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1.1 GENERAL
Concrete is the most widely used construction material in the world. The per capita global consumption of concrete is approximately estimated to be of two tonnes per year. In India, from the last decade mega construction projects are successfully implemented and executed with the use of concrete. The type and quality of concrete being used have undergone varied transformation. Globalisation of the Indian economy, emphasis on durability, appreciation of the quality assurance in general and thrust on infrastructure development has contributed to this growth and transformation. (Praveen Kumar et al., 2003)

The major transformations in the concrete technology include high strength concrete, high performance concrete and self-compacting concrete. These transformations of concrete are discussed in brief as follows.

1.1.1 High strength concrete
High strength concrete is obtained by making optimum use of basic ingredients that constitute the normal-strength concrete. In addition to selection of a high-quality Portland cement, producers optimize aggregates, minimise the water-cement ratio and optimize the combination of materials by varying the proportions of cement, water, aggregates, and admixtures.
This concrete has high cement content which increases the heat of hydration and higher shrinkage leading to potential cracking thereby affecting the long-term performance of structures. (Praveen Kumar et al., 2003)

1.1.2 High Performance concrete (HPC)
During past decade, the potential of Portland cement in terms of strength has been enhanced through use of mineral admixtures. The use of mineral admixtures marked the opening of a new era for designing concrete mix for higher and higher strength. It was recognised over a period of time, that it is not only strength of the concrete that is important, but also other parameters of concrete like long term mechanical properties, low permeability, early age strength, volume stability, placement, compaction and service life in severe environment. This has led to development of high performance concrete.
American Concrete Institute has defined HPC as concrete which meets requirements of special performance which cannot always be achieved by using conventional materials, normal mixing, placing and curing practices. It is a concrete made with appropriate materials according to the selected mix design; properly mixed, transported, placed, consolidated and cured so that the resulting concrete will provide an excellent performance.

HPC is a concrete which satisfies, certain criterion proposed to overcome the limitations of conventional concrete. In addition to high strength, the other parameters considered are the structure in which the concrete is to be used, the environment in which the structure is located, the type and number of loads to which the structure shall be subjected. Therefore, HPC is often has high strength, but mere high strength concrete may not be of high performance.

The conventional concrete has four ingredients as cement, aggregate, admixtures and water, whereas HPC has five ingredients. Fifth essential ingredient of HPC is mineral admixture. Mineral admixtures such as Flyash, rice husk ash, Ground Granulated Blast Furnace (GGBFS), lime powder and silica fumes have been used in development of HPC. (A. K. Tiwari, 2005)

Practical experiences have revealed that addition of mineral admixture to concrete helps in achieving the compressive strength or durability performance. At the same time, chemical admixtures such as high-range water-reducers are needed to ensure that the concrete is easy to transport, place and finish. Mix proportions for high-performance concrete (HPC) are influenced by factors like specified performance properties, locally available materials and cost.

1.1.3 Self Compacting Concrete
The quality of concrete has been improved in HPC but the basic techniques of compacting concrete remained the same as the conventional concrete. Conventional concrete requires vibration immediately after it is placed to eliminate entrapped air. In conventional concrete compaction is carried out by workers with a vibrator. One of the problems associated with compaction by vibration is the assurance of quality especially in complex structures due to insufficient compaction during casting. Insufficient compaction substantially lowers ultimate performance of concrete. Apart from reducing the strength of concrete, lack of compaction influences the permeability of concrete, which in turn reduces the durability of concrete structures.
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Vibration also creates health problems in workers. It causes Hand Arm Vibration Syndrome (HAVS) due to prolonged or continuous use of pneumatic or other types of hand-held vibration compactors. High level of noise generated in the compaction process may cause damage to the ear and even lead to other psychological problems also.

As shown in figure 1.1 even in adequate and inadequate compaction many serious problems can arise. Hence, the need of concrete was felt that provide durability without the requirement of vibration. (YanKaLok, 2007)

![Figure 1.1: Problems Caused by Compaction](image)

Figure 1.1: Problems Caused by Compaction

All the factors delineated above, brought out the need for some significant breakthrough in concrete construction from the point of view of quality assurance and increased efficiency, as well as improved working conditions. The introduction of self-compacting concrete (SCC) technology has significantly changed the way in which concrete operation is executed. It enables the improvement in concrete construction techniques for increased and efficient results. Elimination of discontinuous mechanical vibration makes concrete structures more consistent with reliable properties. General enhancement of the working environment is paid off by improvement in health and safety of workers, which also adds to the increase in productivity. SCC is new and improved way of executing the concreting operation, while maintaining homogeneity while dispensing the need for external vibration.

Self-Compacting Concrete (SCC) is defined as a category of High Performance Concrete that has excellent deformability in the fresh state and high resistance to segregation and can be placed and compacted under its self-weight without applying vibrations. It is an innovative concrete that does not require vibrations during placing and compaction. It is able to flow under its own weight, completely filling formwork...
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and achieving full compaction even in congested reinforcement without segregation and bleeding.

The necessity of this type of concrete was proposed by Okamura in 1986. The fundamental study on the workability of self-compacting concrete had been carried out by Ozawa and Maekawa at University of Tokyo in 1989.

Achieving self compactability involves high workability apart from resistance to segregation. For the concrete to be self-compacting it should have filling ability, passing ability and resistance against segregation.

(EFNARC Guidelines for SCC, 2002)

- **Filling ability**- It is the ability of SCC to flow into and fill completely all the spaces in the formwork.
- **Passing ability**- It is the ability of concrete mix to pass through obstacles like narrow sections in the formwork and closely spaced reinforcement bars without getting blocked by interlocking of aggregate particles.
- **Resistance to segregation**- Segregation resistance of self-compacting concrete is its capability to retain homogeneity in the distribution of ingredient in fresh state both during static and moving condition i.e. during mixing, transportation and placing. It is dependent on viscosity of the mix in the fresh state.

1.2 POTENTIAL BENEFITS OF SCC

The Potential benefits of SCC related to environment, cost, quality and health are explained below

a) **Environment**: The use of SCC completely eliminates the need of vibration, which improves the environment. Jost Walraeven (2003) had reported that using self-compacting concrete in precast industry decreases noise level from 93 dB to far below critical level of 80 dB for which no precautionary measures like ear protection are necessary. Use of supplementary cementing materials such as flyash, rice husk ash, silica fumes etc. help to decrease environmental hazards and green house gas emission. Fewer labourers and less equipment on site result in lower working cost, better working environment, better productivity and reduction in number of construction accidents.

b) **Economics**: The Cost of equipment, labour and time that are used during compaction are saved entirely. Self compacting concrete requires large quantity of
powder or filler material. The filler content in SCC plays an important role. It not only provides flowability to concrete but also replaces some amount of cement. As the cost of fillers is less than that of cement, overall cost of construction is reduced.

c) **Quality**: SCC is homogeneous suspension which flows through every corner of formwork and gaps of reinforcing bars. Self compacting concrete gives excellent surface quality. It does not require finishing work unlike conventional concrete. Self-compacting concrete with a similar water-cement or water-binder ratio will usually have a slightly higher strength compared to the traditional vibrated concrete, due to an improved interface between the aggregate and hardened paste.

d) **Health**: SCC avoids Hand Arm Vibration Syndrome (HAVS) caused due to vibration. It prevents noise pollution which may damage the ear or create psychological disorder problems in workers.

### 1.3 BENEFITS OF SCC TO STAKE HOLDERS

The high deformability of SCC and the elimination of vibration offer substantial benefits to the quality of concrete structures and to the construction process. There are three major advantages that SCC technology offers to the concrete construction sector: productivity improvement, design opportunities and an improvement of working environment.

It also brings benefits to stake-holders viz: architects, designers, contractors and concrete manufacturers. *(MichaleKharpko, 2007)*

a) **Architects**

Concrete structures made with SCC have a high quality form finish. Achieving finer details are no longer a problem with SCC.

b) **Designers**

When designed for it, SCC can consistently produce very high strength concrete. It would be quite normal for SCC to have 30 to 60 MPa of compressive strength. High strength, flowability and the passing ability of SCC allows for smaller, heavily-reinforced sections to be designed, which potentially lead to lighter structures and lower material usage without compromising on the strength.

c) **Contractors**

SCC technology allows the concrete construction process to be accelerated, as it requires less labour to cast structures and generally much less effort for its placement. SCC can be placed by pumping from the top or from the bottom of the formwork by bucket or skip.
Elimination of the need to vibrate concrete produces significant improvement in the working environment and in the health and safety of workers. Exposure to harmful noise levels is recognised as a serious occupational hazard which can now be reduced if not altogether eliminated. Not only is the noise directly detrimental to the workers’ hearing, but also it creates difficulties in effective communication.

There is also an increasing awareness of ‘hand-arm vibration syndrome’ also known as ‘white finger syndrome’ caused by regular or prolonged use of vibrators. Self-compacting concrete technology eliminates the use of vibrating equipment and so minimizes the risk of injuries or harm caused by exposure to continuous high frequency noises and mechanical vibration.

d) **Concrete Manufacturers (Precasters)**

Precast concrete production is more suitable to the implementation of automation. In Europe, the precast concrete industry is using SCC at much greater volumes than the construction industry. Some factories have converted to 100% usage of SCC and are fully automated. SCC has enabled improvement and improved the working environment.

### 1.4 LIMITATIONS IN APPLICATIONS OF SCC

Inspite of lot of research in SCC, there are few limitations in widespread applications of SCC. F.Csigh (2007) highlighted the opportunities and limitations in utilisation of SCC as under

a) **Lack of standards:** The most significant limitations concern the lack of established reliable test standards which can quantify properties of SCC. Testing methods have yet not been included in Indian Standard Code for the present. In order to accurately assess quality, uniform standards must exist for SCC that can be accepted and used in practice. EFNARC has recommended L-box test, V-funnel test, J-Ring test, U-box test & Fill box test for determining rheological properties of SCC.

b) **Standard Mix Design Procedure:** There is no specific mix design procedure for any grade of concrete which can be directly adopted for application. Country wise it would be different and also available design may need to be modified. Standard mix design procedure is yet to be established. It is an inherent obstacle to the wider application of SCC and its rapid spread all over the world.

c) **Lack of Awareness:** Lack of awareness in all sections of society is a significant hindrance to the expanded use of SCC in the immediate future.
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**d) Higher Cost:** One of the obvious limitations in producing SCC as compared to conventional concrete is the higher costs for the admixtures and quality-control testing methods needed for concrete.

**e) Need of Special Formwork:** The pressure exerted by SCC on formwork is higher than that of conventional concrete. It requires special formwork which can withstand a pressure of 8 to 10 t/m². SCC’s high fluidity requires proper sealing to avoid leakage.

**f) Other factors:** SCC is suspected of a higher shrinkage cracking tendency than normal concrete. SCC mixtures are usually designed with a higher volume of paste i.e., lower aggregate content than ordinary concrete. The higher the volume of paste, the lower is the modulus of elasticity and higher the creep.

**1.5 USE OF MINERAL ADMIXTURES IN SCC**

Self-compacting concrete has the potential to consume a large amount of industrial by-products/ waste as powder material. These waste materials are less energy intensive material, mainly industrial by-products requiring little or no processing. **P.L. Domone (2005)** analyzed Sixty eight case studies of Self Compacting Concrete during 1993-2003. It provides the idea about materials used for SCC, range of properties and mix proportions of SCC. Various mineral admixtures like flyash, silica fumes, limestone powder and GGBFS have been used for production of SCC. These are also called as mineral admixtures which contribute to the properties of hardened concrete through physical and chemical processes including pozzolanic activities partially replacing cement. These are siliceous and aluminous material, which chemically react with calcium hydroxide liberated on hydration, to form compounds, possessing cementitious properties.

Use of these materials in SCC improves properties in fresh as well as hardened state. From worldwide research, it can be inferred that binary or ternary blend of flyash, Rice husk ash, Metakaolin, GGBFS or Silica fumes not only improves rheological properties of SCC but also compressive strength of concrete, increased resistance to Sulphate attack, resistance to freezing and thawing, alkali-silica reaction, reduction of micro cracks and increased impermeability of concrete besides reduced cost.

Incorporation of these waste materials in concrete achieves following objectives:

1. Solves problem of their disposal thereby rendering the environment clean.
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2. Reduces the raw material and energy requirement in cement manufacturing, as these products partially replace cement in concrete and reduce consumption of cement. (A. K. Mullick, 2007)

1.6 WORLD-WIDE CURRENT STATUS OF SCC
Self-compacting concrete originated in Japan in 1990 and worldwide interest has been growing since then. In the light of experience of last 17 years in this technology, Japan now produces around 400,000 m$^3$ of SCC annually which is being used for different types of projects from bridges to buildings. SCC is being used in large quantities in many countries around the world. RILEM, France played major role in widespread utilisation of SCC in Europe. In Italy, Netherlands, Spain and other European countries about 30% of concrete used is SCC. Utilisation of this technology for precast construction in United States has increased from 1% in 2000 to almost 15% today. (Ouchi et al., 2003)

In India, the development of concrete possessing self-compacting properties is still very much in its initial stages. During the last couple of years, few attempts were made in the laboratories and in the field; to develop and apply SCC. It was also used by Nuclear Power Corporation of India Ltd. at Kaiga and Rajasthan Atomic Power Project (RAPP). Some pioneering efforts have been made in Delhi Metro Project. In the near future, there is every prospect of considerable usage of SCC, especially in special applications.

Over the last two decades, significant amount of work has been carried out on self-compacting concrete all over the world. The potential use of SCC has been effectively demonstrated in some countries. Due to inherent advantages it has caught the attention of engineers of Europe, UK and now in India also.

Case study of Delhi Metro Project, SCC in Nuclear Power Plants, Ritto Bridge, Higashi-Oozu Viaduct and SodraLanken Project (SL), Sweden are highlighted below.

a) Delhi Metro Rail Project
In Delhi Metro Rail Project, the adoption of SCC was considered essential on account of congested reinforcement around steel stanchion, which had to be concreted in a single pour. It was also used in columns, for permanent lining across the cross passage between tunnels and dome shape station roofs. M.S. Shetty, Klaus Muenz and Norben Gall (2005) have presented the case study on Delhi Metro Project. The SCC
was designed as M35 grade and a target mean strength adopted was 43 MPa. As against the required strength the results obtained varied from 44 to 49 MPa at 28 days. About 10000 cum of SCC was poured at 40 locations in the project and was the largest quantity of SCC poured in India so far.

**Photograph 1.1 : Delhi Metro Rail Project**

**b) SCC in Nuclear Power Plants**

In Nuclear Power Plants most of the structures have congested reinforcement with a result, pouring and compaction of concrete become almost impossible. Utilisation of SCC in construction of some of nuclear power projects in India is given below in Table 1.1

**Table 1.1: Nuclear Power Projects in India Constructed Using SCC**

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Name of Project</th>
<th>Location</th>
<th>Grade of Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rajasthan Atomic Power Project Unit 5 &amp; 6</td>
<td>Beams, columns and walls in Nuclear Power Plant</td>
<td>M30</td>
</tr>
<tr>
<td>2</td>
<td>Kaiga Atomic Power Project Unit 3 &amp; 4</td>
<td>Pump house, Turbine building, control building and tunnel</td>
<td>M30</td>
</tr>
</tbody>
</table>

**Photograph 1.2: Rajasthan Atomic Power Project**
c) Ritto Bridge, Japan
A typical application example of Self-compacting concrete is Ritto Bridge with the highest pier height of 65m. Very dense reinforcement and high strength concrete was required to meet the earthquake resistance standards, hence high strength self compacting concrete of grade M50 was used for this bridge. Over 12,000 cum of SCC was placed successfully in the piers of this bridge.

Photograph 1.3: Ritto Bridge, Japan
d) Higashi-Oozu Viaduct, Japan
Precast, prestressed T-girders were used for main girders of the Higashi-Oozu Viaduct. In the beginning of the fabrication, the conventional concrete with slump of 80mm was proposed. However, SCC was preferred because of congested reinforcement, desired surface finishing and reduced noise pollution. Utilisation of SCC in the project increased material cost by 4%, decreased labour cost by 33% and decreased overall cost by 7%.

e) The SodraLanken Project (SL) Stockholm, Sweden
SodraLanken Project (SL), one of the largest infrastructure project costing 800 million USD was executed in southern parts of Stockholm. It is 5.5 kilometers long highway, four kilometers out of which run through underground tunnels. SCC has primarily been used in areas difficult to compact by normal vibration like tunnel lining, underground installation structures, tunnel entrances and retention walls.

Photograph 1.4: The SodraLanken Project (SL) Stockholm, Sweden
Table 1.2: Comparison of Self Compacting Concrete used for Case Studies

<table>
<thead>
<tr>
<th>Description</th>
<th>Delhi Metro</th>
<th>Nuclear Plant</th>
<th>Power Plant</th>
<th>Ritto Bridge</th>
<th>Higashi-Oozu Viaduct, Japan</th>
<th>SodraLanke Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade of SCC</td>
<td>M35</td>
<td>M25</td>
<td>M30</td>
<td>M50</td>
<td>M50</td>
<td>M50</td>
</tr>
<tr>
<td>Cement(Kg/m³)</td>
<td>330</td>
<td>225</td>
<td>225</td>
<td>470</td>
<td>457</td>
<td>440</td>
</tr>
<tr>
<td>Fine Aggregate(Kg/m³)</td>
<td>917</td>
<td>988</td>
<td>978</td>
<td>868</td>
<td>840</td>
<td>880</td>
</tr>
<tr>
<td>Coarse Aggregate(Kg/m³)</td>
<td>764</td>
<td>624</td>
<td>713</td>
<td>841</td>
<td>744</td>
<td>720</td>
</tr>
<tr>
<td>Water(Kg/m³)</td>
<td>163</td>
<td>180</td>
<td>165</td>
<td>155</td>
<td>175</td>
<td>168</td>
</tr>
<tr>
<td>Mineral Admixture(Kg/m³)</td>
<td>Flyash 150</td>
<td>Flyash 225</td>
<td>Flyash 225</td>
<td>Flyash 118</td>
<td>Limestone Powder-160</td>
<td></td>
</tr>
<tr>
<td>Water-Cement Ratio</td>
<td>0.34</td>
<td>0.4</td>
<td>0.36</td>
<td>0.33</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>3.12Lit/m³</td>
<td>4.27Kg</td>
<td>5.17Kg</td>
<td>6.11 Kg/m³</td>
<td>1 %</td>
<td>0.5 Lit/ m³</td>
</tr>
<tr>
<td>VMA</td>
<td>1.2Lit/m³</td>
<td>0.45Kg</td>
<td>1.35Kg</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Slump flow Test (mm)</td>
<td>670</td>
<td>690-710</td>
<td>640-700</td>
<td>630</td>
<td>665</td>
<td>740</td>
</tr>
<tr>
<td>Compressive Strength (MPa)</td>
<td>47</td>
<td>35.5</td>
<td>39.6</td>
<td>74</td>
<td>71</td>
<td>70</td>
</tr>
</tbody>
</table>

1.7 PROBLEM STATEMENT
The present problem being undertaken for the purpose of this study entitled; “Development of High Strength Self Compacting Concrete Using Blend of Flyash and Rice Husk Ash” is stated as below.
‘Development’ means formulation of concrete mix by using ingredients in different proportions.
‘High Strength’ refers to the concrete with compressive strength more than conventional concrete.

‘Self -Compacting concrete’ has special performance of self-compaction during the process of placement without segregation and bleeding without any external energy input through vibration.

‘Blend’ means use of flyash and Rice Husk Ash to obtain Self Compacting Concrete

1.7.1 Broad Objectives of Study

The main objectives of this study are to develop SCC using the blend of flyash from and Rice Husk Ash.

1.7.2 Importance of Study

SCC was developed in 1988 in Japan. From Japan, technology spread through Asia and reached Europe around 1993 and now it is being used worldwide. In India, it has been used as ‘special concrete’ only in large companies. Investigative experimentation are going on in laboratories as well as in the field to develop and use self-compacting concrete. It has not been widely used in India except for few projects like Delhi Metro Project and Nuclear Power Plants. One of the bottlenecks in the use of self-compacting concrete as a standard concrete is its economical viability. In order to arrive at the economical SCC, it is necessary to incorporate materials like flyash and rice husk ash as filler which will limit the use of Portland cement. It not only reduces cost but also improves the engineering properties of concrete. Rice Husk Ash is the by-product of agro waste and Flyash is industrial waste product from Thermal Power Station. Utilisation of these waste products as cement replacement will not only improve microstructure and consequently the durability properties of concrete, but also will avoid the environmental and ecological damages caused by quarrying and exploitation of raw materials like limestone for making cement. Substitution of these waste materials for cement shall also help to conserve natural resources.

1.7.3 Scope of Research Work

Self-compacting concrete requires large quantity of powder or filler material. It is necessary to investigate the utilization of filler material in self-compacting concrete. In the present study, flyash and rice husk ash has been used as powder material, where flyash has been obtained from GGSTP, Ropar and rice husk ash obtained from nearby industrial Area of Punjab. The tests on Self compacting concrete have been conducted in laboratory shall be conducted using the equipments being fabricated using the
specifications laid down by EFNARC. The final results from exhaustive analysis may be recommended for use in various projects both big and small.

1.8 ORGANISATION OF THE THESIS
The entire thesis has been divided into five chapters. The first chapter is introduction to self-compacting concrete wherein the main objectives, necessity/need and scope of the investigation have been stated.

The second chapter presents the literature review. Available literature on various aspect of self-compacting concrete is presented and critically evaluated to identify the gap and establish the need for the present study.

The third chapter presents the details of the experimental programme/ laboratory work. The chapter includes properties of materials used for experimental investigation, mortar flow tests, SCC trial mix design and determination of fresh and hardened properties of SCC trial mixes.

The fourth chapter deals with the test data and analysis of the test results obtained on the samples. The model developed using ANFIS (Adaptive Neuro Fuzzy Inference System) to predict 28 days compressive strength of Self compacting concrete has been discussed in this chapter.

The fifth chapter presents discussion of the test results and comparison of the results with the work carried out by other researches in detail.

The sixth chapter presents the conclusion of the study and identifies the scope for further research work.

The list of reference has been appended. The appendices mentioned during the chapters are also attached. The lists of publications based on the present research work are also appended in the end.