatus is shown below in Fig. 4.6.

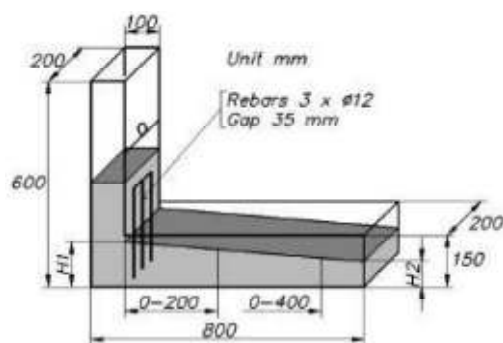


Fig. 4.10: L box. (EFNARC, 2002)

The apparatus consists of a rectangular-section box in the shape of an ‘L’, with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the Concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H_2/H_1 in the diagram). This is an indication passing ability, or the degree to which the passage of concrete through the bars is restricted. The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured.

Equipments

- L box of a stiff non absorbing material
- Trowel
- Scoop
- Stopwatch

Procedure

- About 14 litre of concrete is needed to perform the test.
- Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.
- Fill the vertical section 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 horizontal section.
- Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400 mm marks.
- When the concrete stops flowing, the distances “H1” and “H2” are measured.
- Calculate $H2/H1$, the blocking ratio.
- The whole test has to be performed within 5 minutes.

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. T20 and T40 times can give some indication of ease of flow, but no suitable values have been generally agreed.

- **V – Funnel Test**

The test is designed to measure flow ability of fresh concrete. The equipment consists of a V-shaped funnel, shown in Fig. 4.7 the funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus measured

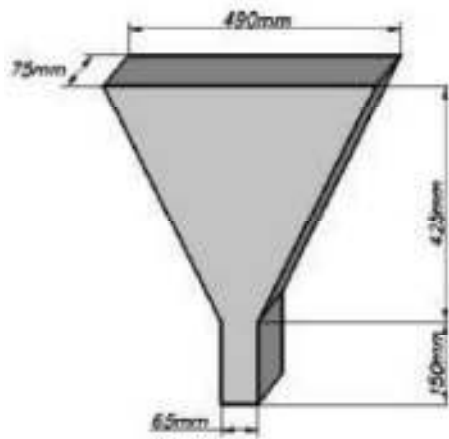


Fig. 4.11: V- Funnel equipment. (EFNARC, 2002).

Equipments

- V-funnel
- Bucket (±12 litre)
- Trowel
- Scoop
- Stopwatch

Procedure

- About 12 litre of concrete is needed to perform the test, sampled normally.
- Set the V-funnel on firm ground.
- Moisten the inside surfaces of the funnel.
- 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). This is taken to be when light is seen from above through the funnel.

- The whole test has to be performed within 5 minutes.

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. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 minutes of settling, segregation of concrete will show a less continuous flow with an increase in flow time.

- **Slump Flow Test**

- It is the most commonly used test and is used to assess the horizontal free flow of SCC in the absence of obstructions. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for 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. Its equipment is shown below in Fig. 4.8. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

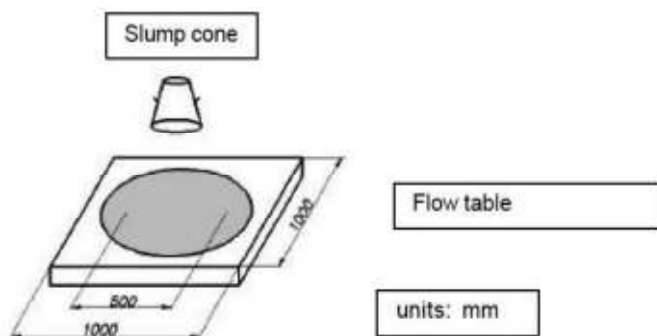


Fig. 4.12: Slump Flow Test Equipment. (EFNARC, 2002).

Equipment

- Mould in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm, conforming to EN 12350-2
- Base plate of a stiff non absorbing material, at least 700mm square, marked with a circle marking the central location for the slump cone, and a further concentric circle of 500mm diameter
- Trowel
- Scoop
- Ruler
- Stopwatch (optional)

Procedure

- About 6 litre of concrete is needed to perform the test.
- 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.
- simultaneously, 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. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± 50 mm, as with the related flow table test, might be appropriate. The T50 time is a secondary indication of flow. A lower time indicates greater flow-ability.



Fig. 4.13: Slump Flow test –SCC-C



Fig. 4.14: Slump Flow test –SCC-100%RFA

- **U – Box Test**

The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R1 and R2 in Fig. 4.9. An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacing of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 litre of concrete then the gate lifted and concrete flows upwards into the other section. The height of the concrete in both sections is measured

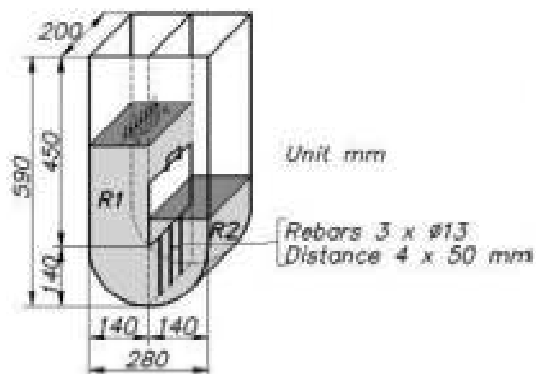


Fig. 4.15: U-Box Test

Equipment

- U box of a stiff non absorbing material see figure 3.1.
- Trowel
- Scoop
- Stopwatch

Procedure

- About 20 litre of concrete is needed to perform the test, sampled normally.
- Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.
- Moisten the inside surfaces of the apparatus, remove any surplus water.
- 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.
- The whole test has to be performed within 5 minutes.

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.

- **GTM Segregation test**

This is a very recent test measuring the separation of aggregate in a sample after a period of time and wet sieving. The test has a potential for detection of tendency to segregate (Dehn et al., 2000). It completes the tests (Slump-Flow, L-Box, etc.) carried out to estimate the filling ability by specifying the segregation resistance. This test can be used in laboratory when developing a concrete mix, as well as on site, when carrying out suitability tests on the delivered concrete.

4.6.2 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 4.16 Compressive Strength Test

4.6.3 Durability Tests & Details

The focus was to check the durability characteristics of SCC made with Recycled fine aggregate. For checking the Durability following tests were conducted.

- Sulphate Resistance Test
- Sorptivity
- Water Absorption
- Rapid Chloride permeability Test

- **Sulphate Resistance Test**

For this purpose, cylindrical specimens of size 150 mm diameter × 300 mm height were cast. The test was conducted at the end of 28 days of curing. The specimens were then subjected to a solution with sodium sulphate; the specimens were placed in a solution of 18 g/l of sodium sulphate in distilled water. A propeller was placed in the basin in order to secure a good circulation of the solution around the specimens. The method for investigation of the damage has been measurement of surface scaling of material by weighing at the age of 3, 7, 14, 21 days (Persson, 2003).



Fig 4.17: - Specimen dipped in sodium sulphate solution

- **Sorptivity**

Sorptivity coefficient can be determined by means of simple test allowing one face of concrete specimen is in contact with water and the mass (non-destructive) or height 98 (destructive) of water absorbed by capillary suction is measured at predefined intervals. For this, Cubical specimens of size 150 mm were casted and cured for 28 days. After curing period cubes were kept in natural air to get dry for 4 hours. Then 4 sides of concrete specimen were sealed by electrician tape to avoid evaporative effect as well to maintain uniaxial water flow during the test. One face of the specimen was in contact with water whilst the water absorption is measured at predefined intervals. The test started with the registration of samples weight and, afterwards, they were placed in a recipient in contact with a height of water capable to submerge them about 5mm. After a predefined period of

time, the samples were removed from the recipient to proceed to weight registration. Before the weight, the samples superficial water was removed with a wet cloth. Immediately after the weight, the samples were replaced in the recipient till reach the following time. The procedure was repeated, consecutively, until the last reading.

The Sorptivity coefficient can be calculated by the following expressions.

$$S = (Q/A) / \sqrt{T}$$

Where S is the Sorptivity (cm/min^{1/2}), Q is the mass of water absorbed in kg, A is the surface area in contact with water in cm² and t is the time in minutes (Bentz et.al. 2001).



Fig.4.18:- Specimen immersed and Sealed with water seal.

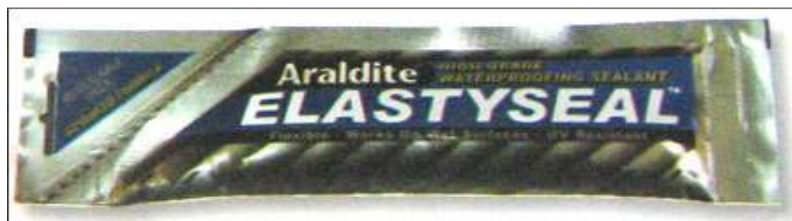


Fig 4.19: Water seal used.

- **Water Absorption**

Cubical specimens of size 75 mm were cast for conducting water absorption tests, by completely immersing dried cube specimens in water at 25°C for 96 hours and noting the amount of water absorbed per unit initial mass in percentage after the age of 28 days and 56 days. This gives percentage water absorbed.

- **Rapid chloride permeability test**

According to ASTM C1202 test, water saturated, 50 mm thick, 100 mm thick diameter concrete specimen is subjected to a 60 v applied DC voltage for 6 hours using the apparatus and the cell arrangement. In one reservoir is a 3.0% NaCl solution and in the other reservoir is a 0.3 M NaOH solution. The total charge passed is determined and this is used to rate the concrete according to the criteria given in ASTM C1202.



Fig 4.20: - Typical Cell Arrangement with Reservoir(RCPT)



Fig 4.21: - Apparatus for measuring current in Amphere(RCPT)



Fig 4.22: - NACL & NaoH solution



Fig 4.22: - Core Cutter

5.1. General

Recycled fine aggregates (RFA) obtained by crushed concrete were used for production of self compacting concrete as discussed in chapter 4. Five different mixes of self compacting concrete prepared, out of which 4 were made by replacing 25%, 50%, 75% & 100% recycled fine aggregate and one with conventional, fresh FA respectively. The mix proportions of the five SCC were designed in order to achieve the same compressive strengths. This chapter discusses the results obtained for Water absorption, Sorptivity, Sulphate resistance, Chloride Permeability of SCC made with RFA. A comparative analysis of all design mixes is done and efficacy of replacing FA with RFA is discussed.

5.2 Fresh Properties of SCC & Modified SCC

SCC containing different proportion of recycled fine aggregates was tested for Slump flow, V-funnel, U-Box, L-box. The results of fresh properties of all Self-compacting concretes are included in Table 5.1.

Table 5.1 Fresh Concrete Properties

Mixture Id	Slump(mm)		V-Funnel (Seconds)		L-Box (H2/H1)		U-Box (H2-H1)mm	
	Experimental Results	EFNARC Limits	Experimental Results	EFNARC Limits	Experimental Results	EFNARC Limits	Experimental 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

Following observations are made

- In terms of slump flow, all SCCs exhibited satisfactory slump flows in the range of 550–800 mm, which is an indication of a good deformability.
- SCC made with recycled fine aggregates typically needs 10% more water than conventional SCC in order to obtain the same workability.
- As per EFNARC, time ranging from 7 to 12 seconds is considered adequate for a SCC. The V-funnel flow times were in the range of 7–12 seconds.

- Test results of this investigation indicated that all SCC mixes made with recycled fine aggregate meet the requirements of allowable flow time.
- 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 Property

- **Compressive Strength**

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

Table 5.2 Compressive Strength Test Results

Mix	Compressive Strength (N/mm ²)		Average Compressive Strength (N/mm ²)	
	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		

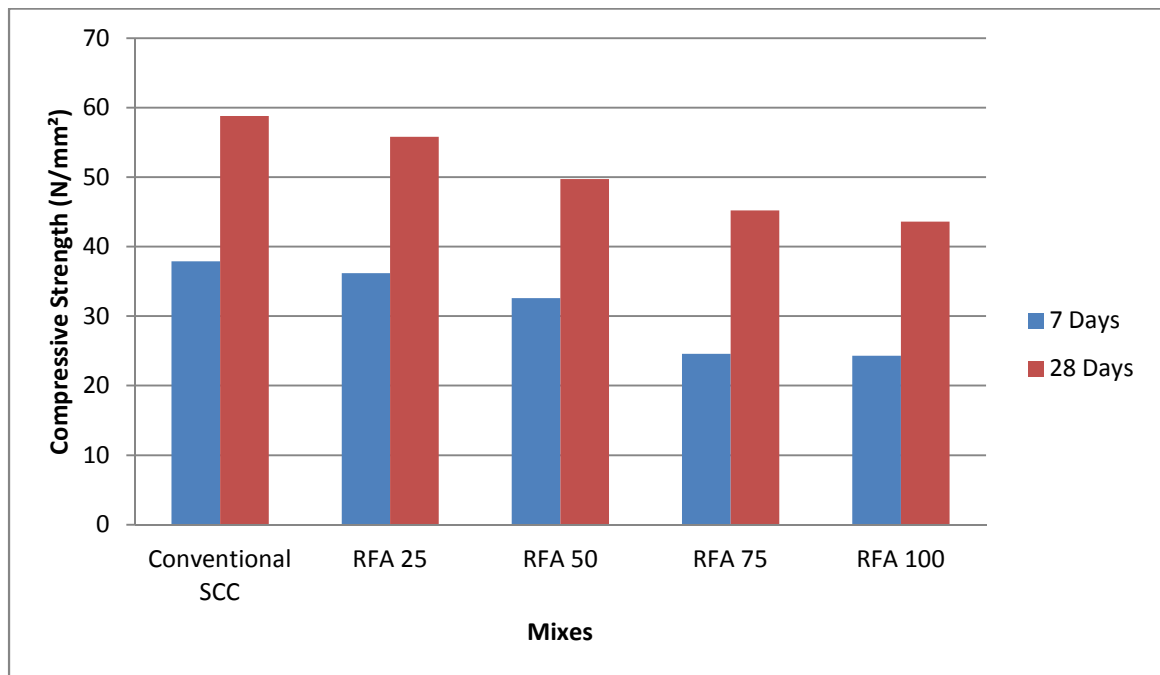


Figure 5.1 Variation of compressive strength with age of curing

- The 7 days compressive strength of conventional SCC was found to be 36.6 N/mm², where as the 7 days compressive strength decreases to 24.3. N/mm² when the fine aggregates was replaced by 100% recycled fine aggregates.
- 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.
- Graphical result represents decrease in strength as percentage of RFA increases.

5.4 Durability Properties

5.4.1 Water Absorption

In order to study the water absorption when recycled fine aggregate(RFA) is added into self-compacting concrete, the cube containing different proportion of RFA were prepared and kept for initial curing for 28 days. After the initial curing the water absorption was carried out further for 28days, as per test procedure mentioned in chapter 4.

Table5.3:- Percentage of Water absorbed at various ages

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

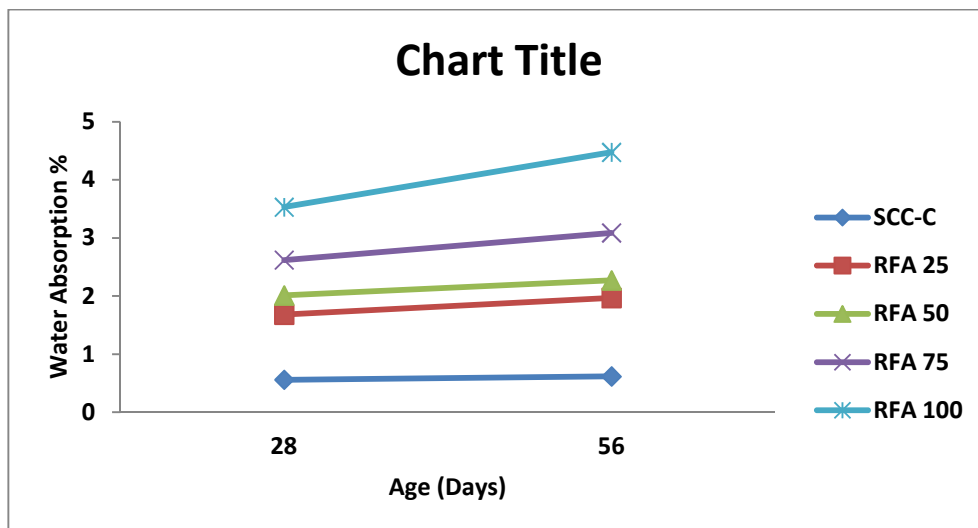


Fig 5.2:- Percentage of Water absorbed of SCC mixes at various ages

Following observation were made

- From the results of water absorption (Table 5.2) it is observed the water 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.

- Fig. 5.2 shows that concrete 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 Self-compacting concretes 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. Absorption is mainly influenced by the paste phase primarily; it is dependent on the extent of interconnected capillary porosity in the paste. Concrete mixes with higher paste contents are bound to have higher absorption values than concretes with lower paste content (at consistent w/c). The absorption values of concrete containing the RFA are higher than that of the conventional concrete and it shows an increasing trend towards higher RFA content.

5.4.2 Sorptivity

Sorptivity coefficient was determined by means of simple test allowing one face of concrete specimen in contact with water and the mass of water absorbed by capillary suction was measured at predefined intervals. For this, cube specimens of size 150 mm were casted and cured for 28 days. After curing period cubes were kept in natural air to get dry for 4 hours. Then 4 sides of concrete specimen were sealed by a water proof seal preferably called as Elastyseal (a product of Araldiet) in the market. To avoid evaporative effect as well to maintain uniaxial water flow during the test and. After a predefined period of time, the samples were removed from the recipient to proceed to weight registration. Before the weight, the sample's superficial water was removed with a wet cloth. Immediately after the weight, the samples were replaced in solution till reach the following time. The procedure was repeated, consecutively, until the last reading. The weight noted is shown in Table 5.3

Table 5.4: Evolution of water absorption by capillarity carried out with ages

	Water absorbed by capilarity (Kg/cm ²)					
Mix	15 min	30 min	1 hour	24 hour	48 hour	72 hour
SCC-C	0.00009	0.00015	0.00025	0.00033	0.00042	0.00054
RFA 25	0.0001089	0.000182	0.000303	0.000399	0.000508	0.000653
RFA 50	0.0001197	0.0002	0.000333	0.000439	0.000559	0.000718
RFA 75	0.0001296	0.000216	0.00036	0.000475	0.000605	0.000778
RFA 100	0.0001404	0.000234	0.00039	0.000515	0.000655	0.000842

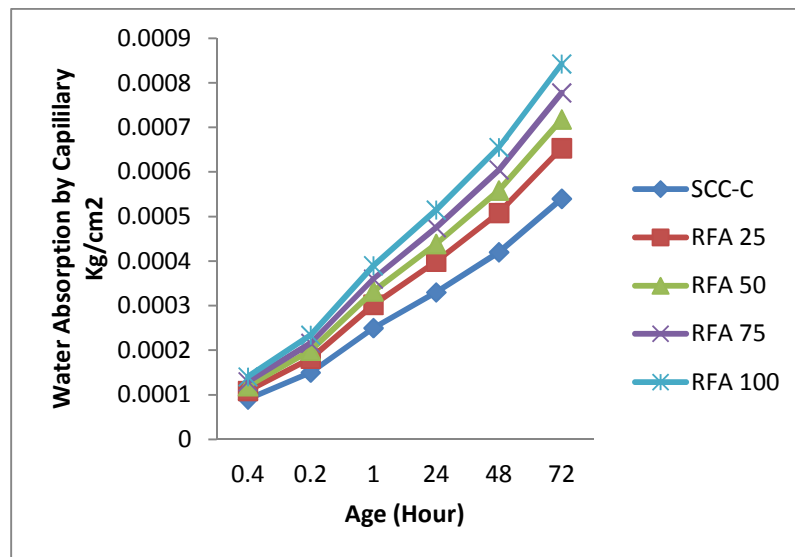


Fig 5.3:- Evolution of Sorptivity carried out with ages

Observation made from Table 5.4 and Fig 5.3 can be summarized

- Fig 5.3 shows that the presence of FRA increases the sorptivity of Concrete. The sorptivity coefficient has a relative increase of 50% for concrete made with 100% FRA compared with the normal SSC.
- Absorption is mainly influenced by the paste phase primarily; it is dependent on the extent of interconnected capillary porosity in the paste.
- It seems that water absorption increases linearly with the replacement ratio; this is to be expected since FRA have a more porous structure, which extends to the concrete matrix.

5.4.3 Sulphate Resistance

External sulphate attack (ESA) to cementations matrix is a complex process that involves the movement of sulphate ions through the pores by means of different mechanisms of transportation and the interaction of aggressive solution with some compounds of cement paste (AFm phases, hydrogarnet phases, unhydrated alumina phases and CH) to form expansive compounds (ettringite and gypsum) that produce cracking, strength loss and softening. The most important factor to prevent external sulfate attack is to reduce the permeability of the concrete (low water/cement ratio, high cement content, well compacted and well cured).Hence usage of supplementary cementing materials increases the resistance against sulphate attack. In an acidic sulfate environment ($\text{pH}<7$), gypsum formation causes local expansion, spalling and strength retrogression. The acid media contribute to the gradual removal of CH from the paste until complete depletion, which promotes decomposition of C–S–H that causes loss of adhesion and stiffness.

After 28 days of curing sulphate resistance was conducted at 3, 7, 14 and 21 days of curing. The Table 5.5 and Fig. 5.4 shows the percentage loss in weight of concrete specimens made by using various amount of replacements in cement quantity by RFA with respect to age when subject to sulphate environment

Table 5.5: Percentage of weight loss with ages

Mix	Percentage loss in weight(%)			
	3 days	7 days	14days	21 days
SCC-C	0.91	1.028	1.603	1.972
RFA 25	1.059	1.197	1.866	2.296
RFA 50	1.12385	1.269	1.979	2.435
RFA 75	1.223	1.382	2.156	2.652
RFA 100	1.390	1.571	2.450	3.014

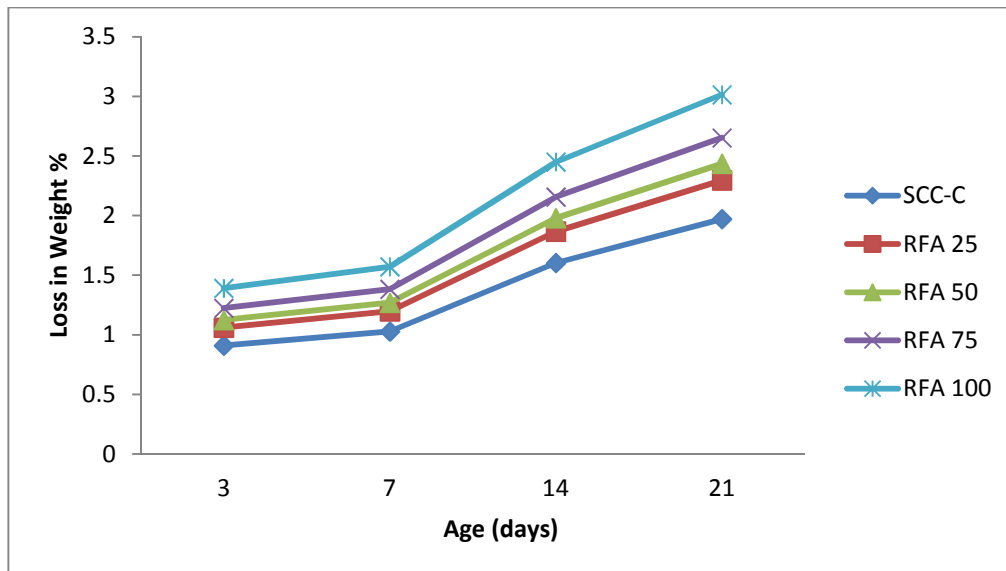


Fig 5.4:- %of Weight loss with ages

Following observations were made.

- There is a remarkable loss in weight of concrete made with 100% RFA, as compared to normal SCC.
- At 3 days exposure to sulphate environment conventional SCC shows 0.91 % loss as compare to 1.39% of SCC made with 100% RFA .
- At the age of 7 days SCC-C losses 1.028 % compared to RFA 100 which lost 1.571 % and by the last reading that is at the age of 21 days SCC-C lost 1.972 % compared to RFA 100 which lost 3.0142 % of weight.
- Irrespective to age sulphate resistance of SCC mixes replaced with RFA reduces incomparision to control mix.
- At 3 days of exposure as the %age of RFA increases from 25-100% mass loss increases from 1% to 1.5%.

It was due to the high absorption capacity of the RFA itself, which has created higher osmosis pressure within the concrete. Concrete mixes with higher paste contents are bound to have higher absorption values than concretes with lower paste content (at consistent w/c). The absorption values of concrete containing the RFA are higher than that of the conventional concrete and it shows an increasing trend towards higher RFA content

5.4.4 Chloride Penetration resistance

This test method consists of monitoring the amount of electrical current passed through 50 thick slice of 100mm nominal diameter. According to ASTM C1202 test, water saturated,

50 mm thick, 100 mm thick diameter concrete specimen is subjected to a 60 v applied DC voltage for 6 hours using the apparatus and the cell arrangement. In one reservoir filled with 3.0% NaCl solution and other reservoir with 0.3 M NaOH solution. The total charge passed in coulomb has been determined and this is used to rate the concrete according to the criteria included as Table-5.6.

Charge Q is calculated as $(Q) = 900(I_0 + 2I_{30} + 2I_{60} + \dots + I_{360})$

Where I_0 is = Current in Amperes at 0 Hrs

I_{30} = Current in Amperes at 30 minutes

This test method covers the laboratory evaluation of electrical conductance of concrete samples to provide a rapid indication of their resistance to chloride ion penetration. Accelerated chloride permeability test was conducted on all the SCC mixes, the results of all these are presented in Table 5.6 & 5.7. The total charge passing in 6 hours as a measure of the chloride permeability has been presented in Fig 5.5.

Table 5.6:- Criteria to rate the concrete as per (EFNARC 2002)

Charge passed (coulombs)	Chloride Ion penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

Table 5.7:- Test Results of Chloride penetration resistance

Sr. No	Time Hr	Current in Amphere				
		SC-C I1	RFA 25 I2	RFA 50 I3	RFA 75 I4	RFA100 I5
1	0	0.0165	0.0198	0.0209	0.027	0.040
2	0.5	0.0165	0.0198	0.0209	0.027	0.040
3	1	0.0225	0.0198	0.0209	0.027	0.040
4	1.5	0.0165	0.0198	0.0209	0.027	0.040
5	2	0.018	0.022	0.023	0.030	0.045
6	2.5	0.018	0.021	0.023	0.029	0.044
7	3	0.018	0.021	0.023	0.029	0.044
8	3.5	0.020	0.024	0.025	0.032	0.048
9	4	0.019	0.022	0.024	0.031	0.046
10	4.5	0.019	0.022	0.024	0.031	0.046
11	5	0.019	0.022	0.024	0.031	0.046

12	5.5	0.021	0.025	0.026	0.034	0.050
13	6	0.020	0.024	0.026	0.033	0.050
Q_s =		421	493	520	676	1007

Table 5.8:-Test Results of Chloride penetration resistance

Mix	28 Days Charge passed in coulombs	Chloride Ion Permeability
SCC-C	421	Very Low
RFA 25	493	Very Low
RFA 50	520	Very Low
RFA 75	676	Very Low
RFA 100	1007	Low

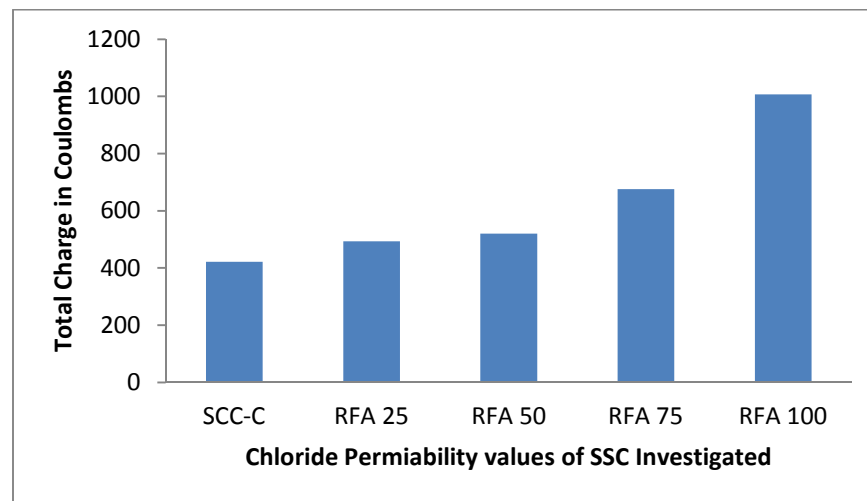


Fig 5.5:- Chloride Permeability values of SSC Investigated

Following observations have been made.

- The chloride ion permeability of SCC mixes with replacement of RFA is marginally higher than SCC conventional.
- The chloride ion penetrability limits suggested by ASTM C1202 were compared with the results. It can be seen that all SCC mixes containing RFA upto 75% showed total charge passing less than 1000 Coulombs hence they were assessed as “very low” chloride permeability concretes.
- But the trend is not the same, SSC made with 100% RFA, it showed more than 1000 coulombs charge passing & was assessed as “low” permeability concrete. The results indicates that replacement upto 75% of RFA improves the chloride permeability as compared to SCC conventional.

- As percentage of RFA replacement is more, permeability of chloride increases but it is within acceptable low limits.
- Hence it can be concluded that RFA replacement will not make much disastrous effect as per the permeability of chloride ions.

This can likely be attributed the filler effect of the fine recycled aggregate as it was comprised of a higher percentage of small particles (<0.30 mm) than the river sand

6.1 Fresh SCC Properties

- The fresh property of concrete indicate fine recycled aggregate can be used for SCC production without any loss of workability parameters.
- All workability parameters were within the acceptable limits.
- The initial slump flows of all the RFA-SCC mixtures prepared were at least 590 mm and the blocking ratios varied from 0.79 to 0.9.
- It can be concluded that SCC modified with RFA will not hamper its basic properties.

6.2 Compressive Strength

- The compressive strength investigation of the SCC mixes prepared with the addition of varying proportion of RFA indicate there is marginal fall in initial strength as well as in final strength.
- The maximum compressive were achieved by using 25–50% fine recycled aggregates as a replacement of river sand.
- Since the strength is only marginally less hence it is recommended to use RFA replacement upto 50%.

6.3 Durability Properties

- The resistance to chloride ion penetration of the RFA-SCC mixtures increases with an increase in the fine recycled aggregate content.
- The durability properties are also affected by the increment of recycled aggregates in concrete. Sorptivity and water absorption are higher in concretes prepared with recycled fine aggregates.
- FRA has a more detrimental effect on resistance to water absorption by capillarity than on water absorption by immersion; the sorptivity coefficient has a relative increase of 65% for concrete made with 100% FRA compared with the reference SSC-C.
- In both cases, it seems that water absorption increases linearly with the replacement ratio; this is to be expected since FRA have a more porous structure, which extends to the concrete matrix.

- The water absorption value is directly proportional to the level of the RFA (Recycled Fine aggregate) replacement.
- The intrinsic permeability of concrete increases with the increasing RFA content. The marginal differences compared to the conventional SSC were large during early age. Nevertheless, with continuous water curing, the intrinsic permeability decreasing in the later age and the marginal differences between the highest replacement level of the RFA and conventional SSC would be reduced significantly.
- The absorption test results clearly confirm that the higher the increase of recycled fine aggregates, the higher its porosity is significant, especially more its large capillaries are of significant diameter.
- As it was determined in this report that self compacting concretes produced with up to 50% substitution by fine recycled aggregates are feasible from a technical, economic and environmental point of view.

6.4 Further Scope of Work

- Detailed investigation on strength as well as durability without compromising of performance needs to be done before suggesting any appropriate replacement of RFA in SCC.

REFERENCES

Aitcin, P.,C., “High performance concrete”, E & FN Spoon London,(1999).”

Anagnostopoulos, N.S., Georgiadis, A.S., And Sideris, K.K., (2007). “Carbonation of self compacting concretes produced with different materials.” In: Proceedings of 5th international RILEM symposium on self-compacting concrete. Ghent; pp. 721–727.

ASTM C39., “Standard test method for compressive strength of cylindrical concrete specimens. Annual Book of ASTM Standards.” (2005)

Audenaert, K., Boel, V., and Schutter, G.D., (2002). “Carbonation of Self Compacting Concrete” ,6th International Symposium on High Strength/High Performance Concrete, Leipzig, pp. 853-862.

Bartos, J. M., (2000), “Measurement of Key Properties of Fresh Self-compacting Concrete”, CEN/PNR Workshop, Paris.

Bartos, J.M., Marrs, D.L., And Cleland, D.J., (1996). “Production methods and workability of concrete.”Vol/pp. 271–284.

Bassuoni, M.,T., and Nehdi, M.,L., (2007). “Resistance of self consolidating concrete to sulphuric acid attack with consecutive pH reduction.” Cement and concrete research, Vol. 37, pp. 1070-1084.

Brouwers, H.J.H., and Radix, H.J., (2005). “Self-compacting concrete: theoretical and experimental study.” Cement and Concrete Research; Vol. 35, pp. 2116–36.

Bui, V.K., Montgomery, D., Hinczak, I., and Turner, K., (2002). "Rapid testing method for segregation resistance of self-compacting concrete", Cement and Concrete Research, Vol. 32, pp. 1489-1496.

Bassuoni and Nehdi (2007) “ Resistance of self-consolidating concrete to sulfuric acid attack with consecutive pH reduction”, *Cement and Concrete Research*, Vol 37 1070–1084.

Dehn, F., Holschemacher, K., And Weisse, D., (2000). “Self-Compacting Concrete - Time Development of the Material Properties and the Bond Behavior”, *LACER* No 5, pp. 115-123.

E Vejmelkova, Keppert.M and Cerny.K, (2011) “Properties of self-compacting concrete mixtures containing metakaolin and blast furnace slag”, *Construction and Building Materials* ,Vol25 1325–1331.

EFNARC, (2002). “Specifications and Guidelines for Self-Compacting Concrete”, EFNARC, UK , (www.efnarc.org), pp. 1-32.

El-Dieb, A., S., (2009). “Mechanical, durability and microstructural characteristics of ultra high strength self compacting concrete incorporating steel fibres.” *Material and design*, Vol. 30, pp. 4286-4292.

Felekoglu, B., (2007). ‘Utilisation of high volume limestone quarry wastes in concrete industry (self compacting concrete case)’, *Resources Conservation & Recycling*, Vol. 51, pp. 770-791.

Felekoglu, B., Turkel, S., And Baradan, B., (2007). “Effect of water/cement ratio on the fresh and hardened properties of self-compacting concrete.” *Building and Environment*, Vol. 42, pp. 1795–1802.

Ferraris, C. F., Brower, L., Daczko, J., And Ozyldirim, C., (1999). “Workability of Self-Compacting Concrete”, *Journal of Research of NIST*, Vol. 104, pp. 461-478.

Ferraris, C. F., (1999), “Measurement of the Rheological Properties of High-Performance Concrete”, *J. Res. Natl. Inst. Techn.*, Vol. 104, pp.461-477.

Grdic, Z. J., Gordana, A., Curcic, T., Iva, M., Despotovic, And Ristic, N. S., (2010). "Properties of self-compacting concrete prepared with coarse recycled concrete aggregate." *Construction and building material*, Vol. 24, pp. 1129-1133.

Guneyisi, E., Gesog̃lu, M., and Ozbay, E., (2010). "Strength and drying shrinkage properties of self-compacting concretes incorporating multi-system blended mineral admixtures." *Construction and building material*, Vol. 24, pp. 1878-1887.

Hassan, A.A., Lachemi, M., and Hossain, M.A., (2012). "Effect of metakaolin and silica fume on the durability of self-consolidating concrete." *Cement and concrete composites*, Vol. 34, pp. 801-807.

Hui Zhao,WeiSun, Xiaoming Wu and Bo Gao (2012)"The effect of coarse aggregate gradation on the properties of self-compacting concrete"

IS: 3812, (2003). "Indian standard on pulverised fuel ash – specification. (Part 2). For use as admixture in cement mortar and concrete." Bureau of Indian Standards, New Delhi (India).

IS 383. (2002). "Specification for coarse and fine aggregates from natural sources for concrete." Bureau of Indian Standards, New Delhi (India).

Kathirvel, P., Kapilarasan, M., Hameed, M.S., And Sekar, A.S.S., (2010). "Effect of Sulphate Attack on Self compacting Concrete." *NBM Constructions Information*, NBM Media Pvt. Ltd.

Khayat, K.,H., and Aitcin, P.,C., (1987). "Silica Fume A unique Supplementary Cementitious Material," *Mineral Admixture in Cement and Concrete*, Vol.4.

Khayat, K.H. And Guizani, Z., (1997). "Use of Viscosity-Modifying Admixture to Enhance Stability of Fluid Concrete", *ACI Materials Journal*, Vol. 94, pp.332-340.

Kosmas K. Sideris & Nikolaos (2013) "Durability of normal strength self-compacting concretes and their impact on service life of reinforced concrete structures "Construction and Building Materials 41 (2013) 491–497.

Khayat, K.H., Assaad, J., And Daczko J., (2004). "Comparison of Field-oriented Test Methods to Assess Dynamic Stability of Self-Consolidated Concrete", ACI Materials Journal, Vol. 101, pp. 168-176.

Khayat, K.H., (1999) "Workability, Testing and Performance of Self Consolidated Concrete", ACI Materials Journal, Vol. 96, pp. 346-352.

Khatib, J.M., (2005). "Properties of concrete incorporating fine recycled aggregate." Cement and Concrete research; Vol. 35, pp. 763–769.

Khaloo, A. R., And Houseinian, M. R., (1999). "Evaluation of properties of silica fume for use in concrete." International Conference on Concretes, Dundee, Scotland.

Kou, S.C., And Poon, C.S., (2009). "Properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates." Cement and concrete composites, Vol 31, pp. 622-627.

Lachemi, M., Hossain, K.M.A., Lambros, V., Nkinamubanzi, P.C., And Bouzoubaa, N., (2004). "Performance of new viscosity modifying admixtures in enhancing the rheological properties of cement paste", Cement and Concrete Research, Vol. 34, pp. 185-193.

Lee, S.T., Moon, H.Y., Hootona, R.D., And Kim, J.P., (2005). "Effect of solution concentrations and replacement levels of metakaolin on the resistance of mortars exposed to magnesium sulfate solutions." Cement and Concrete research; Vol. 35, pp. 1314–1323

Mata, L. A., (2004). "Implementation of Self-Consolidating Concrete (SCC) for Prestressed Concrete Girders, MS Thesis, North Carolina State University."

Mindess, S., Young, J.F., And Darwin, D., (2003). Concrete. 2nd ed. New Jersey: Prentice Hall.

Nanthagopalan, P., And Santhanam, M., (2011). "Fresh and hardened properties of self-compacting concrete produced with manufactured sand." Cement and concrete composites, Elsevier Ltd., Vol. 33, pp. 353-358.

Nehdi, M., Pardhan, M., And Koshowski, S., (2004). "Durability of self-consolidating concrete incorporating high-volume replacement composite cements". Cement and Concrete Research, Vol. 34, pp. 2103-2112.

Okamura, H. and Ouchi, M., (2003). "Self-compacting concrete", Journal of Advanced Concrete Technology, Vol. 1, pp. 5-15.

Okamura, H., (1997). "Self-Compacting High-Performance Concrete", Concrete International, Vol. 19, pp. 50-54.

Ouchi, M., Hibino, M., Sugamata, T., And Okamura, H., (2001). "A quantitative evaluation method for the effect of superplasticizer in self-compacting concrete", Transactions of JCI, pp. 15-20.

Ouchi, M., Hibino, M., And Okamura, H., (1996). "Effect of Superplasticizer on Self-Compactability of Fresh Concrete", TRR 1574, pp.37-40.

Ouchi, M., And Hibino, M., (2000). "Development, Applications and Investigations of Self-compacting Concrete".

Persson, B., (2003). "Sulphate resistance of self compacting concrete." Cement and concrete research, Vol. 33, pp. 1933-1938.

P. Dinakar, K.G. Babu and Manu Santhanam (2008) "Durability properties of high volume fly ash self compacting concretes "Cement & Concrete Composites 30 (2008) 880-886

Pathak.N &Siddique.R (2012), "Properties of self-compacting-concrete containing fly ash subjected to elevated temperatures "Construction and Building Materials 30 (2012) 274-280

Ramachandran, V.,S., (1984). "Concrete Admixtures Handbook, Properties, Science, and Technology." Noyes Publications.

RILEM Committee CPC-18, (1988). "Measurement of hardened concrete carbonation depth." *Material and Structures*, pp. 18:453–455.

Sahmaran,M., Yaman,O.I., And Tokyoy,M., (2009). "Transport and mechanical properties of self consolidating concrete with high volume fly ash." *Cement & Concrete Composites*; Vol. 31, pp. 99–106.

Stephan Assie, Gilles Escadeillas &Vincent Wal (2007), "Estimates of self-compacting concrete 'potential' durability" *Construction and Building Materials*,Vol 21 (2007) 1909–1917

Siddique, R. (2011). "Properties of self-compacting concrete containing class F fly ash". *Materials and Design*, Vol. 32, pp. 1501-1507.

Taylor H. F.W., (1997). "Cement chemistry". 2nd ed. London: Thomas.

Uysal, M.,And Sumer.M, (2011) "Performance of self-compacting concrete containing different mineral admixtures." *Construction and building material*, Vol. 25, pp. 4112-4120.

Zhimin W., Yunguo Z., Jianjun Z., And Yining D., (2009). "An experimental study on the workability of self-compacting lightweight concrete." *Construction and building material*, Vol. 23, pp. 2087-2092.

Zhu, W., Gibbs, C. J., And Bartos, P. J. M., (2001). "Uniformity of in situ properties of self compacting concrete in full-scale structural elements", *Cement & Concrete Composites*, Vol. 23, pp. 57-64.

Zongin, Li., Bin, Mu., and Stanley, N.,C., (1999). "Systematic study of properties of extrudates with incorporated metakaolin or silica fume." *ACI Mater Journal*, Vol. 96(5), pp. 574