CHAPTER – I
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INTRODUCTION

1.0 DEVELOPMENT OF SELF COMPACTING CONCRETE (24)

For several years beginning in 1983, the problem of the durability of concrete structures was a major topic of interest in Japan. The creation of durable concrete structures requires adequate compaction by skilled workers. The designs of modern reinforced concrete structures become more advanced, the designed shapes of structures are becoming increasingly complicated and heavy reinforcing is no longer unusual. Furthermore, the gradual reduction in the number of skilled workers in Japan’s construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structure independent of the quality of construction work is the employment of Self compacting concrete, which can be compacted into every corner of a form work, purely by means of it’s own right and without the need for vibrating compaction. Okamura proposed the necessity of this type of concrete in 1986. Studies to develop self compacting concrete, including a fundamental study on the workability of concrete, have been carried out by “Ozawa and Maekawa” at the university of Tokyo.

The prototype of self-compacted concrete was first completed in 1988 using materials already in the market. The prototype performed satisfactorily with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties. This concrete was named “High performance Concrete” and was defined as follows at the three stages of concrete.

- Fresh : Self-Compactable
- Early age : Avoidance of initial defects
- After hardening : Protection against external factors
Necessity for self compacting concrete

**1.1 SELF COMPACTABILITY OF FRESH CONCRETE**

**1.1.1 Mechanism for achieving self compactability**

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. Okumara and Ozawa have employed the following methods to achieve self compactability.
• Limited aggregate content
• Low water-powder ratio
• Use of superplasticizer

The frequency of collision and contacts between aggregate particles can increase as the relative distance between the particles decreases and then internal stress can increase when concrete is deformed, particularly near obstacles. Research has found that the energy required for flowing is consumed by the increased internal stress, resulting in blockage of aggregate particles. Limiting the coarse aggregate content, whose energy consumption is particularly intense, to a level lower than normal 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, paste with a high viscosity also prevents localized increases in 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 to a very low value.

Methods for achieving self compactability
Mechanism for achieving self-compatability

1.1.2. Mixture proportioning methods

Self compacting concrete should be designed for a combination of filling ability, resistance to segregation and ability to pass through and around reinforcement without blockage. Correct selection of aggregate size and gradation, along with adjustments in paste rheology are essential self compacting concrete.

Self compacting concrete mixtures had high cementitious materials content, providing a high degree of stability to the mixture. As a result, water contents of self compacting concrete mixtures were about 190-220 l/m$^3$. With the development of viscosity modifying agents specially suited for self compacting concrete applications, however, it has been possible to reduce the content of cementitious materials, bringing down the water contents to the values closer to conventional concrete (160-190 kg/m$^3$).
Principles of self compacting concrete mixture design

1.2 ADVANTAGES OF SELF COMPACTING CONCRETE

- Modern, presently day self compacting concrete can be classified as an advanced construction material. Self compacting concrete as the name suggests, does not require to be vibrated to achieve full compaction. This offers many benefits and advantages over conventional concrete.
  - Improved quality of concrete and reduction of on site repairs.
  - Faster construction times.
  - Lower over all costs.
  - Facilitation of introduction of automation into concrete construction.
  - Improvement of health and safety is also achieved through elimination of handling of vibrators.
  - Substantial reduction of environmental noise loading on and around a site.
  - Possibilities for utilization of "dusts", which are currently waste products demanding with no practical applications and which are costly to dispose of.
  - Better surface finishes.
• Easier placing.
• Thinner concrete sections.
• Greater Freedom in Design.
• Improved durability and reliability of concrete structures.
• Easy of placement results in cost savings through reduced equipment and labour requirement.
• Self compacting concrete makes the level of durability and reliability of the structures independent from the existing on site conditions related to the quality of labour, casting and compacting systems available.
• The high resistance to external segregation and the mixtures self-compacting ability allow the elimination of micro-defects, air bubbles and honeycombs responsible for penalizing mechanical performance and structure durability.

1.3. DEFINITIONS

1.3.1. Self compacting concrete

Concrete that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity.

1.3.2. Admixture

Material added during the mixing process of concrete in small quantities related to the mass of cement to modify the properties of fresh or hardened concrete.

1.3.3. Binder

The combined cement any hydraulic addition in a self compacting concrete.

1.3.4. Passing ability (confined flow ability)

The ability of Self compacting concrete to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking.

1.3.5. Filling Ability (On confined flow ability)

The ability of self compacting concrete to flow into and fill completely on spaces within the formwork, under its own weight.
1.3.6. Finings

Material of practical size smaller than 0.125mm. It will also include the size fraction of the sand.

1.3.7. Mortar

The fraction of the concrete comprising paste plus those aggregates less than 4mm.

1.3.8. Paste

The fraction of the concrete comprising powder plus water and air.

1.3.9. Segregation resistance (stability).

The ability of self compacting concrete to remain homogeneous in composition during transport and placing.

1.3.10. Workability.

A measure of the ease by which fresh concrete can be placed and compacted, it is a complex combination of aspects of fluidity, cohesiveness, transportability, compatibility and stickiness.

1.4. SPECIFICATIONS

Self compacting concrete is the modified concrete with the use of chemical and mineral admixtures in the concrete. It is designed generally with high content of powder/fine material. To facilitate flow and penetration through congested reinforcement zones, it is desirable to avoid 20 mm aggregate. If more coarse aggregate is used, flow rate will be diminished due to frictional loss and stresses. The lower the maximum size of aggregate, higher would be the permissible input of coarse aggregate, but within the range specified.

In European Method it was recommended that

- The water/powder ratio by volume be 0.8 to 1.10.
- Total powder content, should be between 400-600 Kg/m³
- water to cement ratio to be selected based on strength and durability requirements water content generally does not exceed 200 lt/m³.
- Coarse aggregate content normally 28 to 35 percent by volume of the mix.
• Max cement content should be 350-450 Kg/m³

• Cement having C₃A content more than 10% should not be used in self compacting concrete because of its role in early setting. It may cause problems of poor workability retention.

There appears to be no codal specifications for self compacting concrete in any country except the guidelines by EFNARC European Federation for Specialist Construction Chemicals and Concrete Systems, formulated in Europe. However the Technology developers have evolved certain study methodologies based on application needs.

1.5 WORKABILITY OF SELF COMPACTING CONCRETE

• A Good self compacting concrete shall normally reach a slump flow value exceeding 60 cm without segregation.

• If required, self compacting concrete shall remain flow able and self compacting for at least 90 minutes.

• If required self compacting concrete shall be able to withstand a slope of 3% incase of free horizontal surface.

• If required self compacting concrete shall be pumpable for at least 90 minutes and through pipes with a length of at least 100 m.

1.6 MECHANICAL CHARACTERISTICS:

• Characteristic compressive strength at 28 days shall be 25-60 MPa

• Early age compressive strength shall be 5-20 MPa at 12-15 hours (equivalent age at 20°C)

• “Normal” creep and shrinkage.

1.7 HOW DOES IT WORK:

A self compacting concrete must

• Have a fluidity that allows self-consolidation without external energy.

• Remain homogeneous in a form during and after the placing process

• Flow easily through reinforcement.
To achieve this performance, Okamura redesigned the concrete mix design process. His mix design procedure focused on three different aspects.

- Reduction of the coarse aggregate content in order to reduce the friction, or the frequency of collisions between them, increasing the overall concrete fluidity.
- Increasing the paste content to further increase fluidity.
- Managing the paste viscosity to reduce the risk of aggregate blocking when the concrete flow through obstacles.

In rheological terms, even though a significant amount of research tends to show that self compacting concrete's viscosity varies with the shear rate and acts as a pseudoplastic material, self compacting concrete is often described as a Bingham fluid (viscoelastic) where the stress/shear rate ratio is linear and characterized by two constants—viscosity and yield stress.

Back to the performance-based definition of self compacting concrete, the self-consolidation is mainly governed by yield stress, while the viscosity will affect the homogeneity and the ability to flow through reinforcement. As self compacting concrete viscosity can be adjusted depending on the application, the yield stress must remain significantly lower than other types of concrete in order to achieve self-consolidation.

1.8 APPLICATIONS

1.8.1 Current condition on application of self compacting concrete

After the development of the prototype of self compacting concrete at the University of Tokyo, intensive research was begun in many places, especially in the research institutes of large construction companies. As a result, self compacting concrete has been used in many practical structures. The first application of self compacting concrete was in a building in June 1990. Self compacting concrete was then used in the towers of a prestressed concrete cable-stayed bridge in 1991. Lightweight self compacting concrete was used in the main girder of a cable-stayed ridge in 1992. Since then, the use of self compacting concrete in actual structures has gradually increased. Currently, the main reasons for the employment of self compacting concrete can be summarized as follow:-

- To shorten construction period.
• To assure compaction in the structure: especially in confined zones where vibrating compaction is difficult.
• To eliminate noise due to vibration effective especially at concrete product plants.

The production of self compacting concrete as a percentage of Japanese ready-mixed concrete, which accounts for 70% of total concrete production in Japan, is only 0.1%. The current status of self compacting concrete is "special concrete" rather than "standard concrete." Other applications of self compacting concrete are summarized below.

- Bridge (anchorage, arch, beam, girder, tower, pier, joint between beam & girder)
- Box culvert
- Building
- Concrete filled steel column
- Tunnel (lining, immersed tunnel, fill of survey tunnel)
- Dam (Concrete around structure)
- Concrete products (block, culvert, water tank, slab and segment)
- Diaphragm wall
- Tank (side wall, joint between side wall and slab)
- Pipe proof

In India experimental work has been done by M/s L & T, SERC, Chennai etc., however this technology has been put to use first time by NPCIL at Kaiga-3 & 4 project. Subsequently, this technology is being adopted by DMRC at Delhi, by L & T at Khopoli. Some of the walls of pump houses of Tarapur Atomic Power Project 3&4 (TAPP) were 14.4m high and all the other structures around these walls were completed and achieve good compaction.
1.8.2. Large scale construction

Self compacting concrete is currently being employed in various practical structures in order to shorten other construction period of large-scale constructions. The anchorages of Akashi-Kaikyo Bridge opened in April 1998, a suspension bridge with the longest span in the world (1991 meters), are a typical example. Self compacting concrete was used in the construction of the two anchorages of the bridge. A new construction system that makes full use of the performance of self compacting concrete was introduced for this purpose. The concrete was mixed at the batcher plant next to the site, and was then pumped out of the plant. Air was transported 200 meters through pipe to the casting site, where the pipes were arranged in rows 3 to 5 meters apart. The concrete was cast from gate valves located at 5 meter intervals along the pipes. These valves were automatically controlled so that the surface level of the cast concrete could be maintained. The maximum size of the coarse aggregate in self compacting concrete used at this site was 40mm. The concrete fell as much as 3 meters, but segregation did not occur, despite the large size of coarse aggregate. In the final analysis, the use of Self compacting concrete shortened the anchorage construction period by 20% from 2.5 to 2 years.

Self compacting concrete was used for the wall of a large LNG tank belonging to the Osaka Gas Company. The adoption of self compacting concrete in this particular project had the following merits.

- The number of lots decreased from 14 to 10 as the height of one lot of concrete was increased
- The number of concrete workers was reduced from 150 to 50.
- The construction period of the structure decreased from 22 months to 18 months.

In addition, a rational acceptance test for self-compatibility at the job site was newly introduced. The concrete casting was completed in June, 1998.
1.8.3. Concrete products:

Self compacting concrete is often employed in concrete products to eliminate vibration noise. This improves the working environment at plants and makes the location of concrete products plants in urban areas possible. In addition, the use of self compacting concrete extends the lifetime of mould for concrete products. The production of concrete products using self compacting concrete has been gradually increasing.

1.8.4 Necessity for new structural design and construction systems

Using large self compacting concrete saves the cost of vibrating compaction and ensures the compaction of the concrete in the structure. However, total construction cost cannot always be reduced, except in large-scale constructions. This is because conventional construction systems are essentially designed based on the assumption that vibrating compaction of concrete is necessary.

Self compacting concrete can greatly improve construction systems previously based on conventional concrete that required vibrating compaction. This sort of compaction, which can easily cause segregation, has been an obstacle is eliminated, concrete construction can be rationalized and a new construction system, including formwork, reinforcement, support and structural design, can be developed.

<table>
<thead>
<tr>
<th>Self – Compacting Concrete</th>
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<td>No Vibration</td>
<td>Resistance to Segregation</td>
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Less Restriction to Design Less Restriction to Practice

New Type of Structure Rational Construction System

Rational Combination of Concrete & Steel

New Construction system achieved by making full use of self compacting concrete

(Proposed by Ozawa)
1.9 PROPERTIES OF AR - GLASS FIBRES

- Rapid dispersion into mono-filament reinforcement.
- 220 million filaments per kg.
- Effective at very low dosage.
- Safe and easy to handle.
- Control and prevention of young and hardened concrete cracking.
- Homogeneous mix.
- Proven technology.
- Overall enhancement of durability and physical properties of RMC.

1.9.1 Cem-Fil Anti-Crack HD

Cem-Fil Anti-Crack™ HD is an engineered AR -Glass chopped strand designed for mixing with concrete, mortar and all hydraulic binder-based mix-designs where uniform dispersion of the fiber reinforcement is needed. Cem-FIL® Anti-Crack™ HD is typically used at a low level of addition to prevent cracking & improve the performance of concrete, flooring, renders or other special mortar mixes.

Anti-Crack™ HD fibers do not protrude from the surface and require no further finishing. The reinforcement gets incorporated in the mass of concrete and is absolutely invisible. These fibres are designed to be used with normal concrete mixes at low addition rate levels-typically 0.6 kg per cubic meter of concrete. Anti-Crack™ HD can be added at the central mixing plant to the wet concrete mix or directly into the ready-mix truck. They disperse instantly in wet concrete giving disturbed monofilament reinforcement and are highly effective in suppressing plastic shrinkage cracking. The large number of filaments gives a very small distance between fibres whilst the high aspect ratio gives maximum effect in the setting period.

1.10. CHEMICAL ADMIXTURES

Self compacting concrete requires a very high deformability at a low water cement ratio, hence chemical admixtures are inevitable and in particular, the high range water reducer, also known as superplasticiser (SP). A number of categories of superplasticiser
exist. The molecular weight of superplasticiser may vary from 100 and 100,000. These chemicals help to reduce the inter particle attraction of fine powder pastes to such an extent that considerable quantities of water can be removed from the system. The superplasticisers can be classified into the following four main categories:

1) Sulphonated melamine formaldehyde condensate.
2) Sulphonated naphthalene formaldehyde condensate.
3) Modified lignosulphonates
4) Poly carboxylic esters.

1.10.1 Modified Polycarboxyclic Ether (GLENIUM™ B 233) (63)

GLENIUM B 233 has been primarily developed for applications in the ready mixed precast concrete industries and high performance concrete where the highest durability and performance is required. The excellent dispersion properties of GLENIUM B 233 make it the ideal admixture for precast and ready mixed concrete where low water cement ratios are required. This property allows the production of very high early and high ultimate strength concrete with minimal voids and therefore optimum density.

1.10.2. Advantages of modified polycarboxyclic ether

- Increased early ultimate compressive strength.
- Increased flexural strength.
- Higher E modulus.
- Improved adhesion to reinforcing and stressing steel.
- Better resistance to carbonation.
- Low permeability.
- Better resistance to aggregate atmospheric conditions.
- Reduced shrinkage.
- Increased durability.
1.11. VISCOSITY- ENHANCING ADMIXTURES

Viscosity-enhancing admixtures (VEAs) are also known as thixotropic agents, anti-washout admixtures. They are relatively new admixtures used to enhance the cohesion and stability of Cement based systems. Such admixtures can reduce the risk of separation of the heterogeneous constituents of concrete during transport, placement, and consolidation and provide added stability to the cast concrete while in the plastic state. The use of flow able concrete to facilitate the casting of the congested or restricted areas can result in an unstable dispersion of cement paste and aggregate particles since the tendency of the heterogeneous materials to separate increases with the reduction in viscosity. This can be obtained when the consistency of the flow able concrete increases or when the concrete is subjected to high shear rate, such as that encountered during pumping and consolidation. The incorporation of a viscosity enhancing admixtures in flow able concrete can enable the production of a stable and yet highly flow able concrete to facilitate filling of the congested reinforced members with minimal vibration and segregation.

1.11.1. Viscosity modified admixture GLENIUM™ STREAM 2

GLENIUM STREAM 2 is a ready to use liquid admixture, which should be added to the concrete after all the other components. For best performance it is advisable to continue mixing until the mix is completely homogenous. To produce Rheodynamic concrete, GLENIUM STREAM 2 should be used in combination with the other superplasticizer admixtures of the GLENIUM SCC range in order to guarantee maximum efficiency.

1.12. NECESSITY AND AIM OF THE PRESENT STUDY

On many occasions reinforced concrete elements contain heavy and congested reinforcement necessitated either by structural requirement or constructional need. Using normal concrete in such situations may often result in poor compaction and consequent defects in the placed concrete such as honey combing etc. Long term durability also becomes suspect. One of the important factors which influences the
durability and long term performance of concrete structures is the adequacy and quality of consolidation concrete.

When the construction industry in Japan experienced a decline in the availability of skilled labour in 1980s, a need was felt for a concrete that could overcome the problems of defective workmanship. This led to the development of self compacting concrete, primarily through the work by Okumara. The first usable version of self compacting concrete was completed in 1988 and was named "High Performance Concrete", later proposed as "Self Compacting Concrete".

Since the development of self compacting concrete in Japan, many organizers in the world carried out research in the properties of self compacting concrete. The British-Euran self compacting concrete project was set up to promote the use of self compacting concrete in some of the European countries. A recent initiative in Europe is the formation of the project-Testing SCC- involving a number of institutions in research studies on various test methods for self compacting concrete and developed specifications and guide lines EFNARC for the use of self compacting concrete that covers a number of topics, ranging from materials selection and mixture design to the significance of test methods reduced the construction time and labor cost, eliminating the need for vibration, reduced noise pollution, improved compactability even in highly congested structural members, and finally a better construction ensuring good structural performance.

For a newly developing material like self compacting concrete, studies on the various properties like long term strength, durability, thermal effects, temperature effects and flexural behaviour of beams and slabs of paramount importance for instilling confidence among the engineers and builders. The literature indicate that while some studies are available on steel fibre reinforced self compacting concrete, a comprehensive study which involve studies on glass fibre self compacting concrete are not available. Hence, considering the gap in the existing literature, an attempt has been made to study the various properties of glass fibre self compacting concrete.
1.13. DETAILS OF THE PRESENT STUDIES ON SELF COMPACTING CONCRETE AND GLASS FIBRE SELF COMPACTING CONCRETE

In the present thesis work, exhaustive basic studies on self compacting concrete and glass fibre self compacting concrete composites with different water-powder ratios have been attempted. The experimental investigation being carried out on the following lines.

1. Physical properties of materials
   a) Physical Properties of cement
   b) Properties of coarse and fine aggregate materials.

2. Mix proportions and Mix design of self compacting concrete and glass fibre self compacting concrete mixes.
   Based on the trail and error procedure and by satisfying the Efnarc guidelines the trail mix designs are evaluated for the various grades of self compacting concrete and glass fibre self compacting concrete mixes for M 30 to M 65.

3. Rheological studies on self compacting and glass fibre self compacting concrete mixes
   a) Rheological studies of self compacting concrete mixes.
   b) Rheological studies of glass fibre self compacting concrete mixes.

4. Strength studies on self compacting concrete and glass fibre self compacting concrete
   a) Compressive strength, split tensile strength and flexural strength studies for various grades of self compacting concrete and glass fibre self compacting concrete mixes of M 30 to M 65 at 28, 90 and 180 days.
   b) Secant modulus of elasticity for various grades of self compacting concrete and glass fibre self compacting concrete mixes of M 30, M 40, M 50, M 60 at 28, 90 and 180 days.
c) Variation of compressive strength, split tensile strength and flexural strength of various grades of glass fibre self-compacting concrete mixes of M 30 to M 65 in comparison with self-compacting concrete mixes.

d) Variation of compressive strength, split tensile strength and flexural strength of various grades of self-compacting concrete and glass fibre self-compacting concrete of M 30 to M 65 in comparison with 28 days strength.


a) Compressive strength, split tensile strength and flexural strength of various grades of self-compacting concrete and glass fibre self-compacting concrete mixes of M 30 to M 65 subjected to varying thermal cycles for Zero, 28, 90 and 180 at 50°C.

b) Compressive strength, split tensile strength and flexural strength of various grades of self-compacting concrete and glass fibre self-compacting concrete mixes of M 30 to M 65 subjected to varying thermal cycles for Zero, 28, 90 and 180 at 100°C.

c) Variation of compressive strength, split tensile strength and flexural strength of various grades of self-compacting concrete and glass fibre self-compacting concrete mixes of M 30 to M 65 in comparison with Zero thermal cycles at 50°C and 100°C.

d) Variation of compressive strength, split tensile strength and flexural strength of various grades of glass fibre self-compacting concrete mixes of M 30 to M 65 in comparison with self-compacting concrete at 50°C and 100°C.


a) Compressive strength of self-compacting concrete and glass fibre self-compacting concrete mixes of M 30 to M 65 subjected at 200°C, 400°C, and 600°C at 4, 8, and 12 hours.
c) Variation of impact strength of self compacting concrete and glass fibre self compacting concrete mixes for the grades of M 30 to M 65 in comparison with 60 days impact strength.

9. Flexural behaviour of glass fibre reinforced self compacting concrete beams
   a) Flexural behaviour of glass fibre reinforced self compacting beams of M 30, M 40, M 50 and M 60 with varying percentages of glass fibres from 0 % to 0.1%.
   b) Load deflection characteristics of glass fibre reinforced self compacting beams of M 30, M 40, M 50 and M 60 with varying percentages of glass fibres from 0 % to 0.1%.

10. Flexural behaviour of glass fibre reinforced self compacting concrete slabs
    a) Flexural behaviour of glass fibre reinforced self compacting slabs of M 30, M 40, M 50 and M 60 with varying percentages of glass fibres from 0 % to 0.1%.
    b) Load deflection characteristics of glass fibre reinforced self compacting slabs of M 30, M 40, M 50 and M 60 with varying percentages of glass fibres from 0 % to 0.1%.