Study on the Stress-Strain Behaviour of High Strength Glass Fibre Reinforced Self-Compacting Concrete under Axial Compression with & without Confinement

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Abstract— A self-compacting concrete (SCC) is the one that can be placed in the form and can go through obstructions by its weight and without the need for vibration. Although there are visible signs of its gradual acceptance in the Middle East through its limited use in construction, it has yet to explore the feasibility and applicability of SCC in new construction. The contributing factors to this reluctance appear to be lack any supportive evidence obits suitability with local marginal aggregates and the harsh environmental conditions. Concrete is a vital ingredient in infrastructure development with its versatile and extensive applications. It is the most widely used construction material because of its mouldability into any required structural form and shape due to its fluid behavior at an early age. However, there is a limit to the fluid behavior of normal fresh concrete. Thorough compaction, using vibration, is normally essential for achieving the required strength and durability of concrete. Inadequate compaction of concrete results in a large number of voids, affecting performance and long-term durability of structures. Self-compacting concrete (SCC) provides a solution to these problems. As the use of Concrete becomes more widespread the specifications of concrete-like durability, quality, and compactness of concrete becomes more important. Self -Compacting Concrete is a recently developed concept in which the ingredients of the concrete mix are proportioned in such a way that it can flow under its weight to fill the formwork and passes through the congested reinforcement without segregation and self-consolidate without any mechanical vibration. Self–Compacting Concrete (SCC) is a very fluid concreter and a homogeneous mixture that solves most of the problems related to ordinary concrete. This specification helps the execution of construction components under high compression of reinforcement.

Keywords: Glass-Fibre, Reinforced Self – Compacting Concrete, 6mm Diameter Mild Steel, Admixtures, Stress-Strainin Behavior, a Single Polynomial Empirical Equation

I. INTRODUCTION

A. *Self-Compacting Concrete :*

The development of self-compacting concrete (SCC) is a desirable achievement in The construction industry to overcome problems associated with cast-in-place concrete. Self-compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure and, due to its high-fluidity and resistance to segregation it can be pumped longer distances. Self-compacting concrete was developed at that time to improve the durability of concrete structures, mainly by large construction companies. Investigations for establishing a rational mix-design method and self-compact ability testing methods have been carried out from the view point of making it a standard concrete. Self-compacting concrete is cast so that no additional inner or outer vibration is necessary for the compaction. It flows like "honey" and has a very smooth surface level after placing it. About its composition, self-compacting concrete consists of the same components as conventionally vibrated concrete, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in different proportions. Usually, the chemical admixtures used are high-range water reducers (superplasticizers) and viscosity-modifying agents, which change the rheological properties of concrete. Mineral admixtures are used as extra fine material, basic cement, and in some cases, they replace cement. In this study, the cement content was partially replaced with mineral admixtures, e.g. fly ash, slag cement, and silica fume, admixtures that improve the flowing and strengthening characteristics of the concrete.

1) *Advantages and disadvantages of Self-Compacting Concrete:*

SCC possesses enhanced qualities, and its use improves productivity and working conditions the internal segregation between solid particles and the surrounding liquid is avoided which results in less porous transition zones between paste and aggregate and a more even color of the concrete. Improved strength, durability and finish of SCC can, therefore, be anticipated. The very good finish effect is a pure cement SCC placed in a steel mold, molded 24hours after casting. The surface is so smooth and dense that it can reflect light.

2) *Definition and Properties of Self-Compacting Concrete:*

It is important at this stage to define SCC and its characteristics. Self-compacting characteristics are related to fresh properties. The definitions of SCC given in the literature vary, the most common one is that„s concrete that can flow under its weight and fill the formwork, while maintaining homogeneity even in the presence of congested reinforcement, and then consolidating without the need for vibrating compaction‟. SCC has three essential fresh properties filling ability, passing ability and segregation resistance Testing-SCC,. Filling ability is the characteristic of SCC to flow under its weight and to fill the formwork. Passing ability is the characteristic of SCC to flow through and around obstacles such as reinforcement and narrow spaces without blocking. Segregation resistance is the characteristic of SCC to remain homogeneous during and after transporting and placing. It is the passing ability that distinguishes SCC from other high consistency concrete. Additional properties, such as robustness and consistent retention, are also important in applications of SCC. Robustness refers to the ability of SCC to retain its fresh property when the quality and quantity of constituent

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materials and the environmental conditions change. Consistence retention refers to the period of duration of the fresh properties. Many commonly used tests are subsequently described for evaluating the fresh properties. There is no difference in test methods for hardened properties (strength, stiffness, and durability etc.) between SCC and NVC. Both fresh and hardened properties are key to the successful application of SCC. SCC therefore can be designed by fresh or hardened requirements.

3) Motive for Development of Self-Compacting Concrete:

The motive for the development of self-compacting concrete was the social problem on the 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. As a result of this fact, one solution for the achievement of durable concrete structures independent of the quality of construction work was the employment of self-compacting concrete, which could be compacted into every corner of a formwork, purely using its weight (Figure 1.1). Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were carried out by researchers Ozawa and Maekawa (Bartos, 2000) at the University of Tokyo. During their studies, they found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, they eliminated the main cause for the poor durability performance of the concrete. By 1988, the concept was developed and ready for the first real-scale tests and at the same time the prototype of self-compacting concrete was completed using materials already on the market. The prototype performed satisfactorily about drying and hardening shrinkage, the heat of hydration, denseness after hardening, and other properties and was named "High-Performance Concrete."

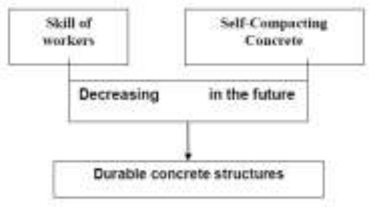

Figure 1.1 Necessity of Self-Compacting Concrete (Ouchi and Hibino, 2000).

B. Construction Issues

By employing self-compacting concrete, the cost of chemical and mineral admixtures is compensated by the elimination of vibrating compaction and work have done to level the surface of the normal concrete (Khayat et al., 1997). However, the total cost for a certain construction cannot always be reduced, because conventional concrete is used in a greater percentage than self-compacting concrete. SCC can greatly improve construction systems previously based on conventional concrete requiring vibrating compaction. Vibration compaction, which can easily cause segregation, has been an obstacle to the rationalization of construction work. Once this obstacle has been eliminated, concrete construction could be rationalized and a new construction system, including formwork, reinforcement, support and structural design, could be developed (Figure 1.2).

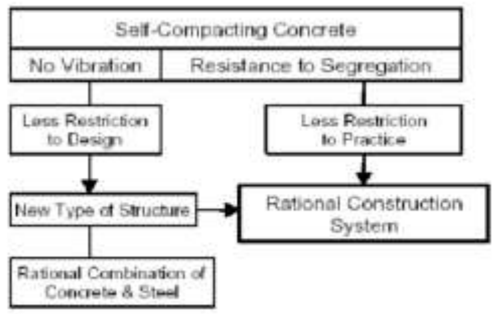

Fig. 1.2 Rational construction system proposed by Ozawa

C. Applications of Self-Compacting Concrete

Since the development of the prototype of self-compacting concrete in 1988, the use of self-compacting concrete in actual structures has gradually increased. The main reasons for the employment of self-compacting concrete can be summarized as follows:

1) To shorten the construction period
2) To assure compaction in the structure: especially in confined zones where vibrating Compaction is difficult.
3) To eliminate noise due to vibration: effective especially at concrete products Plants. That means the current condition of self-compacting concrete is a "special concrete" rather than standard concrete. Currently, the percentage of self-compacting concrete in the annual product of ready-mixed concrete in Japan is around 0.1%. A typical application example of Self-compacting concrete is the two anchorages of Akashi-Kaikyo (Straits) Bridge opened in April 1998, a suspension bridge with the longest span in the world (1,991 meters) (Fig. 1.4). The volume of the cast concrete in the two anchorages amounted to 2,90,000 m³. A new construction system, which makes full use of the performance of self-compacting concrete, was introduced for this. The concrete was mixed at the batch plant beside the site and was then pumped out of the plant. It was transported 200 meters through pipes 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 a surface level of the cast concrete could be maintained. In the final analysis, the use of self-compacting concrete shortened the anchorage construction period by 20%, from 2.5 to 2 years.

Fig. 1.3: Anchorage 4A of Akashi-Kaikyo Bridge

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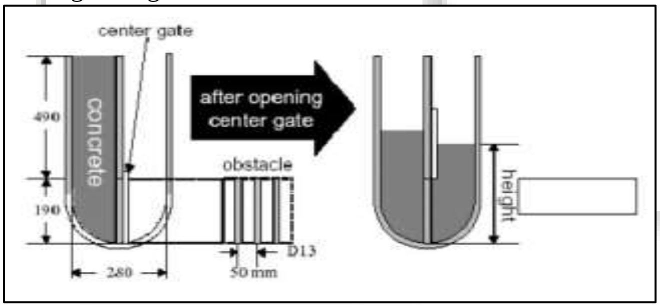
D. Existing Tests for Fresh SCC Mixes Fresh SCC must possess at required levels the following key properties:

1) Filling ability:
This is the ability of the SCC to flow into all spaces within the formwork under its weight.

2) Passing ability:
This is the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its weight.

3) Resistance to segregation:
The SCC must meet the required levels of properties A & B whilst its composition remains uniform throughout the process of transport and placing. Many tests have been used in successful applications of SCC. However, in all the projects the SCC was produced and placed by an experienced contractor whose staff has been trained and acquired experience with interpretation of a different group of tests.

4) U-type test:
Of the many testing methods used for evaluating self-compatibility, the U-type test (Figure 1.5) proposed by the Taisei group is the most appropriate, due to the small amount of concrete used, compared to others (Ferraris, 1999). In this test, the degree of compatibility can be indicated by the height that the concrete reaches after flowing through obstacles.



5) Slump Flow test:
The basic equipment used is the same as for the conventional Slump test. The test method differs from the conventional one by the fact that the concrete sample placed into the mold is not rodded and when the slump cone is removed the sample collapses (Ferraris, 1999). The diameter of the spread of the sample is measured, i.e. a horizontal distance is determined as opposed to the vertical distance in the conventional Slump test. The Slump Flow test can indicate as to the consistency, filling ability and workability of SCC. The SCC is assumed of having a good filling ability and consistency if the diameter of the spread reaches values between 650mm to 800mm.

6) L-Box test:
This method uses a test apparatus comprising of a vertical section and a horizontal trough into which the concrete is allowed to flow on the release of a trap door from the vertical section passing through reinforcing bars placed at the intersection of the two areas of the apparatus (Dietz and Ma, 2000). The time that it takes the concrete to flow a distance of 200mm (T-20) and 400mm (T-40) into the horizontal section is measured, as is the height of the concrete at both ends of the apparatus (H1 & H2). The L-Box test can indicate as to the filling ability and passing ability.

7) Prime test:
The test is based on the principle of an orifice rheometer applied to fresh concrete (Bartos, 2000). The test involves the recording of time that it takes for a concrete sample to flow out from a vertical casting pipe through an interchangeable orifice attached at its lower end. The shorter the Flow-Time, the higher is the filling ability of the fresh mix. The Ouimet test also shows potential as a means of assessment of resistance to segregation on a site.

8) V-funnel test:
The viscosity of the self-compacting concrete is obtained by using a V-funnel apparatus, which has certain dimensions (Figure 1.6), for a given amount of concrete to pass through an orifice (Dietz and Ma, 2000). The amount of concrete needed is 12 liters and the maximum aggregate diameter is 20 mm. The time for the amount of concrete to flow through the orifice is being measured. If the concrete starts moving through the orifice, it means that the stress is higher than the yield stress; therefore, this test measures a value that is related to the viscosity. If the concrete does not move, it shows that the yield stress is greater than the weight of the volume used. An equivalent test using smaller funnels (side of only 5 mm) is used for cement paste as an empirical test to determine the effect of chemical admixtures on the flow of cement pastes

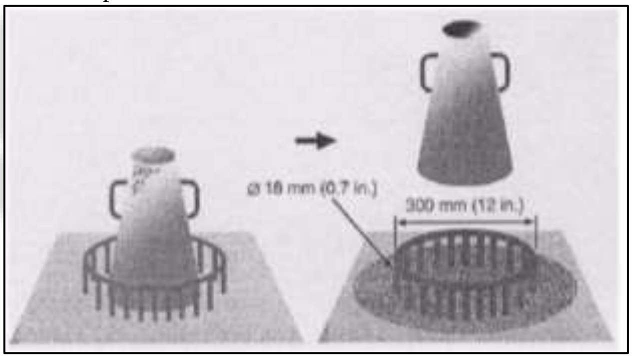


Fig. 1.5: V-funnel.

9) Slump Flow/J-Ring combination test:
This test (Figure 1.7) involves the slump cone being placed inside a 300mm diameter steel ring attached to vertical reinforcing bars at appropriate spacing (the J-Ring itself) (Kosmatka et al., 2002). The number of bars has to be adjusted depending on the maximum size aggregate in the SCC mix. Like in the Slump Flow test, the diameter of the spread and the T-50 time are recorded for the evaluation of SCC viscosity. The Slump Flow/J-Ring combination test is an improvement upon the Slump Flow test on its own as it aims to assess also the passing ability of the fresh mix. In this respect, the SCC has to pass through the reinforcing bars without separation of paste and coarse aggregate

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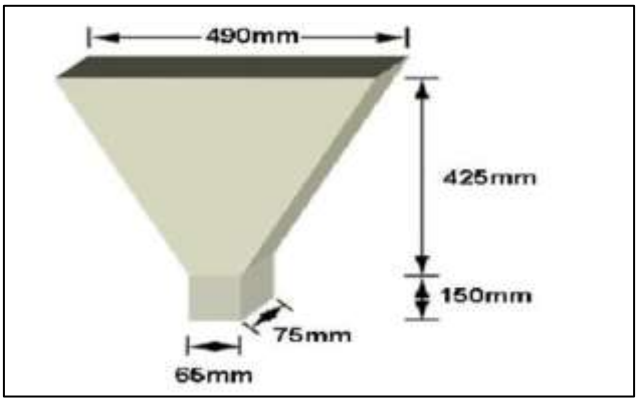

Fig. 1.6: Slump Flow/J-Ring combination test.

10) Prime/J-Ring combination test:

This is recently developed test involves the J-Ring being placed centrally below the orifice of the Ouimet apparatus, allowing the discharged mix to fall into it and flow outwards (Bartos, 2000).The Primetime is recorded as in the conventional Orimet test, along with the diameter of theconcrete spread and the height of the concrete within the JRing. The more dynamic flow ofconcrete in this test simulates better the behavior of an SCC mix when placed in practicecompared with the Slump-Flow variation. The Prime/J-Ring combination test will be used in the future as a method of assessing filling ability, passing ability and resistance to segregation(Bartos, 2000).

11) GTM Segregation test:

This is a very recent test measuring the separation of aggregate in a sample after some time andwet sieving. The test has the potential for detection of the tendency to segregate (Dehn et al.,2000). It completes the tests (Slump-Flow, L-Box, etc.) carried out to estimate the filling abilityin the free or shut-in environment (i.e. with some "wall-effect") by specifying the segregationresistance. This test can be used in the laboratory when developing a concrete mix, as well as onsitewhen carrying out suitability tests on the delivered concrete.

E. Development of Prototype:

The prototype of Self-compacting Concrete was first developed in 1988 using materials alreadyon the market. The prototype performed satisfactorily about drying and hardening shrinkage, the heat of hydration, denseness after hardening, and other properties. This concrete was named“High-Performance Concrete”. At almost the same time, Professor Aitkin defined “High Performance Concrete”

as concrete with high durability due to low water-cement ratio. Since then, the term high-performance concrete has been used around the world to refer to high durability concrete. It has proved beneficial economically because of some factors as noted below.

1) Faster construction,
2) Reduction in site manpower,
3) Easier placing,
4) Uniform and complete consolidation,
5) Better surface finishes,
6) Improved durability,
7) Increased bond strength,
8) Greater freedom in design,
9) Reduced noise levels, due to absence of vibration,
10) Safe working environment. All the engineering components undergo a multi-axial Stress-Strain condition either from the particular geometry of the body or multi-axial nature of the load itself. Many of these components are prone to fatigue failure and hence much effort is spent in understanding the response of the materials.

F. Scope and Objectives of Investigation:

Poor quality of vibration of concrete, in congested locations, has often been a shortcoming of traditional concrete. In such situations, SCC, which follows under its weight and does not require any external vibration for compaction has revolutionized concrete placement. SCC does not show segregation and bleeding. Self-compacted ability is largely affected by the characteristics of materials and mix proportions. In the present study, it was to achieve the required properties of Self-compacting concrete with available materials in the laboratory. Coarse aggregate with nominal size 12.5mm (70%) & 20mm (30%) was used. Also, Viscosity Modifying Admixtures (VMA) was used to increase the suspension power of aggregates and also to eliminate possible segregation. Fine powdered materials like fly ash are also used to eliminate possible segregation.

G. New structural design and construction systems:

By employing self-compacting concrete, the cost of vibrating compaction can be saved and the compaction of the concrete in the structure can be assured. However, the total cost for the construction cannot always be reduced, except in large scale constructions. This is because the conventional construction system is strongly based on the necessity of the vibrating compaction of concrete. Self-compacting concrete can greatly improve construction systems previously based on conventional concrete requiring vibrating compaction. This sort of compaction, which can easily cause segregation, has been an obstacle to the rationalization of construction work. Once this obstacle has been eliminated, concrete construction can be rationalized and a new construction system, including formwork, reinforcement, support and structural design, can be developed.

Fig. 1.8: Anchorage of Akashi-Kaikyo Bridge, Japan

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II. LITERATURE REVIEW:

Present-day self-compacting concrete can be classified as an advanced construction material. As the name suggests, it does not require to be vibrated to achieve full compaction. This offers many benefits and advantages over conventional concrete. These include improved quality of concrete and reduction of on-site repairs, faster construction times, lower overall costs, facilitation of introduction of automation into concrete construction. An important improvement of health and safety is also achieved through the elimination of the handling of vibrators and a substantial reduction of environmental noise loading on and around a site. The composition of SCC mixes includes substantial proportions of fine-grained inorganic materials and this gives possibilities for utilization of mineral admixtures, which are currently waste products with no practical application sand that are costly.

A. *Previous Research Work on Self-Compacting Concrete*

Self-compacting concrete extends the possibility of use of various mineral byproducts in its manufacturing and with the densification of the matrix, mechanical behavior, as measured by compressive, tensile and shear strength, is increased. On the other hand, the use of superplasticizers or high range water reducers, improves the stiffening, unwanted air entrainment, and flowing ability of the concrete. Practically, all types of structural constructions are possible with this concrete.

1) *Okamura:*

A new type of concrete, which can be compacted into every corner of a formwork purely using its weight, was proposed by Okamura (1997). In 1986, he started a research project on the flowing ability and workability of this special type of concrete, later called self-compacting concrete. The self-compactability of this concrete can be largely affected by the characteristics of materials and the mix proportions. In his study, Okamura (1997) has fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that self-compactability could be achieved easily by adjusting the water to cement ratio and superplasticizer dosage only.

Fig. 1.9: Small pipes used as obstacles in formwork

2) *Kazumasa Ozawa:*

After Okamura began his research in 1986, other researchers in Japan have started to investigate self-compacting concrete, looking to improve its characteristics. One of those was Ozawa (1989) who has done some research independently from Okamura, and in the summer of 1988, he succeeded in developing self-compacting concrete for the first time. The year after that, an open experiment on the new type of concrete was held at the University of Tokyo, in front of more than 100 researchers and engineers. As a result, intensive research has begun in many places, especially in the research institutes of large construction companies and at the University of Tokyo. Ozawa (1989) completed the prototype of self-compacting concrete using materials already on the market. By using different types of superplasticizers, he studied the workability of concrete and developed very workable concrete. It was suitable for rapid placement and had a very good permeability. The viscosity of the concrete was measured using the V- funnel test (see Chapter 1 clause 1.6.8-p25). Other experiments carried out by Ozawa (1989) focused on the influence of mineral admixtures, like fly ash and blast furnace slag, on the flowing ability and segregation resistance of self-compacting concrete.

3) *Subramanian and Chattopadhyay:*

Subramanian and Chattopadhyay (2002) are research and development engineers at the ECC Division of Larsen & Toubro Ltd (L&T), Chennai, India. They have over 10 years of experience in the development of self-compacting concrete, underwater concrete with anti washout admixtures and proportioning of special concrete mixtures. Their research was concentrated on several trials carried out to arrive at an approximate mix proportion of self-compacting concrete. The two researchers were trying to determine different coarse and fine aggregate contents from those developed by Okamura. The coarse aggregate content was varied, along with water-powder (cement, fly ash and slag) ratio, being 50%, 48% and 46% of the solid volume. The U-tube trials were repeated for different water-powder ratios ranging from 0.3 to 0.7 in steps of 0.10. Based on these trials, it was discovered that self-compactability could be achieved when the coarse aggregate content was restricted to 46 percent instead of 50 percent tried by Okamura (1997).

B. *Constituent Materials of SCC:*

The constituent materials used for the production of SCC are the same as those for conventionally vibrated normal concrete except that SCC contains lesser aggregate and greater powder (cement and filler particles smaller than 0.125 mm). Fly ash, glass filler, limestone powder, silica fume, etc are used as the filler materials. To improve the self-compatibility, without segregation, a superplasticizer along with a stabilizer is added.

1) *Powder (Mixture of Portland cement and Filler):*

The term 'powder' used in SCC refers to a blended mix of cement and filler particles smaller than 0.125 mm. The filler increases the paste volume required to achieve the desired workability of SCC. The addition of filler in an appropriate quantity enhances both workability and durability without sacrificing early strength (Mata, 2004).

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a) Cement:

Cement used for SCC should not contain C3A content higher than 10% to avoid the problems of poor workability retention (EFNARC, 2002). The selection of the type of cement depends on the overall requirements for concrete, such as strength and durability.

b) Filler:

Materials, such as fly ash, blast furnace slag, ground glass, limestone powder, silica fume, etc, are commonly used as fillers for producing SCC. Savings in labor costs might offset the increased cost related to the use of more cement and superplasticizer, but the use of limestone powder (LSP) as a filler could increase the fluidity of the concrete, without any increase in the cost (Sonebi, 2004).Natural pozzolan: The use of a natural pozzolan has been found to improve the fresh and hardened properties of SCC (Ramsburg and Neal, 2003). Super-pozz®: Super-pozz® is a new emerging mineral admixture containing highly reactive aluminosilicate pozzolan, which adds strength to cementitious mixes whilst its fineness (more surface area) and spherical particle shape improves the workability a lot (Seedat and Dijkema, 2000). So, it can be used as a mineral filler for SCC. The typical chemical composition and physical characteristics of Super-pozz® are given in Table 2.1 (Seedat and Dijkema, 2000).

Chemical Constituent	%	Physical Properties	
SiO2	53.5	Relative Density	2.25
Al2O3	34.3	Surface Area	13000 cm²/g
CaO	4.4	pH	11-12
Fe2O3	3.6	Color	Grey
K2O	0.8	Particle Shape	Spherical
MgO	1.0	Particle Size, D90	11 m
TiO2	1.7	Particle size, D99	25 m
Loss on ignition at 950 °C	0.4		

Table 2.1: Chemical composition and Physical characteristics of Super-pozz®

2) Aggregates

The maximum size and grading of the aggregates depend on the particular application. The maximum size of aggregate is usually limited to 20 mm. The coarse aggregate content in SCC is kept either equal to or less than that of the fine aggregate content. Bui et al., (2002) proposed a rheological model for SCC relating the rheology of the paste to the average aggregate spacing and average aggregate diameter to consider the effect of most of the factors related to aggregate properties and content. For SCC mixtures, a coarse aggregate size of 5 mm to 14 mm and quantities varying from 790 kg/m³ to 860 kg/m³ have been used with satisfactory results(Khayat et al., 2004)

3) Admixtures Superplasticizer:

Superplasticizer (SP) is an essential component of SCC to provide the necessary workability.

C. Hardened Properties of SCC 2.3.1 Compressive, Tensile, and Bond Strength:

SCC with a compressive strength around 60 N/mm² can easily be achieved. The strength could be further improved by using fly ash as a filler The characteristic compressive and tensile strengths have been reported to be around 60 N/mm² and 5 N/mm², respectively

1) Modulus of Elasticity:

Modulus of elasticity of SCC and that of a normally vibrated concrete, produced from the same raw materials, are almost identical. Although there is a higher paste matrix share in SCC, the elasticity remains unchanged due to the denser packing of the particles average modulus of elasticity of SCC to be 16% lower than that of normal vibrated conventional concrete for an identical compressive strength.

2) Shrinkage and Creep:-

Shrinkage and creep of the SCC mixtures are not greater than those of traditional vibrated concrete (Guidelines on SCC, 2000; Persson and Terrasi, 2002). Ramsburg et al. (2003) have reported the shrinkage of SCC as follows: 0.03% for mixes with cement tested at 14 days, 0.03% to 0.04% for mixes with slag cement tested at 28 days, and 0.04 to 0.045% for mixes with calcined shale cement tested at 28 days concrete.

3) Durability:

Durability is a general analysis of the service life and the performance of concrete in an aggressive environment. Physical damage to concrete includes wetting/drying, freeze/thaw or heating/cooling cycles. Chemical damage consists of sulphate attack, acid attack, chloride attack.

4) Water Absorption and Initial Surface Absorption:

Kapoor et al. (2003) have reported a water absorption value of 1% for SCC against 2% for normal vibrated concrete, obtained through the water absorption test conducted as per BS 1881: Part 122. An initial surface absorption value of 0.01 ml/m²/sec has been reported by Kapoor et al. (2003) for SCC against 0.02 ml/m²/sec for normal vibrated concrete, obtained through ISAT conducted as per BS 1881: Part 208.

5) Water Permeability

SCC with high strength and low permeability can easily be produced (Ouchi et al., 2001). Zhu and Bartos have found the permeability of SCC significantly lower as compared to that of normally vibrated concretes of the same strength grade. The Concrete Society (1987) provided some indication of typical and specified results for various concrete, as shown in Table 2.2.

Depth of penetration, mm	Permeability
Less than 30	Low
30 to 60	Moderate
More than 60	High

Table 2.2: Assessment of Concrete Permeability according to Water Penetration Depth.

D. Influence of Admixtures on Concrete Properties:

The following are presented several papers, found in the literature, on the effects of mineral and chemical admixtures on the fresh and hardened concrete. The mineral admixtures referred to are blast-furnace slag, fly ash, and silica fume. The chemical admixtures considered are high range water reducer or superplasticizer and viscosity modifying agent.

Viscosity Modifiers The viscosity modifiers or viscosity modifying admixtures (VMA) were developed in order to improve the rheological properties of cement paste in concretes (Khayat and Guizani, 1997). These admixtures enhance the viscosity of water and eliminate as much as possible the bleeding and segregation phenomena in the fresh concrete. Because not all types of viscosity modifiers have shown satisfactory results, research has concentrated on only two types: welan gum and anti washout admixtures.

III. SELF-COMPACTING CONCRETE COMPOSITION:

Self-compacting concrete (SCC) is a fluid mixture, which is suitable for placing in difficult conditions and structures with congested reinforcement, without vibration. In principle, a self-compacting or self-consolidating concrete must:

1) Have a fluidity that allows self-compaction without external energy,
2) Remain homogeneous in a form during and after the placing process, and
3) Flow easily through reinforcement

The technology of SCC is based on adding or partially replacing Portland cement with amounts of fine material such as fly ash, blast furnace slag, and silica fume without modifying the water content compared to common concrete. This process changes the rheological behavior of the concrete. Generally, SCC has to have a proper flowability and viscosity, so that the coarse aggregate can float in the mortar without segregating. To achieve a balance between flowability and stability, the total content of particles finer than the 150 µm has to be high, usually about 520 to 560 kg/m³. Self compacting concrete is very sensitive to fluctuation in water content; therefore, stabilizers or viscosity-modifying agents such as polysaccharides are used.self-compacting concretes are divided into three different types according to the composition of the mortar:

1) Powder type
2) Viscosity-modifying agent (stabilizer) type
3) Combination type For the powder type,

A high proportion of fines produce the necessary mortar volume, whilst in the stabilizer type, the fines content can be in the range admissible for vibrated concrete. The viscosity required to inhibit segregation will then be adjusted by using a stabilizer. The combination type is created by adding a small amount of stabilizer to the powder type to balance the moisture fluctuations in the manufacturing process. However, after completion of proper proportioning, mixing, placing, curing, and consolidation, hardened concrete becomes a strong, durable, and practically impermeable building material that requires no maintenance.

IV. MATERIALS FOR SELF-COMPACTING CONCRETE:

A. *Cement*

Ordinary Portland cement, 43 or 53 Grade can be used care is taken that it is freshly produced and from a single producer.

B. *Aggregates:*

1) *Fine aggregate:*

Fine aggregates can be natural or manufactured. The grading must be uniform throughout the work. The moisture content or absorption characteristics must be closely monitored, as the quality of SCC will be sensitive to such changes. Particles smaller than 0.125 mm are considered as Fines, which contribute to the fine content.

2) *Coarse aggregate:*

The aggregate of size 10-12mm is desirable for structures having congested reinforcement. Wherever possible aggregates of size higher than 20 mm could also be used. Well-graded cubical or rounded aggregates are desirable. Aggregates should be of uniform quality for shape and grading.

C. *Admixtures:*

Admixtures are defined as, other than cement, aggregate and water which is added to the concrete before or after mixing it.

1) *Mineral Admixtures:*

1) Ground Granulated Blast Furnace Slag (GGBS): GGBS, which is both cementitious and pozzolanic material may be added to improve rheological properties.
2) Silica Fume: Silica fume may be added to improve the mechanical properties of SCC.
3) Tone Powder: Finely crushed limestone, dolomite or granite may be added to increase the powder content. The fraction should be less than 125 micron
4) Fibres: Fibres may be used to enhance the properties of SCC in the same way as for normal concrete.

Advantages:

1) Increased viscosity & thixotropic properties
2) Improved stability during transport & placing
3) Controlled bleeding
4) Reduced segregation, even with highly fluid mix
5) Enhanced pumping and finishing
6) Reduced sagging – dimensional stability
7) Enables flexibility in mixture proportioning.

2) *Mix Design:*

Laboratory trials should be used to verify the properties of the initial mix composition concerning the specified characteristics and classes. If necessary, adjustments to the mix composition should then be made. Once all requirements are fulfilled, the mix should be tested at full scale in the concrete plant and if necessary at site to verify both the fresh and hardened properties.

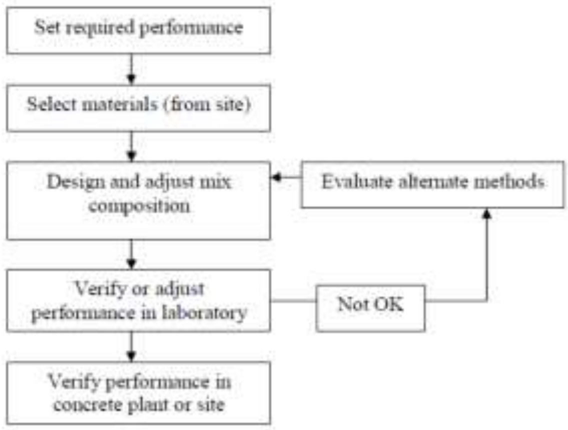

Fig. 2.8. Mix design flow chart

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Constituent	Typical range by mass (kg/m^3)	Typical range by volume (liters/m^3)
Powder	380-600	
Paste		300-380
Water	150-210	150-210
Course aggregate	750-1000	270-360
Fine aggregate (sand)	Content balances the volume of the other constituents typically 48-55% of the total aggregate weight	
Water/powder ratio by volume		0.85-1.1

Table 4.1: Mix composition as per EFNARC guidelines.

V. Quality Aspects of Self- Compacting Concrete Test Methods:

It is important to appreciate that none of the test methods for SCC has yet been standardized, and the tests described are not yet perfected or definitive. The test method presented here are descriptions rather than fully procedures. They are mainly ad-hoc method, of points, which should be taken into account:

1) One principal difficulty in devising such tests is to asses three distinct, properties of fresh SCC – it's filling ability(flowability), its passing ability(free from blocking at reinforcement, and resistance to segregation (stability).
   No single test so far devised can measure all three properties.
2) There is no clear relation between test results and performance on site.
3) There is little precise data, therefore no clear guidance on compliance limits.
4) Duplicate tests are advised.
5) The test methods and values are stated for the maximum aggregate size of up to 20mm, difference test values and/or different equipment dimensions may be appropriate for another aggregate size.
6) Different test values may be appropriate for different reinforcement densities.
7) Similarly, different test values may be appropriate for being placed in vertical and horizontal elements.
8) In performing the test, concrete should be sampled in accordance It is wise to remix the concrete first with a scoop, unless the procedure indicates otherwise.

S.no	METHOD	PROPERTY
1	Slump flow by Abrams cone	Filling ability
2	T_{50} Slump flow	Filling ability
3	J-Ring	Passing ability
4	V-Funnel	Filling ability
5	V-Funnel at T5 minutes	Segregation resistance
6	L-Box test	Passing ability
7	U-Box test	Passing ability
8	Fill Box	Passing ability
9	GTM Screen Stability Test	Segregation resistance
10	Orimet	Filling ability

Table 5.1: List of methods for workable properties of SCC:

Method	Unit	Typical range of values	
		Minimum	Maximum
Slump flow by Abrams cone	mm	650	800
T_{50} slump-flow	Sec	2	5
J-Ring	mm	0	10
V-funnel	Sec	6	12
V-funnel at T5 minutes	Sec	0	15
L-Box	H_2/H_1	0.8	1.0
U-Box	(h_2-h_1)mm	0	30
Fill Box	%	90	100
GTM Screen Stability Test	%	0	15
Orimet	Sec	0	5

Table 5.2: Workability properties of SCC and alternative methods:

VI. Experimental

The development of Self-Compacting Concrete (SCC) marks an important milestone in improving the product quality and efficiency of the building industry. SCC improves the efficiency at the construction sites, enhances the working conditions and the quality and appearance of concrete. Use of glass fibers in SCC bridge the cracks and enhance the performance of concrete by not only avoiding the propagation of cracks but also contribute to increased energy absorption compared with plain concrete. Glass Fiber Reinforced Self- Compacting Concrete (GFRSCC) combines the benefits of SCC in the fresh state and shows an improved performance in the hardened state compared with conventional vibrated concrete.

Self CompactingConcrete (SCC) facilitates and ensures proper filling and good structural performance in restricted areas and heavily reinforced structural members. it has gained wide acceptance in today‟s concrete works. SCC can be considered as an engineered composite material, tailor-made to achieve performance-related properties to suit specific applications.

A. Research Significance

An effort has been made in the present investigation to develop an analytical stress-strain model for SCC & compare the mechanical properties of SCC without and with glass fibers. The mix proportion suitable for Glass Fiber Reinforced Self Compacting Concrete (GFRSCC) accommodating finer filler materials was developed modifying the existing Nansu‟s method of mix design. This study examines and compares the mechanical properties and the stress-strain behavior of self-compacting concrete for GFRSCC. The present work provides very useful information for the practical use of fibrous self-compacting concretes. An analytical model was suggested for fibrous SCC and the stress-block parameters are proposed. The relationship between fibrous SCC for stress, strain at 85% and ductility is proposed.

B. Experimental Programme

The experimental program was done in two phases. In the first phase the aim was to develop GFRSCC and come out

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with optimum GF content based on fresh and hardened properties. In the second phase the mechanical behavior of the optimized GFRSCC was investigated and the stress-strain curve was established and the model was proposed for Glass Fibre Reinforced Self-Compacting Concrete at 28 days for M50 Grade of Concrete. Five different types of GFRSCC specimens were developed in the laboratory and Cubes of 100mm size and cylinders of 150 mm diameter and 300 mm long were cast for testing in compression

VII. DISCUSSIONS OF THE TEST RESULTS

A. Discussions:

The Fresh and hardened properties of GFRSCC with & without confinement at 28 days cylinder and cubes. Peak stress-strain values and the Normalized stress-strain values for both GFRSCC with & without confinement at 28 days cylinder. Stress-strain curves & Normalized Stress-strain Curves of GFRSCC with & without confinement.The Secant Modulus values for GFRSCC with & without confinement are shown in Table 7.1.

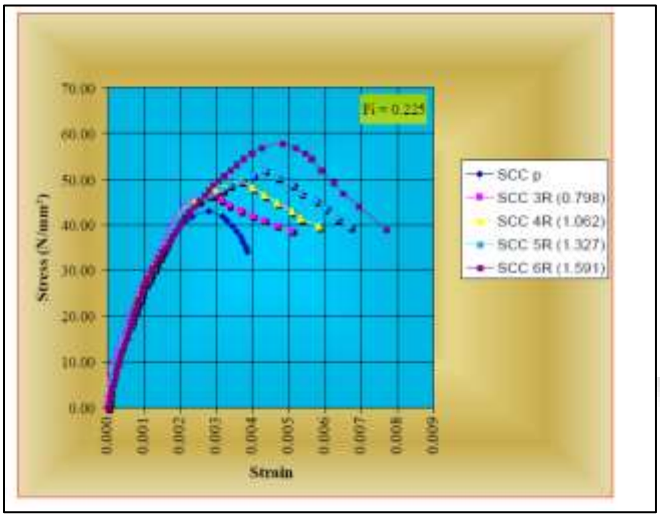

Table 7.1: Stress-strain curves & Normalized Stress-strain Curves of GFRSCC with & without confinement.

Characteristics of GFRSCC Mixes in Hardened State Effect on

1) Compressive Strength

The compressive strength values obtained by testing standard Cylinders of GFRSCC with and without confinement are tabulated. All the specimens with confinement have shown strength above 50 MPa, which is the required strength. The mix, with and without confinement, containing the mineral admixture of Fly ash (33%) has shown higher compressive strength compared to other SCC mixes. Further the GFRSCC with confinement compared to Plain GFSCC has shown an improvement in compressive strength by 7.52% to 44.30%.

2) Modulus of elasticity

The elastic modulus (E-modulus) of concrete is to a larger extent influenced by the volume of aggregate and by the aggregate properties than by the paste properties. In comparison with normal concrete the aggregate content of GFR SCC is smaller and the paste content of GFRSCC is larger. Therefore the elastic modulus of GFRSCC is expected to be somewhat lower than in normal concrete of the same strength class, which also is presented in several reports. However, the differences are small and covered by the safe assumptions included in the formulas within the norms. In cases where the E-modulus is of special importance, its real value ought to be determined.

3) Secant Modulus

The term Young‟s Modulus of elasticity can strictly be applied only to the straight part of the Stress-Strain Curve. In the case of concrete, since no part of the graph is a straight line is drawn connecting a specified point on the Stress-Strain Curve to the origin of the curve. The slope of this line is referred to as Secant Modulus. In this case Secant Modulus ant Esec obtained at 39% Stress level.

4) Stress Strain behavior of GFRSCC with & without confinement

The effect of glass fiber in SCC under axial compression was examined for the stress-strain behavior of GFRSCC. The Stress-Strain behavior of M50 grade GFRSCC at 28 days with and without confinement is shown in Figures 6.9 to 6.18 and is observed to be almost similar in the ascending portion of the curve. The proportionality limit increases as the confinement increases. This is due to the lateral partial restraint of the GFRSCC cylinder provided by confinement. Moreover the characteristic compressive strength increases as the confinement increases. Not only has the ultimate strength of the GFRSCC but also strain at failure stress increased as the confinement increases.

5) Energy absorption capacity or Toughness:

The energy absorption capacity or toughness of concrete in compression has been defined as the area under the stress-strain curve calculated up to a specified strain value. The specific toughness of concrete in compression has been defined as the ratio of the area under the stress-strain curve to the cylinder compressive strength of the concrete The increase in energy absorption with confinement.

6) Ductility

Ductility is a mechanical property of materials that measures the degree of plastic deformation the material can sustain before fracture. If little or no plastic deformation can occur the material is termed "brittle". Ductility can be quantitatively expressed in terms of either percent elongation or percent reduction in an area. Ductility which indicates a deformable characteristic of a material is measured in terms of percentage increase in strain at peak stress with confinement. The percentage increase in ductility is ranging from 5.05% to 73.10% with confinement.

7) Analytical expressions:

An examination of the curves indicates that the behavior is similar for the entire confinements M50 grade, meaning that the stress-strain behavior is linear up to 80-90% of the ultimate and nonlinear beyond this. The post-peak stress-strain response for all the GFRSCC specimens is gradual and appears to have a consistent and constant gradient.

VIII. CONCLUSIONS

Taking into account the findings from this study, The GFRSCC mix developed and satisfied the requirements of Self-compacting concrete specified by EFNARC guidelines.

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The properties like Modulus of Elasticity (Ec), Energy absorption capacity, Ductility, and Stress-Strain behavior were studied and the following conclusions can be drawn: It has been verified, by using the slump flow and U-tube tests, that self-compacting concrete (SCC) achieved consistency and self-compactability under its weight, without any external vibration or compaction. Also, because of the special admixtures used, SCC has achieved a density between 2400 and 2500 kg/m³, which was greater than that of normal concrete, 2370-2321 kg/m³. Self-compacting concrete can be obtained in such a way, by adding chemical and mineral admixtures, so that its compressive strengths are higher than those of normal vibrated concrete. An average increase in compressive strength of 60% has been obtained for SCC. Also, due to the use of chemical and mineral admixtures, self-compacting concrete has shown smaller interface microcracks than the normal concrete, fact which led to better bonding between aggregate and cement paste and an increase in compressive strengths. A measure of the better bonding was the greater percentage of the fractured aggregate in SCC (20-25%) compared to the 10% for normal concrete Also, self-compacting concrete has two big advantages. One relates to the construction time, which in most cases is shorter than the time when normal concrete is used because no time is wasted with the compaction through vibration. The second advantage is related to the place. As long as SCC does not require compaction, it can be considered environmentally friendly, because if no vibration is applied no noise is made. In the high strength concrete which is brittler than ordinary concrete, using confinement reinforcement, ductility is increased to a great extent. When confinement reinforcement spacing is decreased to half, ductility improved twice. As a result, by decreasing confinement reinforcement spacing, the compressive strength of high strength concrete can be improved. Decreasing confinement reinforcement spacing has increased the compressive strength of confined concrete to a maximum of 19%. Based on the experimental study on Glass Fiber Reinforced Self Compacting Concrete (GFRSCC) the following conclusions can be drawn.

1) Self-Compacting Concretes satisfying the specifications laid by EFNARC could be developed for nonfibrous and fibrous concretes. There is a marginal increase in the compressive strength of self-compacting concrete with glass fiber additions.
2) Glass Fiber inclusion in Self Compacting Concrete improved the peak strain and strain at 85% of the ultimate strength in the descending portion. The improvements in strains are pronounced than improvement in strength.
3) The ultimate compressive strength varied linearly with Fiber Index and can be expressed by a relationship that includes the Fiber Index. The prediction equation for ultimate strength is $f_u = f\{(1.0+0.1074F_i)\}$
4) The strain at peak stress varies linearly with Fiber Index and can be expressed by a relationship that includes Fiber Index. The equation obtained by regression analysis is $\varepsilon_u = \varepsilon' \{(1.0+0.1074F_i)\}$
5) The ductility factor (DF) of standard concrete given by the ratio of the strain at 85% of the peak stress on the descending portion of the stress-strain curve has improved with specific surface factors. $DF = 2.4577 + 2.0912\,F_i$

A. Recommendations for Future Research

The following are some suggestions for future research. As GFRSCC technology is now being adopted in many countries throughout the world, in the absence of suitable standardized test methods it is necessary to examine the existing test methods and identify or, when necessary, develop test methods suitable for acceptance as International Standards. Such test methods have to be capable of a rapid and reliable assessment of key properties of fresh SCC on a construction site. At the same time, the testing equipment should be reliable, easily portable and inexpensive. The test procedure should be carried out by a single operator and the test results have to be interpreted with a minimum of training. Also, the results have to define and specify different GFRSCC mixes. One primary application of these test methods would be in the verification of compliance on sites and concrete production plants if self- compacting concrete could be manufactured in large quantities. Further investigations have to be carried out regarding the self-compacting concrete. One major topic, which has to be studied, is related to the influence of cement type and aggregate shape and surface properties on the bonding between cement paste and coarse aggregate. Also, a thorough investigation has to be carried out to obtain an appropriate relationship between the water-cement ratio and the aggregate cement physical interface.

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