CHAPTER 1
INTRODUCTION

1.1 Self compacting concrete (SCC)

It has been found through various research and practical observations that in-situ concreting is highly affected by insufficient and improper compaction and curing. Unfortunately both these factors compaction and curing are highly neglected at sites most of the times. Lack of compaction and curing produce a concrete which has reduced strength. In order to achieve a “STRONGER” concrete, the secret lies in making a Dense concrete. The key element for achieving dense concrete is proper compaction and curing.

Thus the 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. Self compacting concrete was one solution for the above problems. The main reason for the lack of quality was a reduced number of skilled workers, and it was suggested that “vibration-free concrete” might be the solution for their problems because it facilitated remained productivity to a limited number of skilled workers needed [Okamura and Ozawa 1995][118, Ouchi 2000][120, Okamura and Ouchi 2003][116]. Studies to develop self compacting concrete, including a fundamental study on the workability of concrete, were carried out by researchers Ozawa and Maekawa at the University of Tokyo.

Self compacting Concrete (SCC) is highly workable concrete with high strength and high performance that can flow under its own weight through restricted sections without segregation and bleeding [EFNARC 2002][36]. SCC requires excellent filling ability, good passing ability, and adequate segregation resistance.

SCC is produced by exploiting the benefits of high-range water reducer (HRWR) also called superplasticizers and Supplementary Cementing Material (SCM). The use of plasticizer or HRWR is essential to produce SCC. A HRWR contributes to achieve
excellent filling ability and passing ability. In addition, SCMs are incorporated in SCC mostly to enhance the strength and durability of concrete. The specimens incorporating an SCM, when exposed to chlorides exhibit significantly lower total chloride content. It may also contribute to attain good segregation resistance. In Canada and other countries, several well-known SCMs such as silica fume, ground granulated blast-furnace slag, and fly ash have been used to produce SCC [Okamura and Ozawa 1995][118, Khayat 1996][76 Persson 2001][129].

Since, self-compactibility is largely affected by the characteristics of materials and the mix proportions, it becomes necessary to evolve a procedure for mix design of SCC. Okamura and Ozawa have proposed a mix proportioning system for SCC [Okamura and Ozawa 1995][117]. In this system, the coarse aggregate and fine aggregate contents are fixed and self-compactability is to be achieved by adjusting the water/powder ratio and super plasticizer dosage. The coarse aggregate content in concrete is generally fixed at 50 percent of the total solid volume, the fine aggregate content is fixed at 40 percent of the mortar volume and the water/powder ratio is assumed to be 0.9-1.0 by volume depending on the properties of the powder and the super plasticizer dosage. The required water/powder ratio is determined by conducting a number of trials. One of the limitations of SCC is that there is no established mix design procedure yet, only guidelines are available.

SCC has many benefits over Normal Vibrated Concrete (NVC), like reduced labor for transport-placement and vibration, ease of placement operations, reduction in noise levels in absence of vibrators, energy saving, better life of formwork and better aesthetics with improved surface finishing. SCC has substantial commercial benefits because of ease of placement in complex forms with congested reinforcement [Khayat 1996][76].

In 1996, European Federation of National Associations Representing producers and applicators of specialist building products for Concrete’ (EFNARC) has drawn up the specifications and guidelines to produce better quality of SCC which have been revised in 2005. A concrete mix can only be classified as SCC if the requirements for all the following three workability properties are fulfilled (EFNARC, 2005):
1. Filling ability
2. Passing ability
3. Segregation resistance

**Filling ability**

It is the ability of SCC to flow into all spaces within the formwork under its own weight. Tests, such as slump flow, V-funnel etc., are used to determine the filling ability of fresh concrete.

**Passing ability**

It is the ability of SCC to flow through tight openings, such as spaces between steel reinforcing bars, under its own weight. Passing ability can be determined by using U-box, L-box, and J-ring test methods.

**Segregation resistance**

The SCC must meet the filling ability and passing ability along with uniform composition throughout the process of transport and placing.

Higher flowability, excellent deformability and better resistance to segregation and bleeding are some of the unique properties of SCC. The use of SCC is gaining rapid popularity in modern construction industry due to the requirement of high rise buildings and column free spaces.

Many factors influence physical and mechanical properties of concrete, such as water/cement, type of cement, use of materials having pozzolonic activity, type and particle size distribution of aggregates, type and dosage of admixtures. But even other important parameters may have a strong influence on the microstructure and, hence, on elastic and mechanical properties of concrete. These factors include concern rheological properties (cohesion and plastic viscosity), transportation, handling and placing of fresh concrete, segregation and bleeding, plastic settlement and curing. Rheological properties, in fact, can significantly modify nature and structure of the concrete interfacial transition zone (ITZ), between aggregate and
concrete paste, which is responsible for the mechanical properties, water tightness, fire resistance and durability of concrete structures.\cite{Mehta and Aitcin 1990}

The present study has attempted to develop SCC utilizing Fly Ash as a SCM and locally available materials. The key mechanical properties of SCC of two different grade of SCC have been studied. In particular, the effects of different curing techniques on various mechanical properties such as compressive, split tensile, flexural and shear strength of SCCs have been examined. The selected mechanical properties are important for the strength aspect of concrete which is normally of primary importance for concrete structures. Empirical models have been developed for relation between curing technique and the compressive strength of SCC.

1.2 Curing of concrete

Curing is the process of controlling the rate and extent of moisture loss from concrete during cement hydration. This can be achieved by: either supplying the water from outside (Ponding & Spraying), continuously wetting the exposed surface thereby preventing the loss of moisture from it, leaving formwork in place, covering the concrete with an impermeable member, application of a suitable chemical (wax etc.), mixing a suitable chemical in fresh concrete for internal curing or combination of such methods. It is noted that when we choose a particular method of curing it leads to change in temperature and humidity affecting strength of concrete.

The properties of hardened concrete, especially the strength and durability, are greatly influenced by curing since it has a remarkable effect on the hydration of the cement. The advancements in the construction and chemical industry have paved way for the development of the new curing techniques and construction chemicals such as Membrane curing compounds, self curing agents, Wrapped curing, Accelerators, Water proofing compounds etc. With the growing scale of the project conventional curing methods have proven to be a costly affair as there are many practical issues and they have been replaced by Membrane curing compounds and Self-curing agents up to some extent as they can be used in inaccessible areas, Vertical structures, Water scarce areas etc.
It is found that [Kulkarni S.B. August 2011] the chemical reactions between cement & water produces C-S-H gel which bonds the ingredients of concrete, viz. coarse & fine aggregates, mineral admixtures, etc, and converts these fragments into a rock solid mass. It is understood that blended cements require prolonged curing to convert calcium hydroxide into C-S-H gel. However, in case of OPC as well, voids within the concrete mass gets filled up and disconnected by the formation of C-S-H gel after about 10 days of curing. To have a dense microstructure and impermeability, prolonged curing is a must which leads to enhanced durability.

It is observed from the literature review that few methods of curing have been studied for SCC. However comprehensive study of curing techniques usefully applicable in field and its effect on various strengths of SCC may be appreciated. The change in microstructure of concretes due to different curing techniques may also be studied for strength and durability.

1.3 Self curing concrete

The ACI-308 Code states that “internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing Water.” ‘Internal curing’ is often also referred as ‘Self–curing.’

When the mineral admixtures react completely in a blended cement system, their demand for curing water (external or internal) can be much greater than that in a conventional ordinary Portland cement concrete. When this water is not readily available, due to de-percolation of the capillary porosity, for example, significant autogenous deformation and (early-age) cracking may result. This situation is intensified in SCC (compared to conventional concrete) due to its generally higher cement content, reduced water/cement (w/ c) ratio and the pozzolonic mineral admixtures (fly ash, silica fume etc.). Often specially in SCC, it is not easily possible to provide curing water from the top surface at the rate required to satisfy the ongoing chemical shrinkage, due to the extremely low permeability often achieved [Ambily and Rajamane 2007].
The materials that can provide internal water reservoirs are: Light weight aggregate and sand (LWA-LWS), Super-absorbent polymers (SAP), Shrinkage reducing admixture (SRA) and Wood powder. The water required for self curing depends upon chemical and autogenous shrinkages expected during hydration reactions. Water soluble alcohols are generally used as self curing agents. With conventional ingredients it is possible to design reasonably good fast track concrete mixture using admixture [Karjinni and Ahmed 2012][74].

Kumar et al. [2012][89] found that Polyethylene Glycol (PEG400) could help in self curing by giving strength on par with conventional curing. He observed that 0.5-1.0% of PEG400 by weight of cement may be used for different grades of concretes for achieving maximum strength without compromising workability.

In the present study effort has been made to understand the working and efficiency of curing methods which are generally adopted in the construction industry and compared with the conventional water curing method. Comprehensively nine techniques of curing, which can be useful for in-situ curing, have been selected: Traditional immersion or pond method, Hot water, Ice, Sea water, Membrane polyethylene film, Gunny Bag or Wet Covering, external coating of wax based Curing Compound, Dry Curing, Chemical based Internal curing using Polyethylene Glycol 600 (PEG600) and Polyethylene Glycol 1500 (PEG1500). The effect of these curing techniques on mechanical properties of two different grades M30 & M50 of SCC is studied and compared with effect on NVC of similar grade. In addition, self curing technique is also attempted using chemical agent.

The outcome of this study will extend the scope of SCC by increasing sustainability of concrete and thereby sustainability of global resources especially time, energy and water and thus generate new opportunities for the construction industry. Although there is scarcity of water for construction in very few areas in India, the findings of the present study will be useful for the countries with water and labor scarcity.

1.4 Organization of the thesis

The thesis is divided into following chapters:
**Chapter 1:** (Introduction) Introduces SCC and curing, with a short overview of the present research and briefly presents the scope of the thesis. It also describes effect of various parameters, applications and understanding of different techniques for curing and its significance.

**Chapter 2:** (Literature review & Research objectives) This chapter outlines the significant studies conducted on SCC from definition, characteristics, advantages, application and economy. This chapter describes historical development and merits of SCC over conventional concrete, and various applications of SCC. Literature review encompasses the background of SCC, highlights the major issues of SCC, present scenario in India, describes various constituent materials of SCC including their key aspects, fresh properties of SCC, mix design, testing of hardened properties such as compressive strength, split tensile strength, flexural strength and shear strength of SCC and its modeling. Various techniques of curing including self curing have been studied and finally identify several research needs and give the research objectives.

**Chapter 3:** (Materials) Discusses the selection and testing of constituent materials, describes the preparation and emphasizes their usefulness. It covers different curing techniques used in this research and development of self curing self compacting concrete (SCSCC) and its mechanism.

**Chapter 4:** (Methodology) This chapter presents the details of the experimental program such as mix design for trial mixes and reference mix for SCC and NVC, dosages of chemicals and mixing procedures, planning of concrete casting, curing and testing.

The chapter outlines the methodology for assessment of fresh properties of SCC. The properties are assessed as per EFNARC guidelines. It presents the formulation; preparation and testing of various mix and gives the test results for the filling ability, passing ability and segregation resistance. These results highlight the effects of superplasticizers and water-powder (W/p) ratio.

The later part of the chapter includes the preparation of hardened test specimens, describes the test setup, casting schedule of specimen and testing of various hardened concretes, discusses the hardened properties such as compressive
strength, split tensile strength, flexural strength and shear strength of reference SCCs and NVC, highlights the importance of these results, discusses the effects age of concrete, curing techniques and shows the relationships between different hardened properties.

Chapter 5: (Results: Fresh properties and compressive strength) The chapter presents the results of the experimental program. Firstly, it outlines the assessed fresh properties of M30 and M50 grade SCC and compares with standards suggested by EFNARC. Secondly, the results of compressive strength of all the grades of hardened SCC and NVC for different curing techniques is presented, discussed and compared with reference to available standards and previous research. The chapter also includes development of mathematical models for SCCs such as age v/s compressive strength; compressive strength by immersion technique v/s other selected curing techniques. Lastly the microstructure images of few selected concretes and its analysis is presented.

Chapter 6: (Results: Splitting tensile, flexural and shear strength) The chapter presents the results of the experimental program of splitting tensile, flexural and shear strength of all the grades of hardened SCC and NVC for different curing techniques. The results are discussed and compared with reference to available standards and previous research and the relation between compressive and split tensile strength and flexural strength is established.

Chapter 7: (Conclusion and future scope of work) This chapter presents the main conclusions from this study and future scope of work.