INTRODUCTION
CHAPTER 1
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1.1 Self Compacting Concrete

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. With the introduction of super plasticizers and viscosity modifying admixtures, it is now possible to produce concrete with high fluidity and good cohesiveness that does not require external energy for compaction. Self compacting concrete is a form of concrete that is capable of flowing into the congested interior of formwork, passing through the reinforcement and filling it in a natural manner, consolidating under the action of its own weight without segregation and bleeding. Self compacting concrete has many advantages over the conventional concrete. Some of the advantages of SCC are reduction in manpower, excellent surface finishes, easier placing, free from honeycombs, reduced permeability, improved durability, reduction in noise levels, absence of vibration and ensured compaction.

Self compacting concrete is a fluid mixture suitable for placing in structures with congested reinforcement without vibration. Self compacting concrete development ensures a good balance between deformability and stability. This hardened concrete is dense, homogeneous and has better engineering properties and durability when compared with the traditional vibrated concrete.

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 labour 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. SCC provides ample opportunity to use the waste materials such as flyash, silica fume, quarry dust etc thereby reducing the disposal problems of these waste materials.
The introduction of SCC can positively change the construction process and eliminate necessity for mechanical vibration thus improving the working environment and the health and safety of workers. Vibrators used for the compaction of concrete are a major source of noise on construction site and in concrete precast factories. Self compacting concrete technology eliminates the use of vibrating equipment and minimizes the risk of injuries or harm caused by exposure to continuous high frequency noises and mechanical vibration.

The development of self compacting concrete is considered to be one of the most significant developments in the building material domain. This is due to the following benefits that this concrete offers:

- **The technology of producing self compacting concrete can be considered as an energy conservation process, since the electricity consumption for vibration is eliminated.**
- **The mix of self compacting concrete incorporates industrial wastes, such as flyash, silica fume, quarry dust etc.,**
- **Use of self compacting concrete increases the lifetime of the construction moulds and reduces the necessity for skilled workers.**
- **SCC can be used for all types of structures due to the fact that it can be pumped for very long distances without segregation.**
- **From the contractor’s point of view, costly labour operations are avoided improving the efficiency of the building site.**
- **The concrete workers are free from vibration which is a huge benefit for their working environment.**
- **When vibration is avoided from casting operations, the workers experience a less strenuous work with significant less noise and vibration exposure.**
- **Faster placement with less labour.**
- **SCC offers excellent surface finish and often plastering can be avoided.**

### 1.2 Effect of Fire on Concrete

Structural concrete is one of the most commonly used construction materials in the world. Concrete has been used in construction for more than a century as a main
construction material owing to its significant resistance in compression. Much attention has been paid to the mechanical and fracture properties of concrete at room temperature, including strength, stiffness, toughness, brittleness and fracture energy. The rapidly advancing technology of structural design and fire safety has created a need for more precise information on the behaviour of structures during fires.

The fire may cause different degrees of damage to the structure. The structure may be completely burnt or destroyed or only its surface may be slightly damaged. In the first case the whole of damaged portion has to be replaced during restoration of structure while in the later case, only repair and finishing may be required. The extent of damage caused to the structure during a fire depends on the duration of fire and the temperature to which the structure was subjected during the fire. High temperature during a fire reduces the strength of reinforced concrete structures due to change in the strength and deformability of materials, reduction in cross sectional dimensions, weakening of bond between the reinforcement and concrete which determines the structural action under the load.

The maximum temperature reached during a fire is normally estimated indirectly from the melting of ingredients of concrete. A temperature of 1000°C to 1100°C has been observed during fire in residential buildings. The duration of this fire was mostly found to be between 1 and 2 hours. It has been observed that during fires in public buildings, temperature rises up to 1100°C to 1200°C and the fire duration may exceed 2 to 3 hours in some cases. Still higher temperatures have been observed during fires in industrial buildings and ware houses in which considerable quantities of solid and liquid lubricants are stored. The fire in industrial buildings may last for more than two hours and the temperature may go beyond 1300°C. Thus duration of a fire and maximum temperature reached can vary over a wide range. Temperature of 1000 to 1100°C during fires which lasted for a duration of 1 to 2 hours has been observed more frequently.

An accurate estimate of the performance characteristics of structures which have been damaged in a fire helps in developing effective restoration or rehabilitation
measures. The performance characteristics take into account the physicochemical and mechanical properties of the materials burnt.

The strength and stiffness of concrete and steel decrease as the temperature of the members increases. Dimensional changes may also occur at high temperatures. The changes in strength and stiffness of concrete are influenced by the type of cement, type of aggregate, nature of admixtures present and water content. The stresses due to thermal strain cause the beam, column or slab to crack or spall, thus reducing concrete area available to resist the applied forces.

Concrete is a poor conductor of heat, but can suffer considerable damage when exposed to fire. Unraveling the heating history of concrete is important to forensic research or to determine whether a fire exposed concrete structure and its components are still structurally sound. Assessment of fire damage on concrete structures usually starts with visual observation of colour change, cracking and spalling. On heating, a change in colour from normal to pink is often observed and this is useful since it coincides with the onset of significant loss of concrete strength.

Concrete elements exposed to fire experience temperature gradients and, as a result, undergo physical changes or spalling, thereby exposing steel reinforcement. The structural property of concrete that has been most widely studied as a function of temperature exposure is the compressive strength. High Performance Concrete (HPC), is being increasingly used in a number of building applications, where structural fire safety is one of the major design considerations. Many research studies clearly indicate that the fire performance of HPC is different from that of Normal Strength Concrete (NSC) and that HPC may not exhibit the same level of performance as NSC under fire. Relatively few studies have been undertaken on behaviour of self compacting concrete under elevated temperature.

1.3 Present Issues on Performance of Concrete Under Fire

Concrete may experience strength loss when exposed to temperatures higher than 300°C. High strength concrete is more susceptible to explosive spalling when exposed to temperatures above 300°C. The basic understanding of how high
temperatures cause explosive spalling in concrete has not been completely understood. Many attempts are being made to develop models that will predict the behaviour of materials during and after fire.

A combination of experimental and analytical investigations is needed to understand the influence of parameters that affect the performance of concrete under fire. Experimental data which include measurement of internal pore pressures and moisture distribution are also needed for validation of analytical predictions. Effects of compositional and processing factors (curing methods, maturity and self desiccation) on spalling tendency should be assessed. The effects of exposure conditions such as, rate of temperature rise, maximum temperature, uniformity of exposure conditions etc should be examined.

Type of aggregate may also influence the performance of concrete under elevated temperatures. Carbonate aggregate (predominantly limestone) provides higher fire resistance and better spalling resistance in concrete than siliceous aggregate (predominantly quartz). This is mainly because carbonate aggregate has a substantially higher heat capacity (specific heat) and low thermal conductivity, which is beneficial in preventing spalling. The temperature at which crushing strength of concrete is reduced to half its initial value is termed as critical temperature. The critical temperature depends upon the type of aggregate used in the concrete. This temperature is 550ºC for concrete with granite or sandstone aggregates and 700ºC for concrete with limestone. Other techniques based on the scanning electron microscope should be developed for analysis of micro structural damage or changes of samples taken from the fire affected structure.

High temperature exposures cause vaporization of pore water in concrete. The slow transport of water and water vapour then leads to development of high pore pressure. Since the elevated pore pressures may be a cause of damage in the concrete, accurate predictions of these pressures need to be developed. Because a sharp interface develops between the saturated and unsaturated parts of the concrete (liquid: vapour interface), it is possible that existing analytical and numerical tools may be inadequate. Therefore the development of new mathematical tools needs to
investigated. The role of polypropylene fibers, in terms of the mechanism by which they can give fire protection, needs to be understood.

Concrete is a viscoelastic material and undergoes dimensional changes with changes in moisture levels. Fire will lead to removal of large amounts of water from concrete, with correspondingly high amounts of induced shrinkage. Thermal stresses and pore pressure caused stresses can be partially relieved by creep, although the amount of relief will be determined by the relative time scales of relaxation processes versus water loss, since the viscoelastic properties of concrete are dependent on water content.

Most of the data available on performance of HSC during fire were obtained by testing HSC specimens using different heating rates, specimen sizes, shapes and loading combinations. These differences may result in incompatible test results, especially for HSC since the rate of pore pressure build up and the moisture escape path have an important influence on the performance of the test specimen. In order to permit the comparison of data from different research programs, it will be necessary to establish a suite of standard test methods. Factors such as maturity and conditioning prior to testing need to be studied and standardized. Experimental studies should also include measurements of other mechanical properties such as tensile strength, time dependent behaviour, and fracture mechanics parameters. The effects of specimen shape and size and previous load histories on measured properties should also be examined. In addition, other material characteristics, including transport properties, thermal properties, sorption isotherms, and water release during dehydration, need to be measured as functions of temperature to provide input data for numerical models.

1.4 Aims and Significance of the Research

Fire resistance of structures is an important safety aspect which is to be considered in the design of buildings. The resistance of materials to fire had been studied by few researchers in the past. The behaviour of materials subjected to higher temperature is a known phenomenon. However the behaviour of composite structural members like Reinforced Cement Concrete (RCC) beams, column etc.,
where two or more members act together under fire load has not been studied extensively. The Indian standards for plain and reinforced cement concrete IS 456:2000 has a clause for fire resistance. As per this clause, fire resistance of RCC elements is a function of cover to the reinforcement and the size of the element. As per the code, higher cover results in higher fire resistance. However the fire resistance depends on many other parameters such as grade of concrete, grade of steel, density of concrete, reinforcement percentage, intensity and duration of fire etc. Since SCC is a new material, only very few literature is available on its fire resistance. In order to completely understand the behaviour of SCC beams under elevated temperature, an experimental and analytical investigation has been carried out during the present research work.

1.5 Objectives of the Research

The objectives of the research work are given below:

- To study the behaviour of self compacting concrete subjected to elevated temperatures.
- To carry out an experimental investigation and to determine the compressive strength, tensile strength, flexural strength, stiffness and energy absorption capacity of heated SCC specimens.
- To carry out an experimental and analytical investigation to understand the effect of cover on the performance of SCC beams subjected to elevated temperatures.
- To carry out an experimental and analytical investigation to understand the effect of tension reinforcement percentage on the performance of SCC beams subjected to elevated temperatures.
- To carry out an experimental and analytical investigation to understand the effect of grade of concrete on the performance of SCC specimens subjected to elevated temperatures.
1.6 Organization of Thesis

The thesis consists of six chapters

- An exhaustive review of literature relevant to the objectives of the study has been carried out during the study and the details are presented in chapter 2.
- Chapter 3 deals with development of SCC with SP and VMA. Material properties and workability tests on SCC are discussed in this chapter.
- Chapter 4 explains the details of the Finite element analysis of reference and heated SCC specimens. The details of the elements used for modelling the concrete and steel bars, rate of heating and cooling, stress strain behaviour of SCC are given. The results of the finite element analysis are compared with those of the experimental investigation and their details are given in this chapter.
- Chapter 5 deals with the experimental and analytical investigation of reference and heated SCC specimens. The details of the experimental and analytical investigations, results of the experimental and analytical investigations and the findings that are obtained from the investigations are presented in this chapter.
- The conclusions derived based on this study and the scopes for further research are given in chapter 6.