A

PROJECT REPORT

ON EFFECT OF SIZE OF AGGREGATE ON SELF COMPACTING CONCRETE OF M70 GRADE.

SUBMITTED BY

P.RAGHUVER 08241A0131

S.CHANDRASHEKAR REDDY 08241A0111

K.NAGARAJU 08241A0122

DEPARTMENT OF CIVIL ENGINEERING

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY BACHUPALLY, HYDERBAD-72.

DECLARATION BY THE CANDIDATES

We, **Parupalli Raghuver, K.Nagaraju, S.Chandrashekar Reddy** hereby declare that the project report entitled "**STUDY OF EFFECT OF SIZE OF AGGREGATE ON SELF COMPACTING CONCRETE OF M70 GRADE**", Under the guidance of **V.Mallikarjuna Reddy** (M.Tech), Associate Professor, Civil Engineering Department is submitted in the fulfillment of the requirements for the **MAIN-PROJECT**. This is a bonafide work carried out by us and the results embodied in this project report have not been reproduced/copied from any source. The results embodied in this project report have not been submitted to any other university or institution for the award of any other degree or diploma.

Date:

Place:

Civil Engineering Department

GRIET, Hyderabad.

Contact No:

Contact Address:

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CONTENTS

List of Tables

<u>List of Figures</u>

Abstract

Concrete is a versatile widely used construction material. Ever since concrete has been accepted as a material for construction, researchers have been trying to improve its quality and enhance its performance. Recent changes in construction industry demand improved durability of structures. There is a methodological shift in the concrete design from a strength based concept to a performance based design. At present there is a large emphasis on performance aspect of concrete. One such thought has lead to the development of Self Compacting Concrete (SCC). It is considered as "the most revolutionary development in concrete construction". SCC is a new kind of High Performance Concrete (HPC) with excellent deformability and segregation resistance. It can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process.

The guiding principle behind self-compaction is that “the sedimentation velocity of a particle is inversely proportional to the viscosity of the floating medium in which the particle exists”. The other features of mix proportion of SCC include low water to cementitious material ratio, high volume of powder, high paste to aggregate ratio and less amount of coarse aggregate. One of the popularly employed techniques to produce Self Compacting Concrete is to use fine materials like Fly Ash, GGBFS etc; in concrete, besides cement, the idea being to increase powder content or fines in concrete.

The original contribution in the field of SCC is attributed to the pioneering work of Nan Su et al; who have developed a simple mix design methodology for Self Compacting Concrete. In this method, the amount of aggregate required is determined first, based on Packing Factor (PF). This will ensure that the concrete obtained has good flowability, self compacting ability and other desired SCC properties. The European Federation of Producers and Applicators of Specialist Products for Structures (EFNARC) [2005] have also laid down certain guidelines for fresh properties of SCC.

The present investigation is aimed at developing high strength Self Compacting Concrete of M70 Grade. The parameters of study include grade of concrete and effect of size of aggregate. The existing Nan Su [2001] method of mix design was based on packing factor for a particular grade of concrete, obtained on the basis of experimental investigation. SCC characteristics such as flowability, passing ability and segregation resistance have been verified using slump flow, L box and V funnel tests.

Chapter – 1

INTRODUCTION

1.0 General

The versatility and the application of concrete in the construction industry need not be emphasized. Research on normal and high strength concrete has been on the agenda for more than two decades. As per IS: 456–

2000[Code of Practice for Plain and Reinforced Concrete], concretes ranging 25 – 55 MPa are called standard concretes while those above 55 MPa can be termed as high strength concrete. Concretes above 120/150 MPa are called ultra high strength concrete. High strength concrete has numerous applications world wide in tall buildings, bridges with long span and buildings in aggressive environments. Building elements made of high strength concrete are usually densely reinforced. This congestion of reinforcement leads to serious problems while concreting. Densely reinforced concrete problems can be solved by using concrete that can be easily placed and spread in between the congested reinforced concrete elements. A highly homogeneous, well spread and dense concrete can be ensured using such a type of concrete.

Self-compacting concrete (SCC) is a concrete, which flows and compacts only under gravity. It fills the mould completely without any defects. Usually self-compacting concretes have compressive strengths in the range of 60-100 N/mm^2. However, lower grades can also be obtained and used depending on the requirement. SCC was originally developed at the University of Tokyo in Japan with the help of leading concrete contractors during 1980's to be mainly used for highly congested reinforced structures in seismic regions. As durability of concrete structures was an important issue in Japan, an adequate compaction by skilled labors was required to obtain durable concrete structures. This requirement led to the development of SCC. The development of SCC was first reported in 1989.

SCC is a new kind of High Performance Concrete (HPC) which has an excellent deformability and segregation resistance. By name it can be defined as a concrete, which can flow through and fill the gaps of reinforcement and corners of the moulds without any need for external vibration. SCC compacts itself due to its self weight and de-aerates almost completely while flowing in the formwork. 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. Since its inception, it has been widely used in large construction works or projects in Japan. Recently, this concrete has gained wide use for different applications and structural configurations across the world.

High strength concrete can be produced with normal concrete. But these concretes cannot flow freely by themselves, to pack every corner of moulds and all gaps of reinforcement. High strength concrete based elements require thorough compaction and vibration in the construction process. SCC has more favourable characteristics such as high fluidity, good segregation resistance and distinctive self-compacting ability with out any need for external or internal vibration during the placing process. It can be compacted into every corner of formwork purely by means of its own weight without any segregation. Hence, it reduces the risk of honey combing of concrete.

Development of SCC is a very desirable achievement in the construction industry for overcoming the problems associated with cast-in place concrete. It is not affected by the skill of workers, shape and amount of reinforcing bar arrangement of a structure. Due to its high fluidity and resisting power to segregation, it can be pumped over longer distances. It extends the possibility of use of various by products in its manufacturing. The use of SCC not only shortens the construction period but also ensures quality and durability of concrete. It replaces manual compaction of fresh concrete with a modern semi-automatic placing technology. Some of the advantages of Self Compacting Concrete are as follows:

1. Less noise from vibrators and reduced danger from Hand Arm Vibration Syndrome (HAVS).
2. Safe working environment.
3. Speed of placement, resulting in increased production efficiency.
4. Ease of placement, requiring fewer workers for a particular pour.
5. Better assurances of adequate uniform consolidation.
6. Reduced wear and tear on forms from vibrator.
7. Reduced wear on mixers due to reduced shearing action.
8. Improved surface quality and fewer bug holes, requiring fewer patching.
9. Improved durability.
10. Increased bond strength.
11. Reduced energy consumption from vibration equipment.
12. Best suited where reinforcement congestion is a problem.

The functional requirements of a fresh SCC are different from those of a vibrated fresh Normal Concrete (NC). Filling of formwork with a liquid suspension requires workability performance like filling ability, passing ability and resistance against segregation.

Filling ability of concrete is the ability of concrete to flow freely under its own weight, both horizontally and vertically upwards if necessary, and to completely fill the formwork of any dimension and shape without leaving voids.

Passing ability is the ability of concrete to pass through obstacles such as narrow sections of the form work, closely spaced reinforcement etc. without blocking caused by interlocking of aggregate particles.

Resistance to segregation is maintaining homogeneity throughout mixing, transportation and casting. The dynamic stability refers to the resistance to segregation during placement. The static stability refers to the resistance to bleeding, segregation and surface settlement after casting.

1.1Mechanism for Achieving Self-Compactability

Simply increasing the water content in a mix to achieve a flowable concrete like SCC is obviously not a viable option. Instead, the challenge is to increase the flowability of the particle suspension and at the same time avoid segregation of the phases. The main mechanism controlling the balance between higher flowability and stability are related to surface chemistry. The development of SCC has thus been strongly dependent on surface active admixtures as well as on the increased specific surface area obtained through the used fillers.

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. Hajime Okamura et al.,[2003] and Ozawa K et al., [1989] have employed the following methods to achieve self-compactability.

(a) Limited aggregate content

(b) Low water-powder ratio

(c) Use of Super Plasticizer (SP)

The frequency of collision and contact between aggregate particles increases as the relative distance between the particles decreases and the internal stress increases when concrete is deformed, particularly near obstacles. It has been revealed that the energy required for flowing is consumed by the increased internal stresses, resulting in blockage of aggregate particles. Limiting the coarse aggregate content, whose energy consumption is particularly intense, to a level lower than normal proportions is effective in avoiding this kind of blockage.

Highly viscous paste is also required to avoid the blockage of coarse aggregate when concrete flows through obstacles. When concrete is deformed, the paste with high viscosity also prevents localized increase in the internal stress, due to the approach of coarse aggregate particles. High deformability can be achieved only by the employment of a superplasticizer, keeping the water-powder ratio at a very lower level.

1.2 Constituents of SCC

1.2.1 Coarse aggregate:

The coarse aggregate chosen for Self Compacting Concrete should be well graded and smaller in terms of the maximum size than that used for conventionally vibrated concrete (NC). For typical conventional concrete (NC) the coarse aggregate size may be 20 mm and even more in general. The rounded aggregates and smaller size of aggregate particles improves the Flowability, deformability and segregate resistance of SCC. The gradation is an important factor in choosing a coarse aggregate, where, highly congested reinforcement patterns are used and where, very small dimensional elements are to be produced. In case of conventional concrete (NC), the size of the coarse aggregate depends upon the type of the construction. Like in case of conventional concrete (NC), size of aggregate has a key note to play in SCC designs also. Hence, studies are needed to assess the maximum size of aggregate for a particular grade of concrete. Usually, the maximum size of the coarse aggregate used in production of SCC, ranges approximately between10mm and 20mm.

1.2.2 Fine Aggregate:

All normal river sands are suitable for SCC. Both crushed and rounded sands can be used. Siliceous and calcareous sands can be used for production of SCC. The amount of fines less than 0.125mm is to be considered as powder which is very important for the rheology of SCC . A minimum amount of fines must be maintained to avoid segregation. The amount of fines has a very significant effect on SCC mix proportions. Fine sand requires more water and Super Plasticizer (SP), but less filler than coarse sand. The SP dosage, water content and cement/filler content could be adjusted by treating the fines (>150 um) in sand as part of the filler.

1.2.3 Cement:

All types of cements conforming to Bureau of Indian standards are suitable as per Indian conditions. Selection of the type of the cement is made depending on the over all requirements of SCC such as strength, durability etc. The cement content can be 350 – 450 kg/m^3. The usage of cement more than 500 kg/m^3 may increase the shrinkage in the hardened state of concrete, where as, the quantity less than 350 kg/m^3 may decrease the durability of SCC. Hence, cement content shall be judged properly. Less than 350 kg/m^3 may also be used with the inclusion of other fine fillers such as fly ash, Ground Granulated Blast furnace Slag (GGBS) and rice husk ash.

1.2.4 Water:

Potable water shall be used for the production of SCC. In case of conventional concretes (NC), the water is proportionate only with the cement content. It is called as the water-cement ratio. This influences the mix and thereby workability. But, in the case of SCC, instead of water-cement ratio the term water binder-ratio will be used. This means the content of water mixed in the SCC is proportionate to the total binders such as cement, fly ash etc.

1.2.5 Mineral admixtures:

Mineral admixtures are added to concrete as a part of the cementitious material. They may be used as an addition to or as a part replacement of Portland cement in concrete. This depends on the properties of materials and the desired effect of concrete. Optimum amount of mineral admixtures are used to improve specific concrete properties such as workability and strength.

Self Compacting Concrete is now considered as a high performance concrete, due to its quality, homogeneity in fresh state, improved durability, faster construction and achieving higher strength. To get better strength properties and good performance of SCC, it requires high quality of cementitious material, mineral admixtures like fly ash, silica fume, GGBFS, limestone powder. To keep the cement quantity at reasonable level, pozzolanic additives are often used. Pozzolonas are also used to produce high performance concrete in terms of strength, workability and durability. This can also be cost effective.

The general advantages of mineral admixture additives are:

1. It increases the hydration process and reduces the porosity of concrete.
2. It fills and closes the pores or adjusts the type of pore structure.
3. It increases hydration products in addition to the filling effect of micro aggregate
4. It adjusts the grading of the components to achieve an optimum compact.
5. It can adjust the cohesiveness and reduce the heat of hydration and reaction rate.
6. It can improve the workability.

7. It can improve the durability and resistance to chemical attack and thus reduce micro cracks in the transition zones.

In this study, only fly ash is used as the mineral admixture and an attempt is made to maximize the fly ash content in Self Compacting Concrete.

a. Fly Ash:

Fly ash or pulverized fuel-ash is a residue from the combustion of pulverized coal collected by mechanical separators, from the fuel gases of thermal plants. The composition of fly ash varies with type of fuel burnt, load on the boiler and type of separation. Fly ash material solidifies while suspended in the exhaust gasses and is collected by electrostatic precipitators or filter bags. Fly Ash consists mostly of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), and is hence a suitable source of aluminum and silicon for geopolymers. They are also pozzolanic in nature and react with calcium hydroxide and alkali to form Calcium Silicate Hydrates (C – S – H).

The average particle size of fly ash is about 20 microns, which is similar to the average particle size of Portland cement. Particles below 10 microns provide the early strength in concrete, while particles between 10 and 45 microns react more slowly. **Fig.1.1** shows the SEM micrograph of fly ash particles. The specific gravity of fly ash particles ranges between 2.0 to 2.4 depending on the source of coal. The fineness of fly ash is in the range of 250 - 600 m^2/kg.

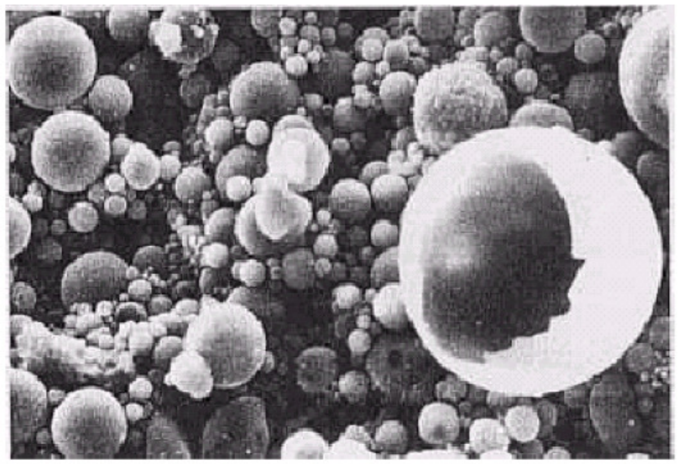

Fig 1.1 SEM Micrograph of fly ash particles

1.2.6 Chemical admixtures:

Chemical admixtures are used in Self Compacting Concrete as ingredients which can be added to the concrete mixture immediately before or during mixing. The use of chemical admixtures such as water reducers, retarders, high-range water reducers or Super Plasticizers (SP), and Viscosity Modifying Admixtures (VMA) is necessary in order to improve the fundamental characteristics of fresh and hardened concrete. They help in the efficient use of large amount of cementitious material in high strength and self-compacting concretes so as to obtain the lowest water to cementing materials ratio.

a. Super Plasticizer:

Generally, in order to increase the workability, the water content is to be increased provided a corresponding quantity of cement is also added to keep the water cement ratio constant, so that the strength remains the same. Portland cement, being in fine state, has a tendency to flocculate in wet concrete. This flocculation entraps certain amount of water used in the mix and there by all the water is not freely available to increase the fluidity of mix. On the other hand, to avoid the use of excess quantity of water and cement, SP is used to increase the fluidity of the mix and improve the workability of concrete. When plasticizers are used, they get absorbed on cement particles. The absorption of charged polymer on cement particle creates particle to particle repulsive forces, which over come the attractive forces. This repulsive force is called zeta potential which depends on the base, solid contents and quality of super plasticizer used. Then, the cement particles are deflocculated and the water trapped inside the flocks gets released and the water is available to fluidify the mix. The job of super plasticizer is to impart a high degree of flowability and deformability which are essential for the development of SCC.

However, the higher dosages of SP can lead to a high degree of segregation. Superplasticizer is a chemical compound used to increase the workability without adding more water. It has the property of spreading the given water in the concrete through out the concrete mix resulting in a uniform mix. Thus, superplasticizer is essential for the creation of SCC.

b. Viscosity Modifying Agent:

The use of Viscosity Modifying Agent (VMA) gives higher possibilities of controlling segregation in SCC when the amount of powder is limited. This admixture helps to maintain very good homogeneity and also reduces the tendency to segregate. The VMA is incorporated to enhance the yield value and viscosity of fluid mixture.

1.3 World-wide utility of Self Compacting Concrete:

Self compacting concrete has already been used in several countries. In Japan, SCC is used in major construction projects in the late '90s. Today, SCC is treated as a special concrete and efforts are made to integrate in the day-to-day concrete industry production. Currently, the percentage of self-compacting concrete in the annual production of Ready-Mixed Concrete (RMC), as well as Precast Concrete (PC), in Japan i s around 1.2% and 0.5% of concrete products.

In United States, the precast industry is also implementing SCC technology through the Precast/Prestressed Concrete Institute (PCI) which has done some research on the use of SCC in precast/prestressed concretes. There is a wide application of SCC in Precast/Prestressed industries in United States. There is an estimated 8000 m^3 of SCC used just in the first quarter of 2003, almost 1% of the annual ready-mix concrete. Several state departments of transportation in the United States are involved in the study of SCC. Due to a high level of interest from the construction industry, as well as manufacturers of this new concrete, use of SCC is growing at a tremendous rate in the United States and across the world. Even though material constituents of SCC are same as that of conventional concrete [NC] including the whole process, from mix design to placing practices, including quality control procedures, there is a need to review and adapt this new technology to be applied properly.

Self compacting concrete is being studied worldwide, with papers presented at almost every concrete related conference, but until 2003, there was no universally adopted standardized test methods for evaluation of Self-Compatability of concrete. Currently, the use of self-compacting concrete is being rapidly adopted in many countries. The use of self-compacting concrete should overcome concrete placement problems associated with the concrete construction industry.

1.4 Development of Self-Compacting Concrete in India

The development of Self Compacting Concrete (SCC) is considered as the most sought development in construction industry due to its numerous inherited benefits. In India, this technology is yet to realize its full potential. Central Road Research Institute (CRRI) [2005] New Delhi, has been working on SCC technology since the year 2000 and carried out significant research work on various aspects of SCC starting from selection of suitable ingredients including superplasticizer, viscosity modifying agent, mineral admixtures, mix proportion optimization, evaluation of the characteristic properties at fresh stage and hardened properties such as compressive strength, splitting tensile strength, flexural strength, Young's modulus of elasticity. Further, in-situ performance evaluation of the structural element cast by using SCC in comparison with conventional plasticized concrete of similar strength i.e. 50 MPa at 28 days were carried out by using semi-destructive and non-destructive test methods. Structural behavior of SCC in heavily reinforced T beams was conducted to study cracking pattern, deflection and ultimate load bearing capacity. On the basis of manufacturing cost, SCC is about 20% costlier than the conventional concrete of similar compressive strength which is compensated by several benefits of using it such as saving in electricity, saving in labor cost related to compaction work, increase in productivity etc. SCC technology is considered as an energy conservation technique in construction industry as it eliminates electricity requirement for compaction of concrete and provides ample opportunity to use by product materials such as fly ash, quarry dust etc. With a wide knowledge and experience in this technology, CRRI can provide technical advice/ suggestion related to the manufacturing of SCC.

Self Compacting Concrete (SCC) technology is a boon when Nuclear Power Corporation of India Limited (NPCIL) is planning for vast expansion of power generation within a short period of time. This concept can save time, cost, enhance quality, durability and moreover it is a green concept. In order to speed up the construction activities, to reduce the cycle time and to enhance quality, the innovative concept of self compacting concrete (SCC) is being considered in large scale for the construction work of Kaiga Power project (India) [Bapat S G et al,2004]. When Department of Atomic Energy (DAE) is celebrating its 50th year of glorious existence, the use of SCC in its building is a step forward towards green technology.

1.5 Mechanical properties of SCC

1.5.1 Fresh and hardened properties of SCC

Fresh SCC mixes must meet three key properties:

1. Ability to flow into and completely fill intricate and complex forms under its own weight
2. Ability to pass through and bond to congested reinforcement under its own weight.
3. High resistance to aggregate segregation.

Due to the high cement, SCC may show more plastic shrinkage or creep than ordinary Concrete mixes. These aspects should therefore be considered during designing and specification of SCC. Current knowledge of these aspects is limited and is an area requiring further research.

The workability of SCC can be characterized by the properties like filling ability, passing ability and segregation resistance. Tests on fresh concrete are Slump flow & T_{50} test, V- Funnel test & V-Funnel at T_5 minutes, L - Box test, U - Box apparatus test, J-Ring test and Orimet Test.

The hardened properties of SCC like compressive strength, split tensile strength and flexural strength are determined after proper curing of concrete specimens.

Chapter – 2

Objectives and scope of the work

Despite its advantages and versatile nature, SCC has not gained much popularity in India, though it has been widely promoted in the Middle East for the last two decades. Awareness of SCC has spread across the world, prompted by concerns with poor consolidation and durability in case of conventionally vibrated normal concrete.

All the researchers have developed SCC taking the CA/FA ratio and also considered the limited content of coarse aggregate and more content of fines. But, there are very limited investigations reported considering the size effect of coarse aggregate content in the development of SCC. Keeping this in view, the present experimental investigation is taken up to study the effect of size of coarse aggregate in the development of M70 grade of Self Compacting Concrete. Powder content is the main aspect of a SCC mix design. In the present work, flyash is maximized in the SCC mixes as a filler material.

Keeping in view the idea explained above, a detailed and a systematic experimental program is laid down as explained in the next paragraphs. The main objective of the present investigation is:

To study of effect of the size of aggregate on the strength and flow of M70 grade of Self compacting concrete by using Nansu mix design procedure.

Fig.2.1 shows a schematic diagram of the flow of the work with the objectives laid as explained above.

With the above objectives in mind the experimental program is categorized as detailed below.

Casting of 27 standard cubes, 27 standard cylinders and 27 standard prisms, covering M70 grade of concrete, three aggregate sizes, three periods of curing and three specimens of each type.

In this study, high strength (M70) of SCC with three different maximum size of aggregate (20, 12.5, 10 mm) were designed based on Nan Su method, to determine the effective maximum size of aggregate. The grade of concrete and age of curing were the parameters in the study.

A detailed experimental program was planned to achieve the objective of the study is explained in Chapter – 3.

Effective Size of Aggregate

↓

Collection of materials, tests on materials

↓

↓

Arriving at effective size of aggregate for different grades of SCC using 10, 12.5, 20mm

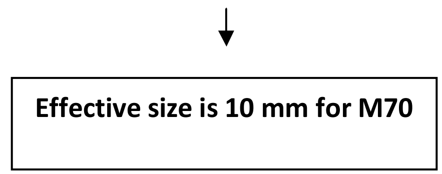

Fig.2.1 Schematic representation of the flow of work

Chapter – 3

Experimental Program

3.0 General

Wide spread applications of SCC have been restricted due to lack of standard mix design procedure and testing methods. It is pertinent to mention that only features of SCC have been included in Indian Standard Code of practice for plain and reinforced concrete (fourth revision), [2000]. Slump flow test, L-box test, V-funnel test, U-box test, Orimet test & GTM Screen test are recommended by EFNARC [European Federation of Producers and Applicators of Specialist Products for Structures, May 2005] for determining the properties of SCC in fresh state.

The experimental program consisted of casting and testing specimens for arriving at the maximum size of aggregate. M70 grade of concrete is considered in this study. In the first stage the effective maximum size of aggregate for M70 grade of concrete was arrived. Nan Su method of mix design [2001] was adopted to arrive at the suitable mix proportions. The mix proportion for M70 grade was arrived, taking the different sizes of aggregate into consideration. The effective size of aggregate was arrived for M70 grade of concrete, based on the mechanical properties and fresh properties of SCC. A total of 27 cubes of standard size 150 mm x 150 mm x 150 mm, 27 prisms of standard size 100 mm x 100 mm x 500 mm and 27 cylinders of 150 mm diameter and 300 mm height were cast for determining the compressive strength, flexural strength and split tensile strength respectively. The parameters of the study thus included size of aggregate and age of curing for satisfying the fresh properties of SCC as per EFNARC specifications [2005] based on a number of trials.

The present investigation is mainly directed towards developing a mix with good SCC, with different sizes of coarse aggregate and for M70 grade of concrete.

The details of fresh properties and hardened properties of SCC with different sizes of coarse aggregate and different are discussed in detail in Chapter – 4. The details of the materials, mix proportioning, specimen preparation and test methodology are briefly presented in this chapter.

3.1 Materials

The materials used in the experimental investigation are locally available cement, sand, coarse aggregate, mineral and chemical admixtures. The chemicals used in the present investigation are of commercial grade.

3.1.1 Cement

Ordinary Portland cement of 53 grade [IS: 12269-1987, Specifications for 53 Grade Ordinary Portland cement] has been used in the study. It was procured from a single source and stored as per IS: 4032 – 1977. Care has been taken to ensure that the cement of same company and same grade is used throughout the investigation. The cement thus procured was tested for physical properties in accordance with the IS: 12269 – 1987.

Table 3.1 shows the physical characteristics of cement used, tested in accordance with IS: 4031-1988 [Methods of physical tests for hydraulic cement].

Table: 3.1 Physical properties of Ordinary Portland Cement

S. No	Property	Test Method	Test Results	IS Standard
1.	Normal Consistency	Vicat Apparatus (IS: 4031 Part - 4)	30%	
2.	Specific gravity	Sp. Gr bottle (IS: 4031 Part - 4)	3.09	
3.	Initial setting time Final setting time	Vicat Apparatus (IS: 4031 Part - 4)	96 minutes 207 Minutes	Not less than 30 minutes Not less than 10 hours
4.	Fineness	Sieve test on sieve	1.3%	10%

		no.9 (IS: 4031 Part – 1)		
5.	Soundness	Le-Chatlier method (IS: 4031 Part – 3)	2 mm	Not more than 10 mm

3.1.2 Fine Aggregates

The fine aggregate used was locally available river sand without any organic impurities and conforming to IS: 383 – 1970 [Methods of physical tests for hydraulic cement]. The fine aggregate was tested for its physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS: 2386 – 1963 [Methods of test for aggregate for concrete] and is shown in **Table 3.2**. The sand was surface dried before use.

3.1.3 Coarse Aggregate

The coarse aggregate chosen for SCC was typically round in shape, well graded and smaller in maximum size than that used for conventional concrete. The size of coarse aggregate used in self compacting concrete was between

10mm to 16mm. The rounded and smaller aggregate particles provide better flowability and deformability of concrete and also prevent segregation. Graded aggregate is also important particularly to cast concrete in highly congested reinforcement or formwork having small dimensions. Crushed granite metal of sizes 16 mm to 10 mm graded obtained from the locally available quarries was used in the present investigation. These were tested as per IS 383-1970 [Methods of physical tests for hydraulic cement]. The physical properties like specific gravity, bulk density, flakiness index, and elongation index and fineness modulus are shown in **Table 3.2.**

Table: 3.2 Physical properties of Coarse and Fine aggregate

S. No	Property	Method	Fine Aggregate	Coarse Aggregate
1.	Specific gravity	Pycnometer IS:2386 Part 3-1986	2.41	2.63
2.	Bulk Density Loose Compacted	IS:2386 Part 3-1986	1548 kg/m^3 1680 kg/m^3	1451kg/m^3 1602kg/m^3
3.	Bulking	IS:2386 Part 3-1986	6% w c	--
4.	Flakiness Index	(IS:2386 Part 2-1963)	--	8.08%
5.	Elongation Index	(IS:2386 Part 2-1963)	--	0%
6.	Fineness Modulus	Sieve Analysis (IS:2386 Part 2-1963)	3.62	6.04

3.1.4 Water

Water used for mixing and curing was potable water, which was free from any amounts of oils, acids, alkalis, sugar, salts and organic materials or other substances that may be deleterious to concrete or steel confirming to IS : 3025 – 1964 part22, part 23 and IS : 456 – 2000 [Code of practice for plain and reinforced concrete]. The pH value should not be less than 6. The solids present were within the permissible limits as per clause 5.4 of IS: 456 – 2000.

3.1.5 Fly Ash

Fly ash is one of the most extensively used supplementary cementitious materials in the construction field resembling Portland cement. It is an inorganic, noncombustible, finely divided residue collected or precipitated from the exhaust gases of any industrial furnace. Most of the fly ash particles are solid spheres and some particles, called cenospheres, are hollow and some are the plerospheres, which are spheres containing smaller spheres inside. The particle sizes in fly ash vary from less than 1 µm to more than 100 µm with the typical particle size measuring less than 20 µm. Their surface area is typically 300 to 500 m^2/kg, although some fly ashes can have surface areas as low as 200 m^2/kg and as high as 700 m^2/kg. Flyash is primarily silicate glass containing silica, alumina, iron, and calcium. The relative density or specific gravity of flyash generally ranges between 1.9 and 2.8 and the color is generally grey.

Flyash used in this investigation was procured from Kakatiya Thermal Power Project, Andhra Pradesh, India. It confirms with grade I of IS: 3812 – 1981 [Specifications for flyash for use as pozzolana and admixture]. It was tested in accordance with IS: 1727 –1967 [Methods of test for pozzolana materials]. A typical oxide composition of Indian fly ash is shown in **Table 3.3**. The chemical composition and physical characteristics of flyash used in the present investigation were given in **Tables 3.4** and **Table 3.5**.

Table: 3.3 Typical Oxide Composition of Indian fly ash.

S No	Characteristics	Percentage
1.	Silica, SiO_2	49-67
2.	Alumina Al_2O_3	16-28
3.	Iron oxide Fe_2O_3	4-10
4.	Lime Ca O	0.7-3.6
5.	Magnesia Mg O	0.3-2.6
6.	Sulphar Trioxide SO_3	0.1-2.1

7.	Loss on Ignition	0.4-1.9
8.	Surface area m^2/kg	230-600

Table: 3.4 Chemical requirements of fly ash

S No.	Characteristics	Requirements (% by weight)	Fly Ash used (% by weight)
1.	Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3)	70 (minimum)	94.46
2.	Silicon dioxide (SiO_2)	35 (minimum)	62.94
3.	Magnesium Oxide (MgO)	5 (max.)	0.60
4.	Total sulphur as sulphur trioxide (SO_3)	2.75 (max.)	0.23
5.	Available alkalies as sodium oxide (Na_2O)	1.5 (max.)	0.05
6.	Loss on ignition	12 (max.)	0.30
7.	Chlorides		0.009

Table: 3.5 Physical requirements of fly ash

S No	Characteristics	Requirements for grade of flyash (IS:3812-1981)		Experimental Results
		Grade – I	**Grade – II**	
1.	Fineness by Blain's apparatus in m^2/kg	320	250	335
2.	Lime reactivity (MPa)	4.0	3.0	9.8
3.	Compressive strength at 28 days as percentage of strength of corresponding plain cement mortar cubes	Not less than 80%		86%
4.	Soundness by Autoclave expansion			Nil

3.1.6 Super Plasticizer

High range water reducing admixture called as super plasticizers are used for improving the flow or workability for lower water-cement ratios without sacrifice in the compressive strength. These admixtures when they disperse in cement agglomerates significantly decrease the viscosity of the paste by forming a thin film around the cement particles. In the present work, water-reducing admixture Glenium conforming to IS 9103: 1999 [Specification for admixtures for concrete], ASTM C – 494 [Standard Specification for Chemical Admixtures for Concrete] types F, G and BS 5075 part.3 [British Standards Institution] was used. The details of the super plasticizer used are given in **Table 3.6**.

Table: 3.6 Details of Super Plasticizer

S. No.	Property	Result
1.	Form or state	Liquid (sulphonated naphthalene based formaldehyde)
2.	Colour	Brown
3.	Specific gravity	1.220 to 1.225 at 30°C
4.	Chloride content	Nil to IS:456
5.	Air entrainment	Approx. 1% additional air is entrained
6.	Compatibility	Can be used with all types of cements except high alumina cement. Conplast SP430 is compatible with other types of Fosroc admixtures when added seperately to the mix.
7.	Workability	Can be used to produce flowing concrete that requires no compaction.
8.	Cohesion	Cohesion is improved due to dispersion of cement particles thus minimising segregation and improving surface finish.
9.	Compressive strength	Early strength is increased upto 20%. Generally, there is improvement in strength upto 20% depending upon W/C ratio and other mix parameters.
10.	Durability	Reduction in w/c ratio enables increase in density and impermeability thus enhancing durability of concrete
11.	Dosage	The rate of addition is generally in the range of 0.5 - 2.0 litres / 100 kg cement.

3.1.7 Viscosity Modifying Agent

These admixtures enhance the viscosity of water and eliminate the bleeding and segregation phenomena in the fresh concrete as much as possible. VMA is a neutral, biodegradable, liquid chemical additive designed to reduce the bleeding, segregation, shrinkage and cracking that occur in high water/cement ratio concrete mixes. VMA also contribute to stabilization for SCC mixes that are susceptible to segregation at high slump ranges. The VMA used in this investigation was Glenium stream-2 which is a product of BASF construction chemicals. The properties of VMA are given in **Table 3.7**.

Table: 3.7 Details of Viscosity Modifying Agent

S. No.	Property	Result
1.	Aspect	Colourless free flowing liquid
2.	Relative density	1.01
3.	pH	≥6
4.	Chloride ion content	< 0.2%
5.	Compatibility	Can be used with all types of cements
6.	Incompatible	use with naphthalene sulphonate based superplasticiser admixtures.
7.	Mechanism of action	It consists of a mixture of water soluble copolymers which is adsorbed onto the surface of the cement granules, thereby changing the viscosity of the water and influencing the rheological properties of the mix.

8.	Dosage	50 to 500 ml/100 kg of cementitious material.

3.2 MIX PROPORTIONING

The mix proportioning was done based on the Nan Su approach [2001]. The mix proportion is given in **Table 3.8**, for different aggregate sizes.

Table: 3.8 Mix Proportion and Quantities of M70 grade of SCC

Size of Graded Aggregate (mm)	Mix Proportion	w/b	Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	S.P	VMA
20	1: 1.42: 4.49: 3.76: 0.043	0.455	210	300	944	791	9.12	1.75
12.5	1:0.425:1.250:1.181 :0.024	0.257	680	289.28	850.30	803.17	16.82	1.75
10	1:0.450:1.250:1.170: 0.023	0.269	680	305.50	850.30	795.65	15.85	1.75

3.3 BATCHING AND MIXING OF SCC

The proportioning of the quantity of cement, cementitious material like Flyash, fine aggregate and coarse aggregate has been done by weight as per the mix design. Water, super plasticizer and VMA were measured by volume. All the measuring equipments are maintained in a clean serviceable condition with their accuracy periodically checked.

The mixing process is carried out in electrically operated concrete mixer. The materials are laid in uniform layers, one on the other in the order - coarse aggregate, fine aggregate and cementitious material. Dry mixing is done to obtain a uniform color. The fly ash is thoroughly blended with cement before mixing. Self Compacting characteristics of fresh concrete are carried out immediately after mixing of concrete using EFNARC specifications [2005].

The workability properties of Normal Concrete (NC) Viz., slump was maintained in the range of 75 – 100 mm and compaction factor was 0.9. In higher strength concretes, these are maintained by adjusting the mineral and chemical admixtures.

3.4 FRESH PROPERTIES OF SCC

3.4.1 Requirements of Self Compacting Concrete

SCC mixes must meet three key properties:

1. Ability to flow into and completely fill intricate and complex forms under its own weight
2. Ability to pass through the congested reinforcement under its own weight.
3. High resistance to aggregate segregation.

Due to the high powder content, SCC shows more plastic shrinkage or creep than ordinary concrete mixes. These aspects should therefore be considered during designing and specifying the SCC.

By definition of SCC, it is clear that the fresh concrete has to fulfill various properties. The SCC must be adequately free flowing so that the coarse aggregate particles can float in mortar but the air can still rise and escape adequately. Sedimentation of the coarse aggregate particles and upward movement of fine mortar, paste or water before the concrete sets must be avoided. Otherwise, the SCC components will be resulting inhomogeneous compositions that can adversely affect their durability and fitness for use. The paste volume and grading curve must be chosen so that the concrete completely fills the form work and is not held back in front of the gaps between the reinforcement. Suitable test methods by which the corresponding requirements can be verified were developed to ensure that the SCC meets these requirements.

Many different test methods have been developed in an attempt to characterize the properties of SCC. So far, no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly, no single method has been found which characterizes all the relevant workability aspects.

Each mix design should be tested by more than one test method for different workability parameters. The requisite test methods are described in **Table 3.9.**

Table: 3.9 List of test methods for workability properties of SCC

S.NO	Method	Property
1	Slump flow test	Filling ability
2	T_{50}cm Slump flow	Filling ability
3	V-funnel test	Filling ability
4	V-Funnel at T_5 minutes	Segregation resistance
5	L-Box test	Passing ability
6	U – Box test	Passing ability
7	Fill box apparatus test	Passing ability
8	J-Ring	Passing ability
9	Orimet test	Filling ability
10	GTM screen stability test	Segregation resistance

For the initial mix design of SCC all three workability parameters need to be assessed to ensure that all aspects are fulfilled. A full-scale test should be done to verify the self-compacting characteristics of the chosen design for a particular application. For site quality control, two test methods are generally sufficient to monitor production quality. Typical combinations are Slump-flow and V-funnel or Slump-flow and J-ring.

3.4.2 Workability criteria for the fresh SCC

Filling ability, passing ability and segregation resistance are the requirements for judging the workability criteria of fresh SCC. These requirements are to be fulfilled at the time of placing of concrete. Typical acceptance criteria for Self-compacting Concrete with a maximum aggregate size up to 20 mm are shown in **Table 3.10**.

Table: 3.10 Acceptance criteria for Self-compacting Concrete.

S No	Method	Unit	Typical range of values	
			Minimum	Maximum
1.	Slump flow test	mm	650	800
2.	T_{50} cm Slump flow	sec	2	5
3.	J – Ring	mm	0	10
4.	V – Funnel	sec	6	12

5.	V – Funnel at T_5 minutes	sec	6	15
6.	L – Box	h_2/h_1	0.8	1.0
7.	U – Box	$(h_2\text{-}h_1)$ mm	0	30
8.	Fill Box	%	90	100
9.	GTM Screen stability test	%	0	15
10.	Orimet test	sec	0	5

3.4.3 Test Methods

It was observed that none of the test methods for SCC has yet been standardized, and neither the tests described are yet perfected or definitive. A brief description of the tests has been presented below. They are mainly ad-hoc methods, which have been devised specifically for SCC.

3.4.3.1 Slump flow test and T_{50} cm test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of under water concrete. The diameter of the concrete circle is a measure of the filling ability of concrete.

Slump Flow is definitely one of the most commonly used SCC tests at present. This test involves the use of slump cone with conventional concretes as described in

ASTM C 143 [Standard Test Method for Slump of Hydraulic-Cement Concrete]. The main difference between Slump Flow Test and ASTM C 143 [Standard Test Method for Slump of Hydraulic-Cement Concrete] is that the Slump Flow Test measures the spread or flow of concrete sample, once the cone is lifted rather than the traditional slump (drop in height) of the concrete sample. The T_{50} test is also determined during the Slump Flow Test. It is simply the amount of time that the concrete takes to flow to a diameter of 50 centimeters. The slump flow test procedure is as shown in **Fig.3.1**.

a. Slump flow apparatus

The mould used is in the shape of a truncated cone with internal dimensions 200mm diameter at the base, 100mm diameter at the top and a height of 300mm. The base plate is of a stiff non- absorbing material of at least 700mm square, marked with center location for the slump cone, and further concentric circle of 500mm diameter. The other apparatus required are trowel, scoop, ruler, and a stop watch.

b. Procedure

About 6 liter of concrete is needed to perform the test. The base plate and the inside of the slump cone were moistened. The base plate was placed on level stable ground and the slump cone was placed centrally on the base plate and hold down firmly. The concrete was filled into the cone with the scoop without tamping. The excess material on the top of slump cone was removed and leveled with a trowel. The surplus concrete around the base of the cone was removed. The slump cone was raised vertically upwards allowing the concrete to flow out freely. The time taken for concrete to reach the 500 mm spread circle was recorded by using the stopwatch. This is the T_{50} time. After the flow of concrete was stopped, the final diameter of concrete in two perpendicular directions was measured. The average of the two measured diameters is called as slump flow in mm.

Fig. 3.1 Slump flow test and T_{50cm} test procedure (SCC mixes)

3.4.3.2 L – Box test

This test, based on a Japanese design for underwater concrete, has been described by Petersson, 1999. This test assesses the flow of concrete, and also the extent to which it is subjected to blocking by reinforcement. The apparatus is shown in **Fig.3.2**.

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 bars are fitted. The vertical section is filled with concrete, and then the gate is 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 called as H_2/H_1 ratio or blocking ratio. It indicates the slope of the concrete when the concrete is at rest. This is an indication of 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 time taken to reach these points measured. These are known as the T_{20} and T_{40} times and are indicators of the filling ability.

a. Procedure

About 14 liters of concrete is needed to perform the test. The apparatus was placed on the level ground. It was ensured that the sliding gate can open and close freely. The inside surfaces of the apparatus were moistened and surplus water was removed. The vertical section of the apparatus was filled with the concrete sample. The sliding gate of the vertical section was lifted and concrete has allowed flowing out into the horizontal section. The time taken for concrete to reach the 200 and 400 mm marks in the horizontal section was measured simultaneously by using the stopwatch. The distances H_1 and H_2 were measured when the concrete stops flowing and the blocking ratio H_2/H_1 is calculated. The maximum time required for performing this L – box test is 5 minutes.

Fig.3.2 L – Box test apparatus (SCC mixes)

3.4.3.3 V – funnel test and V – funnel test at T_5 minutes

This test was developed in Japan and used by Ozawa et al, [1989]. The equipment consists of a V-shaped funnel, shown in **Fig.3.3**. The V-funnel test is used to determine the filling ability of the concrete with a maximum aggregate size of 20mm. The funnel was filled with about 12 liter of concrete and the time taken for it to flow through the apparatus measured. After this the funnel was refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time increases significantly.

a. Procedure for flow time

About 12 liters of concrete was needed to perform this test. The V-funnel apparatus was placed on the firm ground. The inside surfaces of the V – funnel was moistened and the surplus water in funnel was drained through trap door by opening it. Before starting the test, the trap door was closed and a bucket was placed underneath. The V – funnel apparatus was completely filled with concrete without any compaction. The top surface was leveled with the trowel. The trap door was opened and concrete was allowed to flow out under gravity. By using the stopwatch, the time taken for the complete discharge of concrete from the funnel was measured. The whole test has to be performed within 5 minutes.

b. Procedure for flow time at T_5 minutes

After measuring the flow time, the trap door of the V-funnel was closed and a bucket was placed underneath. Again the concrete was filled into the apparatus completely without any compaction. The top surface was leveled with the trowel. The trap door was opened after 5 minutes and the concrete was allowed to flow out under gravity. The time for the complete discharge of concrete from the funnel was recovered.

Fig.3.3 V – funnel test apparatus (SCC mixes)

3.4.3.4 J – Ring test

The J – Ring test has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals in accordance with normal reinforcement considerations. The diameter of the ring of vertical bars is 300mm, and the height 100 mm.

The J – Ring can be used in conjunction with the Slump flow test. These combinations judge the flowing ability and the passing ability of the concrete. The slump flow spread was measured to assess flow characteristics. The J – Ring bars can be set at any spacing to impose a more or less severe test of the passing ability of the concrete. After the test, the difference in height between the concrete inside and that just outside the J – Ring is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted.

a. Equipment

The mould used is in the shape of a truncated cone with the internal dimensions 200mm diameter at the base, 100mm diameter at the top and a height of 300mm. The base plate is of a stiff non- absorbing material, at least 700mm square, marked with center location for the slump cone, and further concentric circle of 500mm diameter. A rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes is called as J - ring. The holes can be screwed threaded sections of reinforcement bar. The other apparatus required are trowel, scoop, ruler, and a stop watch.

b. Procedure

About 6 liters of concrete is needed to perform this test. Moisten the base plate and inside of slump cone, place the base-plate on level stable ground. The slump cone was placed on the level ground and the J – ring was placed centrally inside the slump cone and was held down firmly. The concrete was filled into the cone with the scoop without any compaction. The top surface of the cone was leveled with the trowel. The surplus concrete around the base of the cone was removed. The slump cone is raised vertically upwards to allow the concrete to flow out freely through the rings. The difference in height between the concrete just inside the bars and that just outside the bars was measured. The average of the difference in height at four locations (in mm) was measured.

3.4.3.5 U – Box test

This test was developed by the Technology Research Centre of the Taisei Corporation in Japan. This test is also called as box-shaped test. It 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 R_1 and R_2 in **Fig.3.4**. An opening with a sliding gate was fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacings of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section was filled with about 20 liters of concrete. The gate was lifted and the concrete flows upwards in the other section. The height of the concrete in both sections is measured.

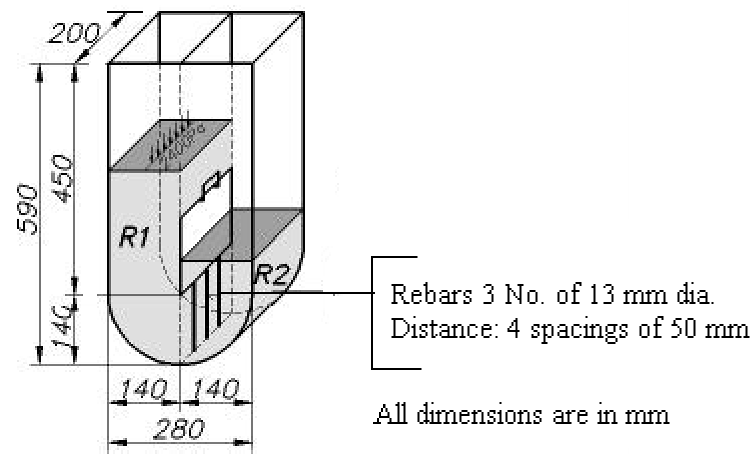

Fig.3.4 U – Box apparatus (SCC mixes)

3.5 Size of test specimen used

The Self Compacting Concrete mixes, after having checked for the satisfaction of the fresh properties of self compacting specifications as per EFNARC [2002] was cast into cube moulds of size 150 mm x 150 mm, beam moulds of size 100mm x 100mm x 500 mm and cylindrical moulds of 300 mm height x 150mm diameter. The moulds were fabricated with steel sheets. It is easy for assembling and removing the mould specimen without damage. Moulds were provided with base plates, having smooth surface to support. The mould is filled without leakage. Care was taken to ensure that there were no leakages.

3.6. Curing of test specimens

After 24 hours of casting, the specimens were removed from the moulds and immediately dipped in clean fresh water. The specimens were cured for 3 days, 7 days and 28 days respectively depending on the requirement of age of curing. The fresh water tanks used for the curing of the specimens were emptied and cleaned once in every fifteen days and were filled once again. All the specimens under immersion were always kept well under water and it was seen that at least about 15 cm of water was above the top of the specimens as shown in **Fig.3.5**.

Fig.3.5 Specimen Casting

3.6 Specimen curing

3.7 Tests on hardened concrete

Testing of hardened concrete plays an important role in controlling and confirming the quality of self compacting concrete.

3.7.1 Compressive Strength

Compressive strength of a material is defined as the value of uniaxial compressive stress reached when the material fails completely. In this investigation, the cube specimens of size 150 mm x 150 mm x 150 mm are tested in accordance with IS: 516 – 1969 [Method of test for strength of concrete]. The testing was done on a compression testing machine of 300 tons capacity. The machine has the facility to control the rate of loading with a control valve. The machine has been calibrated to the required standards. The plates are cleaned; oil level was checked and kept ready in all respects for testing.

After 28 days of curing, cube specimens were removed from the curing tank and cleaned to wipe off the surface water. The specimens were transferred on to the swiveling head of the machine such that the load was applied centrally. The smooth surfaces of the specimen are placed on the bearing surfaces. The top plate was brought in contact with the specimen by rotating the handle. The oil pressure valve was closed and the machine was switched on. A uniform rate of loading 140 $kg/cm^2/min$ was maintained. The maximum load to failure at which the specimen breaks and the pointer starts moving back was noted. The test was repeated for the three specimens and the average value was taken as the mean strength. The test set up is shown in **Fig.3.7**.

In the present investigation, the compressive strength test has been conducted on concretes with different sizes of coarse aggregate. M 70 grade of SCC at 3, 7 and 28 day were tested.

Fig.3.7 Compressive strength test setup

3.7.2 Flexural Strength

Standard beam test (Modulus of rupture) was carried out on the beams of size 100 mm x 100 mm x 500 mm as per IS: 516 [Method of test for strength of concrete], by considering that material is homogeneous. The beams were tested on a span of 400 mm for 100 mm specimen by applying two equal loads placed at third points. To get these loads, a central point load has applied on a beam supported on steel rollers placed at third point as shown in **Fig.3.8**. The rate of loading is 1.8 kN/minute for 100 mm specimens and the load was increased until the beam failed. Depending on the type of failure, appearance of fracture and fracture load, the flexural tensile strength of the sample was estimated.

As explained earlier, in the present investigation, the flexural strength test has been conducted on concretes with different sizes of coarse aggregate M 70 grade of SCC at 3, 7 and 28 days.

If 'a' be the distance between the line of fracture and the nearer support, then for finding the modulus of rupture, these cases should be considered.

i. When a > 133 mm for 100 mm specimen

$f_{cr} = PL/bd^2$, where P = total load applied on the beam

ii. When 110 mm < a < 133 mm, $f_{cr} = 3Pa/bd^2$

iii. When a < 110 mm, the result should be discarded.

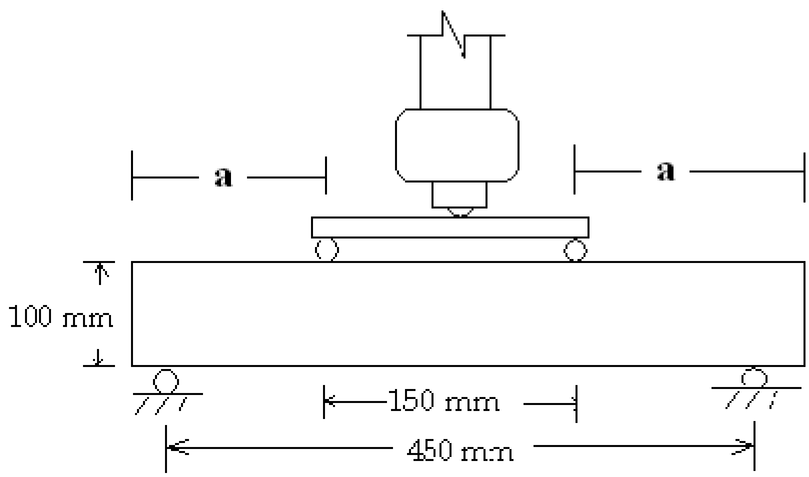

Fig.3.8 Schematic diagram for flexure test setup

Fig.3.9 Flexural strength test

3.7.3 Split tensile strength

This is also some times referred as “Brazilian Test” as this test was developed in Brazil in 1943. This comes under indirect tension test methods. The test was carried out by placing a cylindrical specimen horizontally between the loading faces of a compression testing machine and the load was applied until failure of the cylinder, along the vertical diameter as shown in **Fig.3.10**. A concrete cylinder of size 150mm diameter and 300mm height was subjected to the action of a compressive force along two opposite edges. The cylinder was subjected to compression near the loaded region and the length of cylinder is subjected to uniform tensile stress.

Horizontal tensile stress=2P/Π D L

Where P= Compressive load on the cylinder.

L= Length of cylinder.

D= Diameter of cylinder.

In the present investigation, the split tensile strength test has been conducted on concrete with different sizes of coarse aggregate for M 70 grade of SCC at 3, 7 and 28 days.

Fig.3.10 split tensile strength test

Concluding Remarks:

From the above experimental investigations, the strength aspects of SCC for optimum size of aggregate for M 70 grade of concrete was studied in detail.

The details of the results obtained based on the above mentioned studies have been discussed in chapter – 4.

Chapter – 4

Experimental Results

In chapter – 3, a detailed experimental investigation covering the various mechanical properties viz. compressive strength, split tensile strength and flexural strength have been studied. The present chapter highlights the results obtained from the above experimental investigation

4.1. Mix proportions for SCC

The mix proportion of M70 grade of concrete designed on the basis of Nan Su method for different maximum sizes of aggregates 10, 12.5 and 20 mm. For the mix proportions obtained, **Tables 4.1**, highlights the details of various parameters including total aggregate – cement ratio (A/C), water – cement ratio (w/c), coarse aggregate - fine aggregate ratio (CA/FA) and fine aggregate – total aggregate ratio (S/a) for various aggregate sizes.

Table 4.1 Parameters of M70 grade SCC mix proportions

Size of aggregate (mm)	A/C	w/c	w/p	CA/FA	S/a
10	2.42	0.38	0.269	0.935	0.520
12.5	2.43	0.366	0.257	0.914	0.514
20	2.45	0.365	0.236	0.820	0.550

4.2 Fresh properties of SCC

The details of the fresh properties are shown in **Table 4.2,** M70 grade of concrete.

Table: 4.2 Fresh properties of M 70 grade SCC

S. No	Size of Aggregate	Slump Flow value	T_{50}	V-Funnel	V-Funnel at $T_{5\ Minutes}$	L-Box H_2/H_1 (blocking ratio)

1.	20 mm	720 mm	5 Sec	9 Sec	12 Sec	1.00
2.	12.5 mm	725 mm	5 Sec	6 Sec	8 Sec	1.00
3.	10 mm	735 mm	5 Sec	7 Sec	9 Sec	1.00

4.3. Mechanical properties of SCC with different sizes of aggregate

4.3.1. Compressive strength

The results of the mechanical properties obtained based on the specimens tested as per Indian standard test procedures (as per IS: 516) are discussed. M 70 grade of concrete, three maximum sizes of aggregate and three different ages of curing are the variables of investigation.

The details of the compressive strengths of M70 grade are shown in **Table 4.3**.

Table: 4.3 Compressive strength of M 70 grade SCC

Size of Aggregate	3 Days	7 Days	28 Days
20 mm	31.80	46.30	74.00
12.5 mm	36.20	49.00	77.10
10 mm	38.33	49.66	79.30

4.3.2. Split tensile strength

Table 4.4 shows the details of the split tensile strength of three grades of concrete for different sizes of aggregate.

Table: 4.4 Split tensile strength of M 70 grade SCC

Size of Aggregate	3 Days	7 Days	28 Days
20 mm	2.40	6.04	9.15
12.5 mm	2.80	5.90	9.62
10 mm	2.85	6.36	9.95

4.3.3. Flexural strength

Table 4.5 shows the details of the flexural strength of the different sizes of aggregate and M 70 grade of concrete.

Table: 4.5 Flexural strength of M 70 grade SCC

Size of Aggregate	3 Days	7 Days	28 Days
20 mm	4.03	6.75	8.50
12.5 mm	4.60	7.47	9.13

10 mm	5.35	7.65	9.35

Chapter – 5

Interpretation and Discussion of Test Results

5.0 General

The parameters involved in the study are the size of aggregate (10, 12.5, 20 mm), age of curing (3, 7 and 28 days), grade of concrete (M70) and type of concrete (SCC).

5.1. Discussion on mix proportions adopted for SCC

As described earlier, Nan Su method of mix design [2001] was adopted to design the SCC mix for M70 grade of concrete. As understood, Nan Su method is based on the basic principle that the paste of binders are filled in the voids of aggregates ensuring that the concrete obtained has flowability, self-compacting ability and other desired SCC properties. The packing factors assumed on the basis of better compactability and strength, from a number of trials is 1.12 for M70 grade of concrete. From Nan Su method of mix design for SCC, the density, compactability and strength are dependent on how effectively the aggregates are packed. Hence, the size of aggregate, shape and texture of aggregate also plays a deciding factor in the values of fresh and hardened properties.

The mix proportion of M70 grade of concrete designed on the basis of Nan Su method is given in the **Table 3.8** for different maximum sizes of aggregate Viz. 10, 12.5 and 20mm. For the mix proportions obtained, **Table 4.1** shows the details of various parameters including total Aggregate – Cement ratio (A/C), water – cement ratio (w/c), Coarse Aggregate - Fine Aggregate ratio (CA/FA) and fine aggregate – total aggregate (S/a) for various aggregate sizes

5.2 Effect of size of aggregate on fresh properties of SCC

The details of the fresh properties are shown in **Tables 4.2,** M70 grade of concrete.

Based on the fresh properties of SCC for different sizes of aggregates, it can be noted that M70 grade of concrete with all the different maximum sizes satisfied the required EFNARC specifications [2005]. The fresh properties have improved with the increase in powder content. Also the lower size of aggregate yielded better results in M70 grade of concrete.

5.3. Effect of size of aggregate on the mechanical properties of SCC

5.3.1. Compressive strength

Grade of concrete, maximum size of aggregate and age of curing are the variables of investigation. The details of the compressive strengths of M70 grades are shown in **Tables 4.3**.

From the results it was noted that, as the grade of concrete increased the effective maximum size of the aggregate has deceased. In the above cases, the cement content was 680 kg/m^3 for M70 grades. The three effective sizes for the above three mixes have been arrived and the same was adopted in the further study.

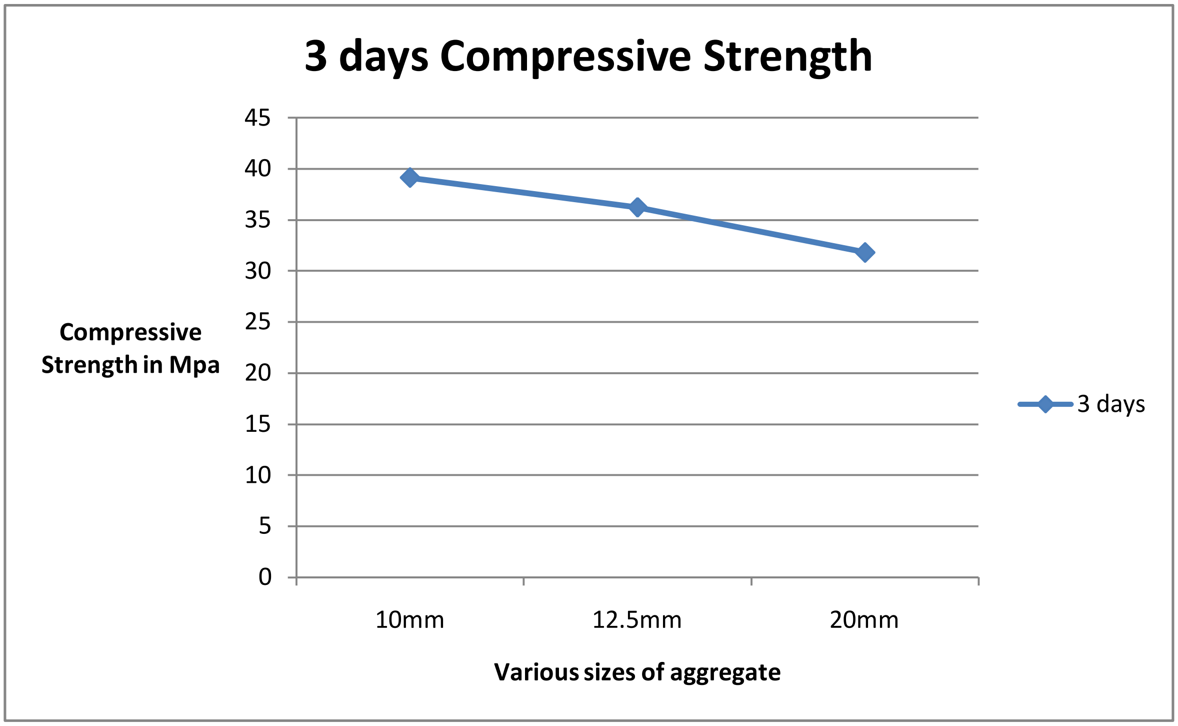

Fig 4.1 3 days Compressive strength with various sizes of Aggregates

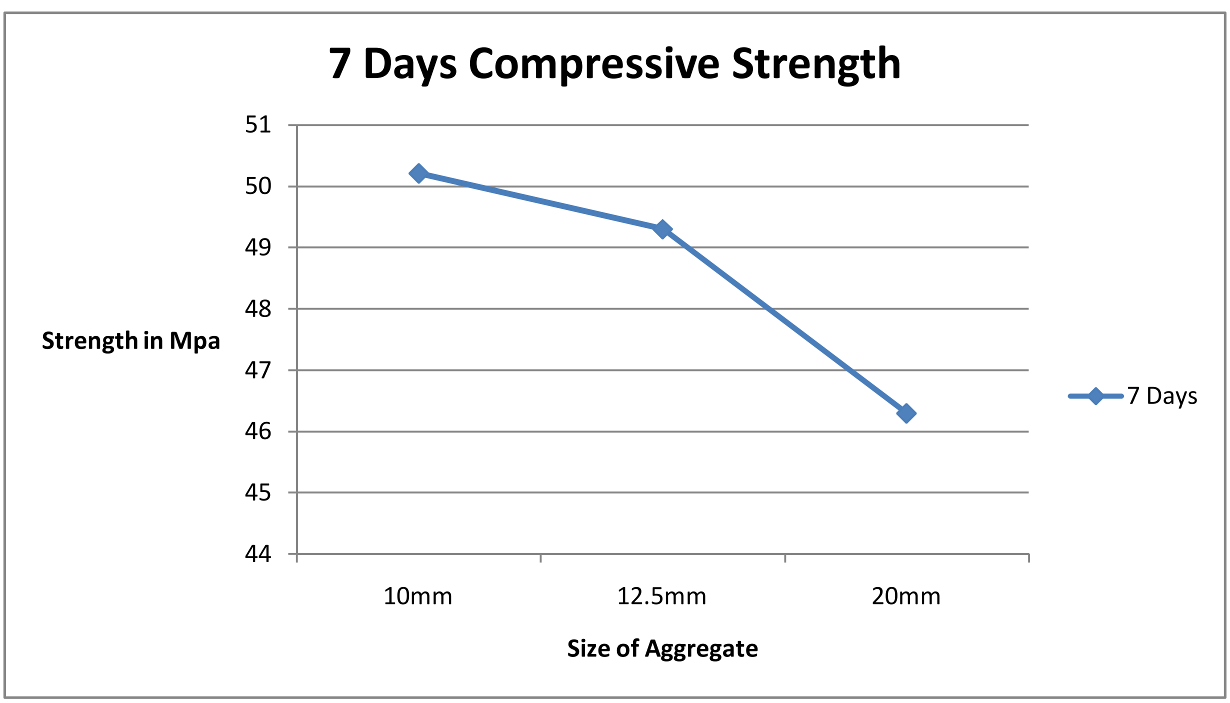

Fig 4.2: 7 days Compressive strength with various sizes of Aggregates

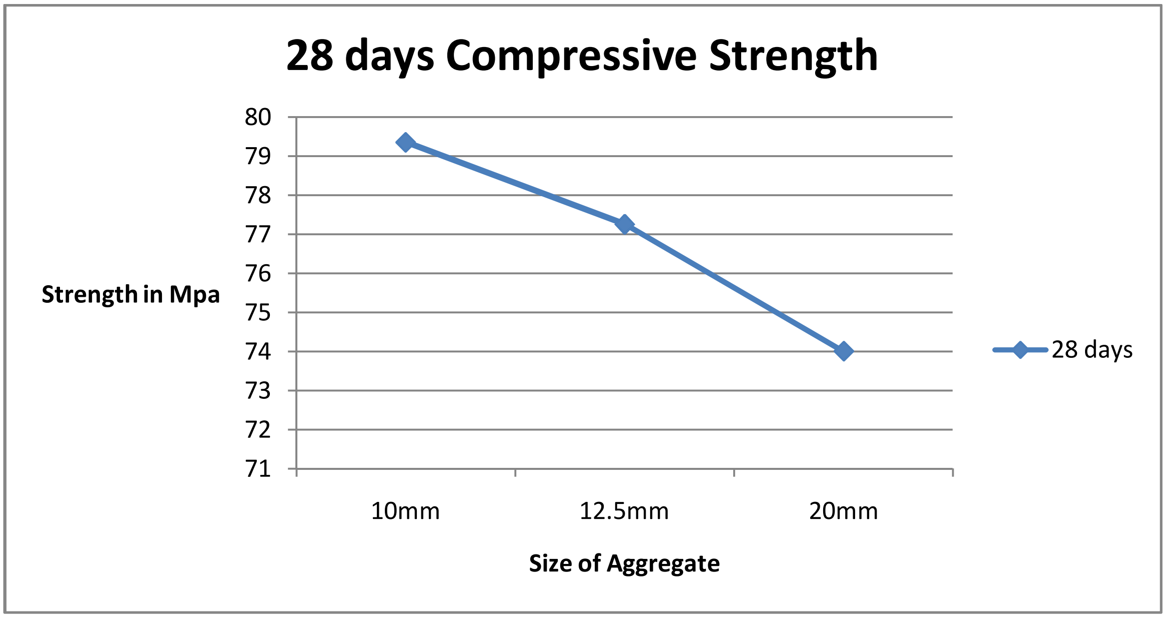

Fig 4.3: 28 days Compressive strength with various sizes of Aggregates

5.3.2. Split tensile strength

Table 4.4 shows the details of the split tensile strength of M 70 grade of concrete for different sizes of aggregate. A similar trend as that of compressive strength was noted with regard to the size of aggregate. This was true at all the three different ages of curing.

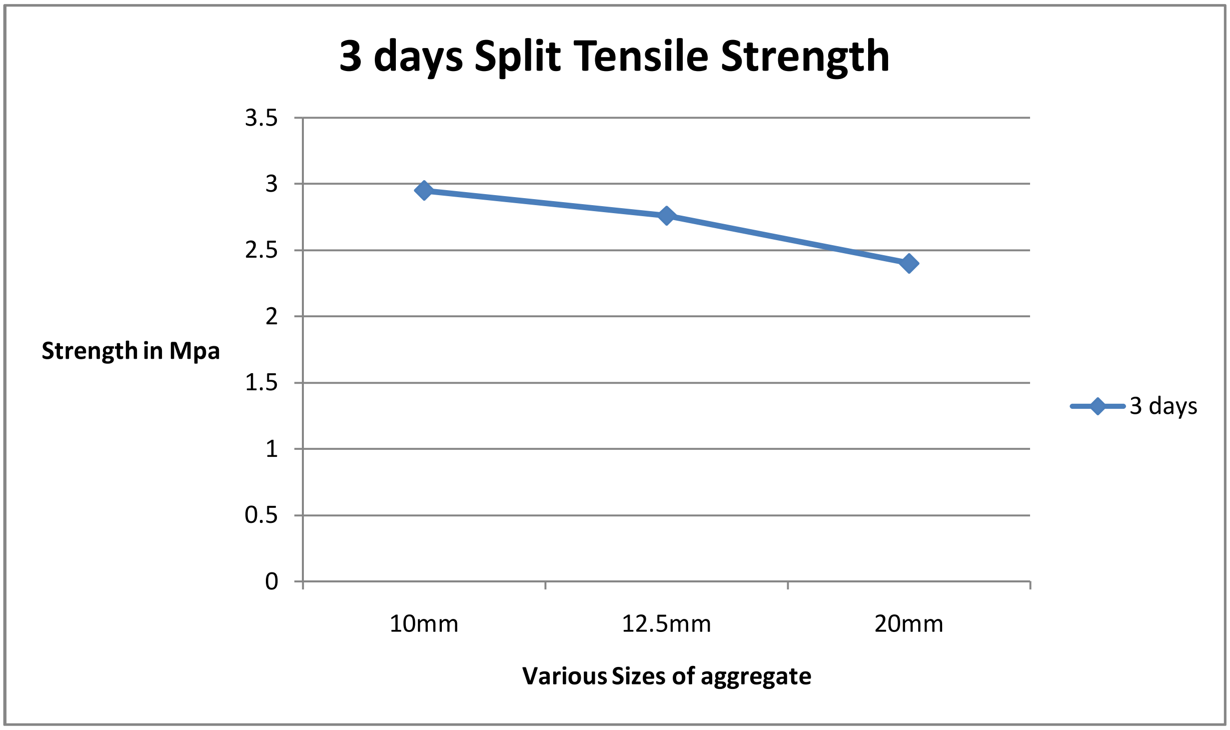

Fig 4.4: 3 days Split Tensile strength with various sizes of Aggregates

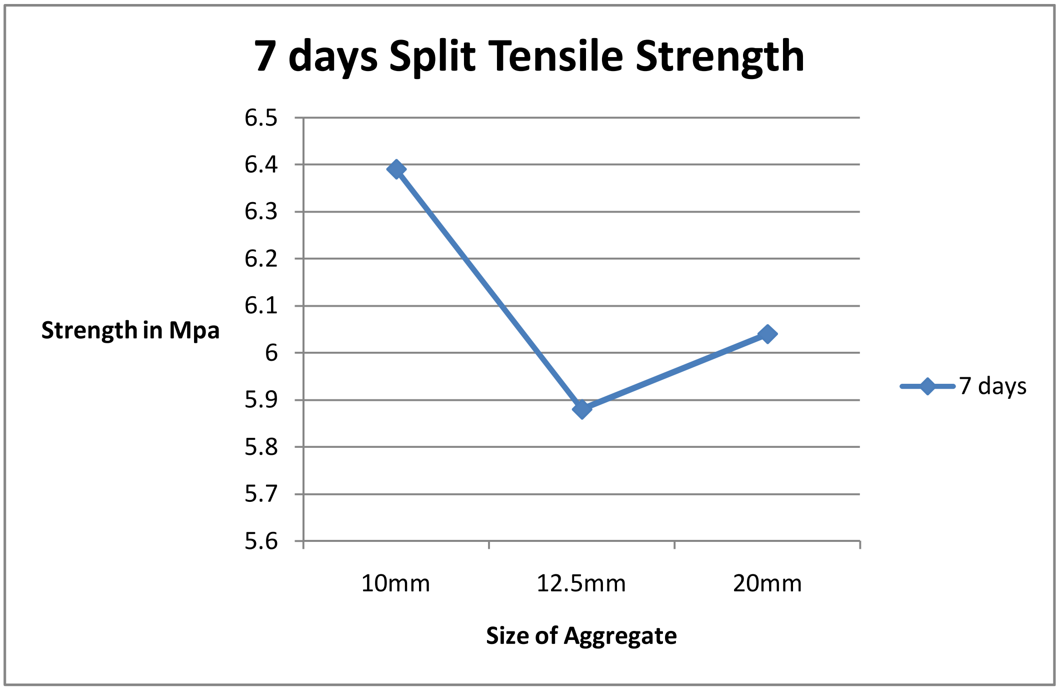

Fig 4.5 7 days Split Tensile strength with various sizes of Aggregates

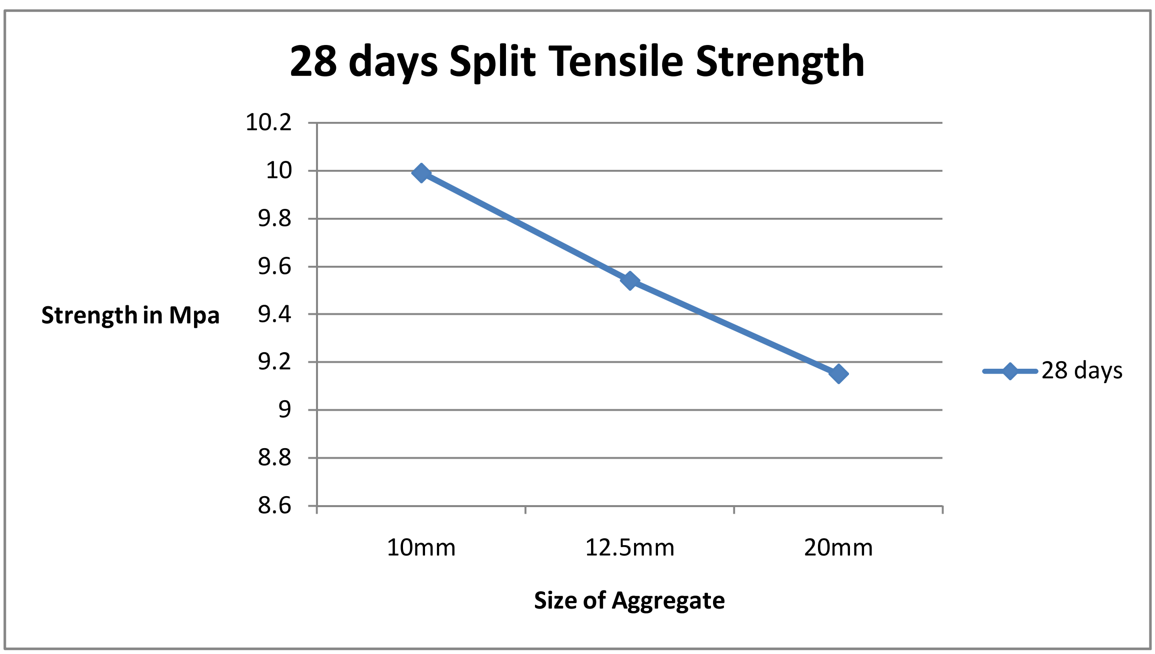

Fig 4.6 28 days Split Tensile strength with various sizes of Aggregates

5.3.3. Flexural strength

Table 4.5 shows the details of the flexural strength of the different sizes of aggregate and three grades of concrete. At 3, 7 and 28 days the effective size of aggregate was 10 mm for M 70 grade.

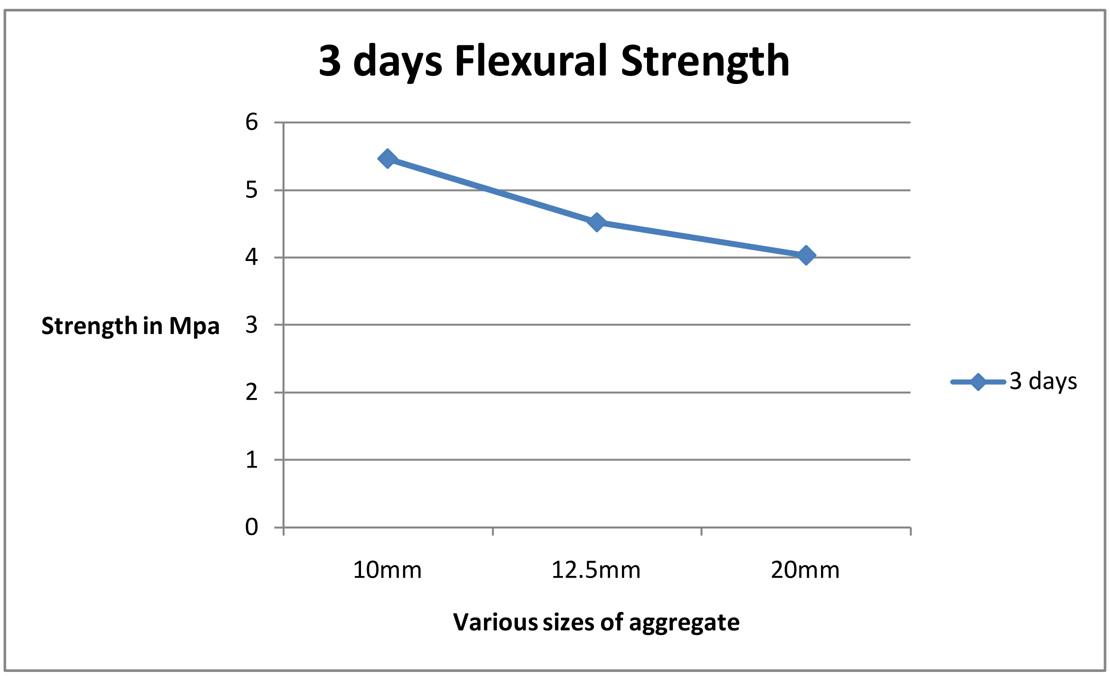

Fig 4.7: 3 days Flexural strength with various sizes of Aggregates

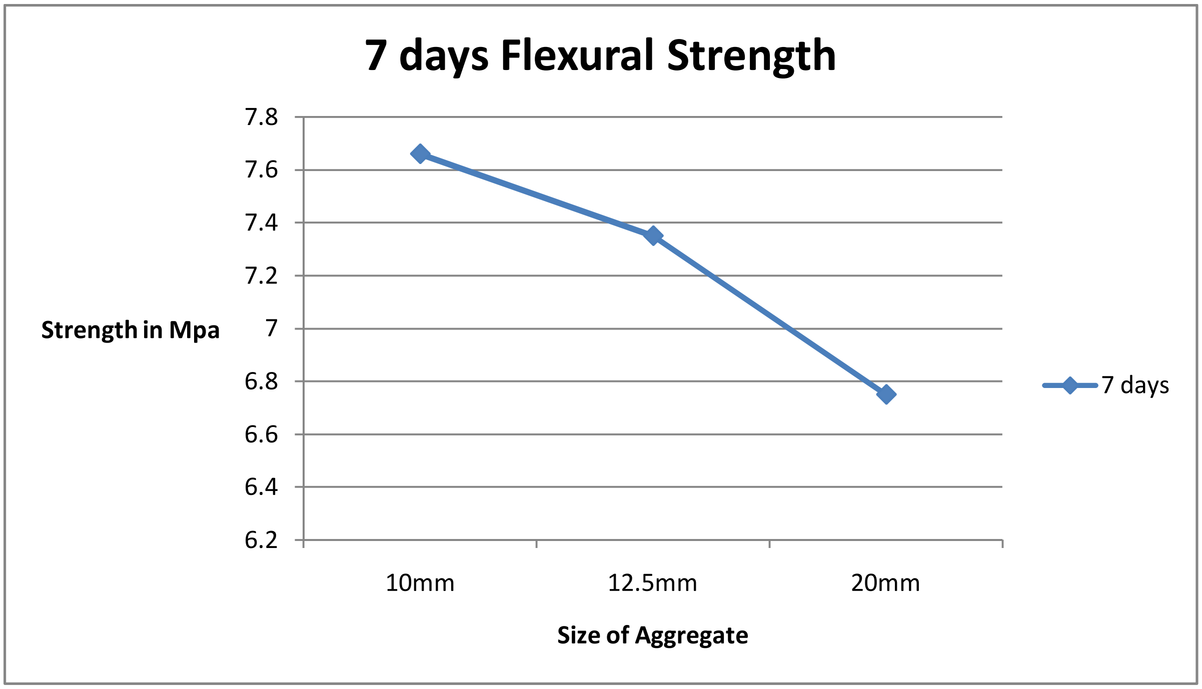

Fig 4.8: 7 days Flexural strength with various sizes of Aggregates

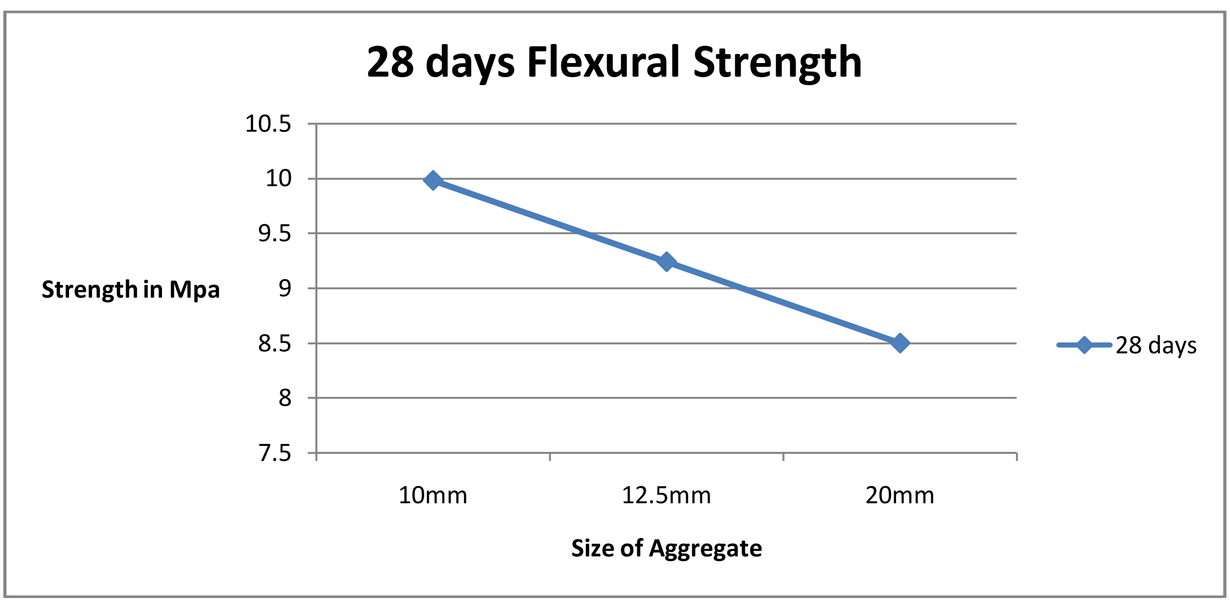

Fig 4.9: 28 days Flexural strength with various sizes of Aggregates

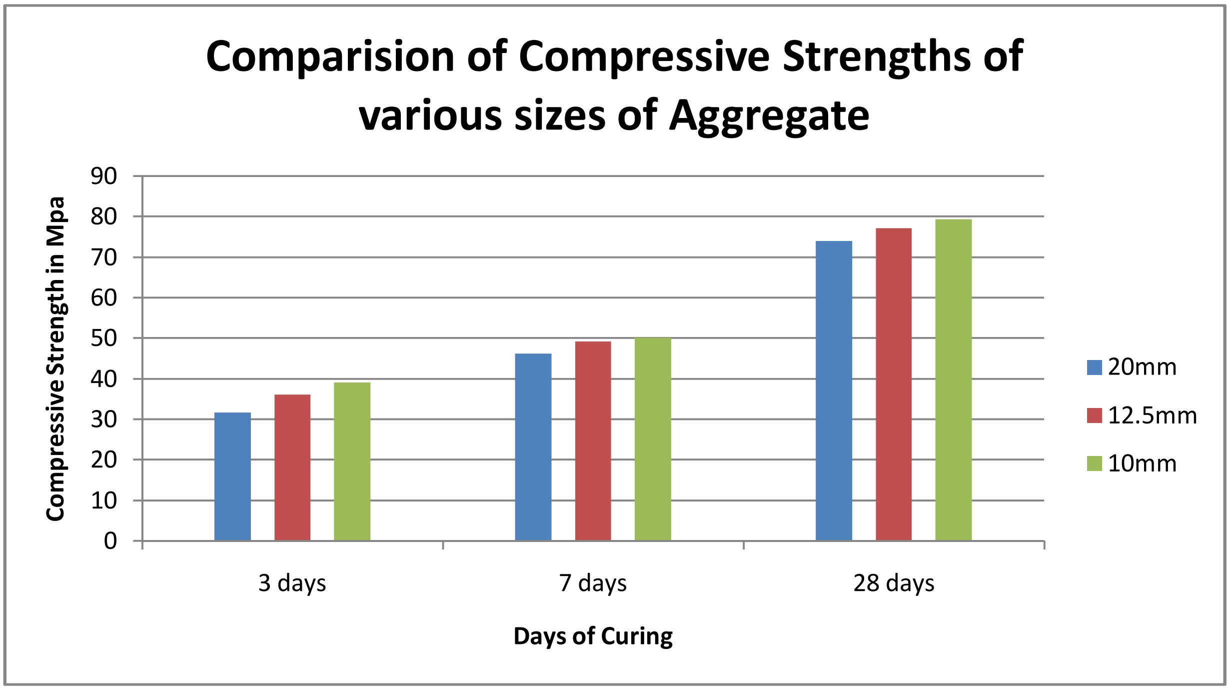

Fig 4.10: Bar Diagram of Compressive Strength with various sizes of Aggregates

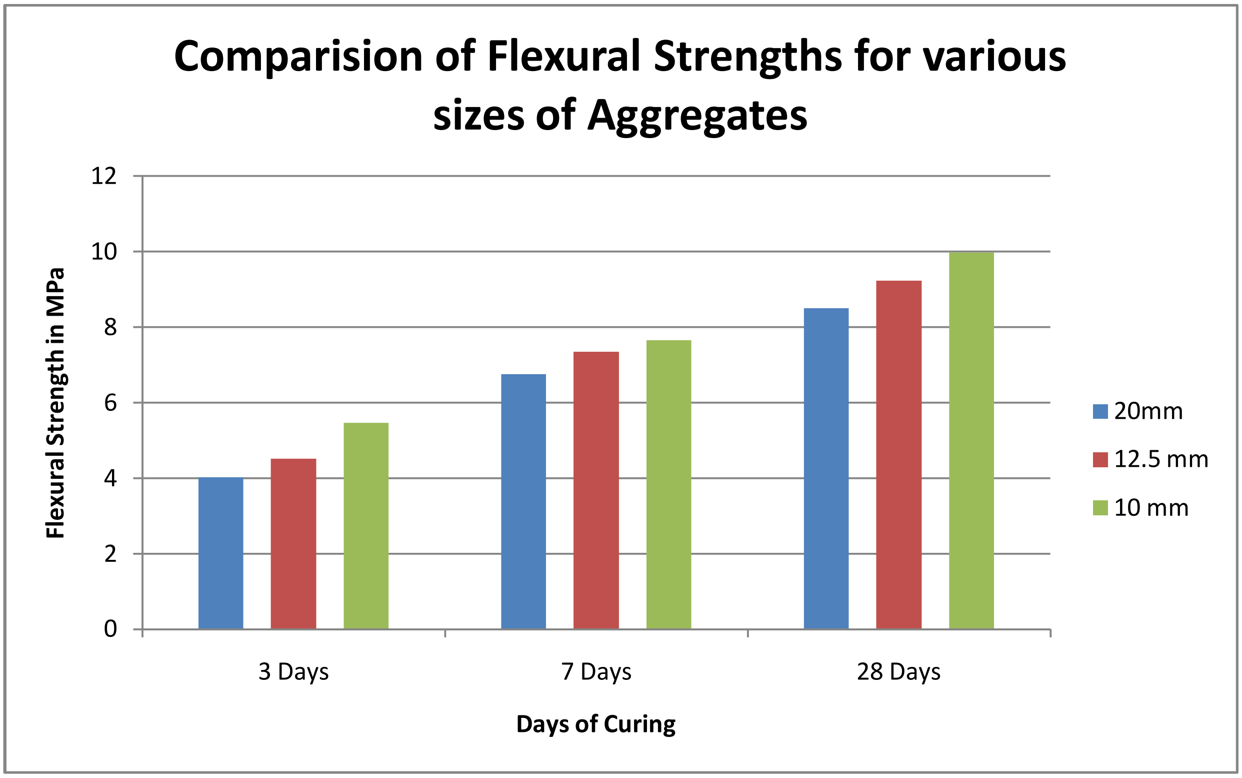

Fig 4.11: Bar Diagram of Flexural Strength with various sizes of Aggregates

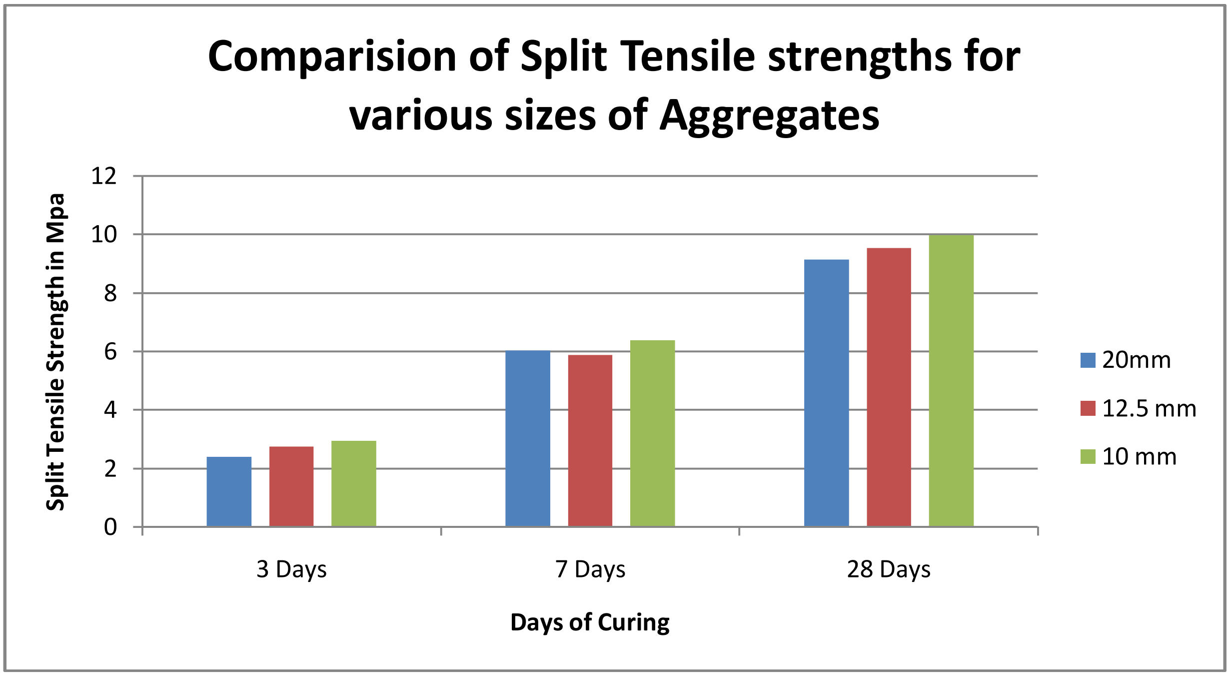

Fig 4.12: Bar Diagram of Split Tensile Strength with various sizes of Aggregates

From the results of the studies on mechanical properties for M70 grade of SCC mix, it is clear that the effective size of aggregate was 10 mm.

Concluding Remarks:

From the above results and discussion on strength aspect of SCC, it can be broadly concluded that the Self Compacting Concrete is better from the performance point of view.

Detailed conclusions of the above results are explained in Chapter – 7.

Chapter – 6

SCC – Mix design Procedure

6.0 Development of a rational mix design procedure:

As per Nan Su's method of mix design of Self Compacting Concrete, the parameters that influence the mix proportions are packing factor, fine aggregate – total aggregate ratio and powder content. However, as per Nan Su's method assumptions in lieu of packing factor, cement content, fly ash content and fine aggregate – total aggregate ratio were made. From the strength and workability studies conducted on SCC in the present investigation, it was noted that there is a significant change in the mix proportions with respect to packing factor, effective size of aggregate, fine aggregate – total aggregate ratio, fly ash content, cement content and water content. It was hence felt that these three parameters, which were otherwise assumed, are of reasonable importance. Hence, a rational mix design methodology modifying the existing Nan Su method has been proposed. The flow chart given in **Fig.6.1** explains the SCC mix design. The following is a stepwise procedure for rational mix design, based on the values obtained from experimental investigations.

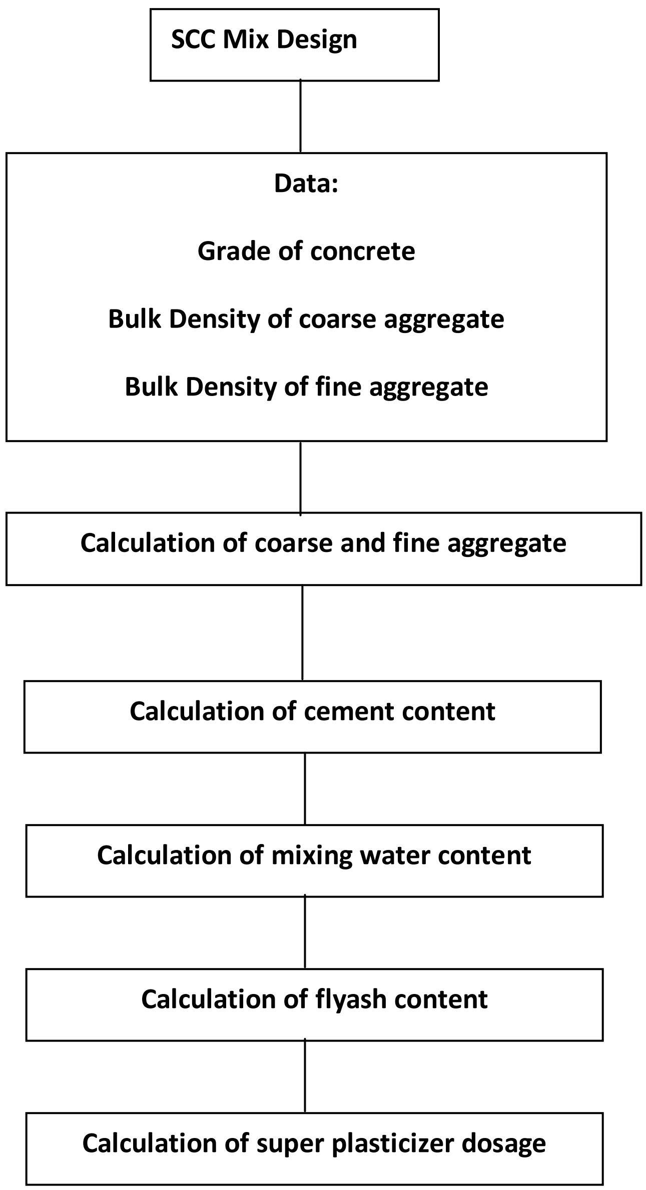
SCC Mix Design
Data:
Grade of concrete
Bulk Density of coarse aggregate
Bulk Density of fine aggregate
Calculation of coarse and fine aggregate
Calculation of cement content
Calculation of mixing water content
Calculation of flyash content
Calculation of super plasticizer dosage

Fig.6.1 Flow chart of SCC mix design

Step1. Calculation of coarse and fine aggregate content:

The size of aggregate plays an important role on the compressive strength of concrete [Neville. A.M , 2000] and hence, on the design of concrete mix. In Nan Su method of mix design, there is no mention of the influence of the size of aggregate. In the present investigation, the effective maximum size of aggregate for M70 grade of concrete was obtained.

It is important to select the optimal Packing Factor (PF) value in the mix design method so as to meet the requirements for SCC properties. In the Nan Su method, PF is assumed based on some trials. However, these trials were not covering the low grades and higher grades of concrete. In the present case, the PF values are modified based on the experimentally obtained values ranging from low to high grade. The details of Packing Factor and the 28 days compressive strength for M70 grade of concrete was given in the **Table. 6.1**

Table:6.1 Details of packing factor and strengths

Grade of Concrete	Size aggregate (mm)	Packing Factor	28 days compressive strength (MPa)
M70	20	1.12	74.00
	12.5	1.12	77.10
	10	1.12	79.30

The content of fine and coarse aggregates can be calculated by using the following equations based on Nan Su method of mix design:

$$W_g = PF \times W_{gL} (1-(S/a)) \quad (7.2)$$

$$W_s = PF \times W_{sL} (S/a) \quad (7.3)$$

Where

W_g = Content of coarse aggregates in SCC (kg/m^3)

W_s = Content of fine aggregates in SCC (kg/m^3)

W_{gL}=Unit volume mass of loosely piled saturated surface-dry coarse aggregates in air (kg/m^3)

W_{sL}=Unit volume mass of loosely piled saturated surface-dry fine aggregates in air (kg/m^3)

PF = Packing factor, the ratio of mass of aggregates of tightly packed state in SCC to that of loosely packed state in air.

S/a=Volume ratio of fine aggregates to total aggregates.

In the Nan Su mix design procedure, (S/a) has been taken constant for all grades of concrete. The flowability, filling capability and stability of fresh SCC are greatly influenced by ratio of volume between coarse aggregate and fine aggregate and there exists an optimum value to achieve the best workability of SCC. Hence, fine aggregate – total aggregate ratio (S/a) is an important parameter in the design of M70 grade of concrete. The ratio of fine aggregate to total aggregate for M70 grade of concrete, from the experimental results was shown in **Table. 6.2**.

Table: 6.2 Fine aggregate to total aggregate ratio

Grade of Concrete	M70
Fine to total aggregate ratio (S/a)	0.52

Step2. Calculation of cement content:

To get a good flowability and segregation resistance, the cement content should not be low. In the Nan Su mix design method, the cement content was calculated based on the assumption that 1 kg of cement gives 0.14 MPa strength of concrete. This is based on experimental results obtained from trials conducted in Taiwan. The detail of cement content, from the experimental results was given in the **Table.6.3**. In the present study, design was based on the experimental results, from a plot between grade of concrete and cement content was drawn and an equation was obtained.

Table: 6.3 Cement content for M70 grade of concrete

Grade of Concrete	Cement Content (from Exp. results) kg/m^3	Cement Content (from Nan Su) kg/m^3

M70	680	500

Step3. Calculation of mixing water content:

From the experimental results, w/c ratio for M70 grade of concrete was given in the **Table. 6.4**.

Table: 6.4 water-cement ratio for M70 grade of concrete

Grade of Concrete	M70
w/c ratio	0.38

Step4. Calculation of Fly Ash content:

Large amounts of powder materials are required to achieve the self compactibility. However, if an excess amount of cement is added, the cost of materials and dry shrinkage will increase. To avoid the above two, a pozzolanic material like flyash (class - F) was taken into consideration in the present mix design procedure..

% fly ash in total powder (y) = 68.43 – 0.535 x grade of concrete (x)   (7.6)

From the above equation, it is easy to find the percentage of fly ash content in total powder for any grade of concrete.

Step5. Calculation of Super Plasticizer dosage:

Adding an adequate dosage of Super Plasticizer (SP) can improve the flowability, self compacting ability and segregation resistance of fresh SCC for meeting the design requirements. Water content of the SP can be regarded as part of the mixing water. In the present work, SNF condensate (SP 430) was used as a water reducing admixture (Super Plasticizer). The dosage of SP was obtained based on trial and error to suit the requirements of EFNARC. The dosage of SP used was ranging from 1.5 to 1.8% by weight of cement.

For higher grade of concrete, silica fume was also used to achieve better strengths. Mix design calculations for M70 grade of concrete are given in Annexure – I.

Chapter – 7

Conclusions

Based on the systematic and detailed experimental study conducted on SCC mixes with an aim to develop performance mixes, the following are the conclusions arrived.

1. The mixes designed using the lower size of aggregate yielded better fresh properties than higher size of aggregates.

2. As the strength of concrete increases, the effective size of aggregate has decreased.

Significant contribution of the Project:

The present investigation has brought out explicitly the effect of size of aggregate on the compressive strength and other mechanical properties of self compacting concrete.

Scope of the future work:

1. The simplified mix design methodology was presented may be extended to the more number of concrete strength ranges.

2. The investigations may be conducted with different mineral admixtures like Rice Husk Ash and GGBS apart from fly ash.

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4. **Jaya Shankar R, Hemalatha T, Palanichamy.K and Santhakumar. S**, “Influence of fly ash and VMA on properties of self compacting concrete”, National Conference on Advances in materials and mechanics of concrete structures Department of Civil Engineering, IIT Madras, Chennai 12-13 August 2005, pp 25 – 32.

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3. IS: 12269-1987 Specifications for 53 Grade Ordinary Portland Cement.
4. IS: 383- 1970 Specification for Coarse and fine aggregates from natural sources for concrete.
5. IS: 2386 – 1963 (all parts) Methods of test for aggregate for concrete.
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9. IS: 9103 – 1999 Specification for admixtures for concrete (first revision).

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11. IS: 5513 – 1996 Specification for vicat apparatus (second revision).

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15. IS: 7320 – 1974 Specification for concrete slump test apparatus.

16. IS: 9399 – 1979 Specification for apparatus for flexural testing of concrete

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2. "Design of Concrete Mixes", by N. Krishna Raju, CBS Publishers & Distributors,Delhi, 1993.
3. "Concrete Technology – theory and practice", by M S Shetty, S. Chand Company Ltd, Delhi, First multicolor illustrative revised edition, reprint 2008.
4. "Concrete Technology" by A R Santhakumar, Oxford university press, Delhi, first published 2007.

Annexure – I

Mix design of SCC

3. Mix design for M 70 grade of SCC

3.1 Mix design using 20 mm size graded aggregates:

Characteristic strength	= 70 MPa.
Target mean strength	= 70 + 1.65 x 6 = 80 Mpa.
	= 11428.5 psi.
Maximum size of graded aggregate	= 20mm
Specific gravity of coarse aggregate, G_g	= 2.63
Specific gravity of fine aggregate, G_f	= 2.41

Bulk density of loose coarse aggregate	= 1451kg/m^3
Bulk density of loose fine aggregate	= 1548 kg/m^3
Specific gravity of cement, G_c	= 3.09
Specific gravity of fly ash	= 2.19
Specific gravity of super plasticizer	= 1.22
Volume of fine/coarse aggregate ratio	= 58/42
Volume ratio of fine aggregates to total aggregates(s/a)	= 58/100

Determination of Coarse aggregate:

Assume P.F = 1.12

Amount of coarse aggregate, W_g = P.F x W_{gL} (1-s/a)

= 1.12 x 1451 x (1-0.58)

= 682.55 kg/m^3

Determination of fine aggregate:

Amount of fine aggregates, W_s = P.F x W_{sL} (s/a)

= 1.12 x 1548 x (0.58)

= 948.42 kg/m^3

Determination of cement:

C = f'$_c$ /20

Given 0.14Mpa = 20 psi

Hence C = 80/.14 =571.42 kg/m^3

Determination of water:

Water/cement ratio for 26.6 Mpa	= 0.25
Hence quantity of water required	= 571.42 x 0.25= 142.85 kg/m^3

Determination of fly ash:

$V_{pf} + V_{pb}$ = 1- W_g / (1000 x G_g)- W_s/(1000 x G_f)-C/ (1000 x G_c)-W_{wc}/ (1000 x G_w)-V_a

=1-682.55/ (1000 x 2.63) 948.42/ (1000 x 2.41)-571.42/ (1000 x 3.09)-142.85/ (1000 x 1) -0.015

= 0.0485 kg/m^3

Total weight of Pozzolanic material(W_{pm}):

$V_{pf} + V_{pb}$ = (1+W/F) x A% x W_{pm}/ (1000 x G_f)

W_{pm} = (V_{pf} + V_{pb}) x

(1000 x G_f)/((1+W/F) x A%)

= 0.0485 x (1000 x 2.19)/ (1+0.25)

= 8.50 kg/m^3

Determination water required for fly ash (W_{wf}):

W_{wf} = W/F x W_{pm}

= 0.25 x 8.50= 2.125 kg/m^3

Determination of S.P dosage (W_{sp});

S.P dosage	=1.8% of (571.42+8.50) =10.44 kg/m^3
Water content in S.P	= (1-0.4) x 10.44= 6.26 kg/m^3

Total water content = 142.85+2.125 – 6.26

= 138.715 kg/m³

Water binder ratio (W/B) = 138.715/ (571.42+8.50)

= 0.24

	Cement	Fly ash	Fine aggregate	Coarse aggregate	S.P	Water, w/b
Quantity (kg/m³)	571.42	8.5	948.42	682.55	10.44	138.715
Proportions	1	0.015	1.66	1.20	0.018	0.24

After conducting number of trials, the following SCC mix proportions are satisfying the required fresh properties as per EFNARC specifications.

	Cement	Silica Fume	Fly ash	F A	C A	S.P	VMA	Water, w/b
Quantity (kg/m³)	680	34	344.7	915.71	750.04	19.34	1.75	241.85
Proportions	1	0.05	0.507	1.346	1.103	0.028	0.0025	0.236

1.2 Mix design using 12.5 mm size graded aggregates:

Characteristic strength = 70 MPa.

Target mean strength = 70 + 1.65 x 6 = 80 Mpa.

	= 11428.5 psi.
Maximum size of graded aggregate	= 12.5 mm
Bulk density of loose coarse aggregate	= 1494kg/m^3
Bulk density of loose fine aggregate	= 1460 kg/m^3
Volume of fine/coarse aggregate ratio	= 52/48
Volume ratio of fine aggregates to total aggregates(s/a)	= 52/100

Determination of Coarse aggregate:

Assume P.F	= 1.12
Amount of coarse aggregate, W_g	= P.F x W_{gL} (1-s/a)
	= 1.12 x 1494 x (1-0.52)
	= 803.17 kg/m^3

Determination of fine aggregate:

Amount of fine aggregates, W_s	= P.F x W_{sL}(s/a)
	= 1.12 x 1460 x (0.52)
	= 850.3 kg/m^3

Determination of cement:

C	= f'_c /20
Given 0.14Mpa	= 20 psi
Hence C	= 80/0.14 =571.42 kg/m^3

Determination of water:

Water/cement ratio for 26.6 Mpa	= 0.25

Hence quantity of water required = 571.42 x 0.25= 142.85 kg/m^3

Determination of fly ash:

$V_{pf} + V_{pb}$ = 1- W_g / (1000 x G_g)- W_s/(1000 x G_f)-C/ (1000 x G_c)-W_{wc}/ (1000 x G_w)-V_a

=1-803.17/ (1000 x 2.92) -850.3/ (1000 x 2.63)-571.42/ (1000 x 3.10)-142.85/ (1000 x 1) -0.015

= 0.02 kg/m^3

Total weight of Pozzolanic material(W_{pm}):

$V_{pf} + V_{pb}$ = (1+W/F) x A% x W_{pm}/ (1000 x G_f)

W_{pm} = (V_{pf} + V_{pb}) x

(1000 x G_f)/((1+W/F) x A%)

= 0.02 x (1000 x 2.19)/ (1+0.25)

= 35.46 kg/m^3

Determination water required for fly ash (W_{wf}):

W_{wf} = W/F x W_{pm}

= 0.25 x 35.46= 8.86 kg/m^3

Determination of S.P dosage (W_{sp});

S.P dosage =1.8% of (571.42+35.46) =10.92 kg/m^3

Water content in S.P = (1-0.4) x 10.92= 6.55 kg/m^3

Total water content = 142.85+8.86 – 6.55

= 145.16 kg/m^3

Water binder ratio (W/B) = 145.16/ (571.42+35.46)

= 0.239

	Cement	Fly ash	Fine aggregate	Coarse aggregate	S.P	Water, w/b
Quantity (kg/m^3)	571.42	35.46	850.3	803.17	10.92	145.16
Proportions	1	0.062	1.48	1.40	0.019	0.239

After conducting number of trials, the following SCC mix proportions are satisfying the required fresh properties as per EFNARC specifications.

	Cement	Silica Fume	Fly ash	F A	C A	S.P	VMA	Water, w/b
Quantity (kg/m^3)	680	34	289.3	850.3	803.17	16.82	1.75	249.1
Proportions	1	0.05	0.425	1.250	1.181	0.024	0.0025	0.257

1.3 Mix design using 10 mm size graded aggregates:

Characteristic strength	= 70 MPa.
Target mean strength	= 70 + 1.65 x 6 = 80 Mpa.
	= 11428.5 psi.
Maximum size of graded aggregate	= 10 mm
Bulk density of loose coarse aggregate	= 1480kg/m^3
Bulk density of loose fine aggregate	= 1460 kg/m^3
Volume of fine/coarse aggregate ratio	= 52/48
Volume ratio of fine aggregates to total aggregates(s/a)	= 52/100

Determination of Coarse aggregate:

Assume P.F	= 1.12
Amount of coarse aggregate, W_g	= P.F x W_{gL} (1-s/a)
	= 1.12 x 1480 x (1-0.52)
	= 795.65 kg/m^3

Determination of fine aggregate:

Amount of fine aggregates, W_s	= P.F x W_{sL} (s/a)
	= 1.12 x 1460 x (0.52)
	= 850.3 kg/m^3

Determination of cement:

C	= f'_c /20
Given 0.14Mpa	= 20 psi

Hence C = $80/0.14 = 571.42\ kg/m^3$

Determination of water:

Water/cement ratio for 26.6 Mpa = 0.25

Hence quantity of water required = $571.42 \times 0.25 = 142.85\ kg/m^3$

Determination of fly ash:

$V_{pf} + V_{pb}$ = $1 - W_g / (1000 \times G_g) - W_s/(1000 \times G_f) - C/(1000 \times G_c) - W_{wc}/(1000 \times G_w) - V_a$

$= 1 - 795.65/(1000 \times 2.92) - 850.3/(1000 \times 2.63) - 571.42/(1000 \times 3.10) - 142.85/(1000 \times 1) - 0.015$

$= 0.022\ kg/m^3$

Total weight of Pozzolanic material(W_{pm}):

$V_{pf} + V_{pb} = (1+W/F) \times A\% \times W_{pm}/(1000 \times G_f)$

$W_{pm} = (V_{pf} + V_{pb}) \times$

$(1000 \times G_f)/((1+W/F) \times A\%)$

$= 0.022 \times (1000 \times 2.19)/(1+0.25)$

$= 40.02\ kg/m^3$

Determination water required for fly ash (W_{wf}):

$W_{wf} = W/F \times W_{pm}$

$= 0.25 \times 40.02 = 10.05\ kg/m^3$

Determination of S.P dosage (W_{sp});

S.P dosage =1.8% of (571.42+40.02) =11.00

kg/m^3

Water content in S.P	= (1-0.4) x 11.00= 6.6 kg/m^3
Total water content	= 142.85+10.05 – 6.6
	= 146.3 kg/m^3
Water binder ratio (W/B)	= 146.3/ (571.42+40.02)
	= 0.239

	Cement	Fly ash	Fine aggregate	Coarse aggregate	S.P	Water, w/b
Quantity (kg/m^3)	571.42	40.02	850.3	795.65	11.00	146.3
Proportions	1	0.07	1.48	1.40	0.019	0.239

After conducting number of trials, the following SCC mix proportions are satisfying the required fresh properties as per EFNARC specifications.

	Cement	Silica Fume	Fly ash	F A	C A	S.P	VMA	Water, w/b
Quantity (kg/m^3)	680	34	289.3	850.3	795.65	15.85	1.75	260.74
Proportions	1	0.05	0.425	1.214	1.170	0.023	0.0025	0.269