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Study on Stress-Strain behaviour of M50 Grade High Strength Glass Fibre Reinforced Self-Compacting Concrete at Different Percentages of Confinements

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Abstract: *Self-compacting concrete (SCC) can be defined as a fresh concrete which possesses superior flowability under maintained stability (i.e., no segregation) thus allowing self-compaction—that is, material consolidation without addition of energy. It was first developed in Japan in 1988 in order to achieve durable concrete structures by improving quality in the construction process. This was also partly in response to the reduction in the numbers of skilled workers available in the industry. This paper outlines a brief history of SCC from its origins in Japan to the development of the material throughout Europe. Research and development into SCC in the UK and Europe are discussed, together with a look at the future for the material in Europe and the rest of the world. Research and development of SCC is being conducted by private companies (mainly product development), by universities (mainly pure research into the material's properties), by national bodies and working groups (mainly the production of national guidelines and specifications) and at European level (Brite-EuRam and RILEM projects on test methods and the casting of SCC, respectively). Although SCC is not expected too ever completely replace conventionally vibrated concrete, the use of the material in both the precast and ready-mix markets in the UK, Europe and the rest of the world is expected to continue to increase as the experience and technology improves, the clients demand a higher quality finished product and the availability of skilled labour continues to decrease. In this work an attempt has been made to study Stress – Strain behaviour of Glass fibre Self–Compacting Concrete M50 grade under confined and unconfined states with different percentages of confinement (in the form of hoops). Since the confinement provided by lateral circular-hoop reinforcement, is a reaction to the lateral expansion of concrete, lateral reinforcement becomes effective only after considerable deformation in the axial direction. Complete Stress – Strain behaviour has been presented and an empirical equation based on rational polynomial is proposed to predict the stress – strain behaviour of such concrete under compression. The proposed empirical equation shows good correlation with the experimental results. There is an improvement in the Compressive Strength, Secant modulus and this is due to the addition of the glass – fibres to the Self- Compacting concrete and also confinement in the form of hoops in Self-Compacting Concrete mix.*

Key words: Glass-fibre, Reinforced Self – Compacting M50 grade Concrete, 6 mm diameter Mild steel, admixtures, Stress – Strain behaviour, A single Polynomial empirical equation.

1. Introduction

Self-compacting concrete (SCC) can be defined as a fresh concrete which possesses superior flowability under maintained stability (i.e., no segregation), thus allowing self-compaction that is, material consolidation without addition of energy. The three properties that characterise a concrete as self-compacting are

- flowing ability, the ability to completely fill all areas and corners of the formwork.
- passing ability, the ability to pass through congested reinforcement without separation of the constituents or blocking.
- resistance to segregation the ability to retain the coarse components of the mix in suspension in order to maintain a homogeneous material.

These properties must all be satisfied in order to design an adequate SCC, together with other requirements including those for hardened performance.

Self-compacting concrete (SCC) was first developed in Japan in 1988 in order to achieve durable concrete structures by improving quality in the construction process. It was also found to offer economic, social and environmental benefits over traditional vibrated concrete construction. Research and development work into SCC in Europe began in Sweden in the 1990s and now nearly all the countries in Europe conduct some form of research and development into the material.

In addition to the benefits described above, SCC is also able to provide a more consistent and superior finished product for the client, with less defects. Another advantage is that less skilled labour is required in order for it to be placed, finished and made good after casting. As the shortage of skilled site labour in construction continues to increase in the UK and many other countries, this is an additional advantage of the material which will become increasingly important.

This paper outlines the history of the development of SCC from its origins in Japan to its development in Sweden and the rest of Europe. The development of the material in Europe is then discussed, with particular reference to the UK.

2. Objective of the Study

In the present study, confinement in the form of hoops of 6 mm diameter was used. The mechanical properties and Stress-Strain behaviour were studied for GFRSCC with and without confinement under compression.

A single polynomial empirical equation in the form of

$$f = \frac{A\varepsilon + D}{1 + B\varepsilon + C\varepsilon^2}$$

is used for both ascending and descending portion of the curve. A, B are the constants and determined using the boundary conditions and verifying whether the experimental data is related with the mathematically calculated data.

where, f is the stress at any level and ε is the strain at any level. To express in non-dimensional stress-strain curves the following form is proposed.

$$\frac{f}{f_u} = \frac{A_1\left(\frac{\varepsilon}{\varepsilon_u}\right) + D_1}{1 + B_1\left(\frac{\varepsilon}{\varepsilon_u}\right) + C_1\left(\frac{\varepsilon}{\varepsilon_u}\right)^2}$$

Where f_u and ε_u are the ultimate stress and strain of the GFRSCC specimen in compression. A single equation to predict the entire behaviour was not giving good correlation. Hence, the constants based on the following boundary conditions were obtained separately for ascending and descending portions.

$$At\ \frac{\varepsilon}{\varepsilon_u} = 0;\ \frac{f}{f_u} = 0;\ At\ \frac{\varepsilon}{\varepsilon_u} = 1;\ \frac{f}{f_u} = 1;\ and\ At\ \frac{\varepsilon}{\varepsilon_u} = 1;$$

$$\frac{d\left(\frac{f}{f_u}\right)}{d\left(\frac{\varepsilon}{\varepsilon_u}\right)} = 0$$

The boundary conditions common for both ascending and descending portions of stress – strain curve.

Stress-Strain analysis of a material is one way to determine many of its physical properties. With the information gained through much analysis, one can predict how a part will react when placed under various working loads.

The major objectives are:

1. Understand the basic process of deformation due to tensile loading
2. Characterize the physical properties of various metals from their stress-strain curves

Unconfined plain concrete, exhibits a brittle failure mode, the failure may be explosive and marks the termination of the Stress-Strain Curve and loss of load-carrying capacity shortly after the peak load.

If there exists a lateral pressure that resists this sideway expansion, however, the core concrete will be in a state of multi-axial compression. It is accepted that when the concrete is experiencing multi-axial compression, both the deformation capacity and strength are improved. The scope of this work was limited to the development of a suitable mix design to satisfy the requirements of GFRSCC using local aggregates and then to determine the strength and durability of such concrete. The mechanical properties and Stress-Strain behaviour were studied for GFRSCC with and without confinement under compression. The specific objectives were as follows.

1. To design a suitable SCC mix utilizing local aggregates, and
2. To assess the strength development and durability of GFRSCC and Stress-Strain behaviour with and without confinement under compression.

In the present study, it was to achieve required properties of Self-compacting concrete with available materials in the laboratory. Coarse aggregate with nominal size 12.5 mm (70%) & 20 mm (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.

3. Literature Review

1) Hajime Okamura: A new type of concrete, which can be compacted into every corner of a formwork purely by means of its own 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.

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 first 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 a concrete which was very workable. It was suitable for rapid placement and had a very good permeability. The viscosity of the concrete was measured using the V- funnel test.

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 on development of self-compacting concrete, underwater concrete with antiwashout 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, which would give the procedure for the selection of a viscosity modifying agent, a compatible superplasticizer and the determination of their dosages. The Portland cement was partially replaced with fly ash and blast furnace slag, in the same percentages as Ozawa (1989) has done before and the maximum coarse aggregate size did not exceed 25mm. 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. On the basis of these trials, it was discovered that self-compactability could be achieved

4) Khayat et al.: The use of self-consolidating concrete can facilitate the placement of concrete in congested members and in restricted areas. Given the highly flowable nature of such concrete, care is required to ensure adequate stability. This is especially important in deep structural members and wall elements where concrete can segregate and exhibit bleeding and settlement, which can result in local structural defects that can reduce mechanical properties. The objective of Khayat's (1997) et al. research was to evaluate the uniformity of in situ mechanical properties of self-consolidating concrete used to cast experimental wall elements Eight optimized SCC mixtures with slump flow values greater than 630 mm and conventional concrete with a slump of 165 mm were investigated. The self-compacting concrete mixtures incorporated various combinations of cementitious materials and chemical admixtures. The water-cementitious materials ratios ranged from 0.37 to 0.42. Experimental walls measuring 95 cm in length, 20 cm in width, and 150 cm in height were cast. After casting, no consolidation was used for the SCC mixtures, while the medium fluidity conventional concrete received thorough internal vibration. Several cores were obtained in order to evaluate the uniformity of compressive strength and modulus of elasticity along the height of each wall. Khayat (1997) et al. found out that all cores from both types of concrete exhibited little variation in compressive strength and modulus of elasticity in relation to height of the wall, indicating a high degree of strength uniformity. However, compressive strength and modulus of elasticity were greater for SCC samples than those obtained from the medium fluidity conventional concrete.

5) ACI committee report No.226 [1987]: Has discussed the effects of Fly ash. The effect on the workability depends on the fineness of Fly ash. The fineness and roundness of particles improve cohesion and workability. Due to workability, there will be reduction in susceptibility of segregation and bleeding which reduces temperature developed during curing in fresh concrete and reduces permeability in the hardened concrete. This reduction reduces the damage of steel corrosion, alkaline sulphite attack. The reports also discussed the specification for material testing, quality assurance for Fly ash concrete and making use of good proportion of Fly ash.

6) Srinivasa Rao.P, [2008]: In his paper "Strength properties of Glass Fibre Self-Compacting concrete" studied the properties of GFSCC using alkali-resistant glass fibres in various proportions and compared the properties for controlled mixes of grade M30 and M35. He concluded that there is an improvement in the compressive strength for both grades of GFSCC and is observed to be 15% over Self-Compacted Concrete.

4. Methodology

4.1. Materials used

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.

Table 1.0 Properties of cement

Properties	Results
Standard consistency	30 %
Initial setting time	30 min
Final setting time	600 min
Compressive strength for 28 days	54.7 N/mm^2

Table 1.1. Chemical compositions of Cement as per manufacturers test Report

Chemical property	Results	Limits as per IS code
Lime saturation Factor (%)	0.78	0.66 min - 1.02 max
Alumina Iron Ratio (%)	1.2	Min 0.665
Insoluble Residue (%)	0.8	Max 2%

Magnesia (%)	2.1	Max 6%
Sulfuric anhydride (%)	1.1	2.5% to 35
Loss on ignition (%)	2.0	Max 5%

b) 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 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.

c) Coarse aggregate: Aggregate of size 10-12 mm 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 with respect to shape and grading.

4.2 Admixtures:

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

a) Mineral Admixtures:

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

Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro-cracks, eventually leading to the brittle fracture of the concrete.

In the past, attempts have been made to impart improvement in tensile properties of concrete members by way of using conventional reinforced steel bars and also by applying restraining techniques. Although both these techniques provide tensile strength to the concrete members, they however, do not increase the inherent tensile strength of concrete itself.

It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties.

Fiber reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. Glass fibre is a recent introduction in making fibre concrete. It has very high tensile strength 1020 to 4080 N/mm^2

b) Fly ash: Fly ash is a by-product of the combustion of pulverized coal in thermal power plants. The dust-collection system removes the fly ash, as a fine particulate residue, from the combustion gases before they are discharged into the atmosphere.

Fly ash particles are typically spherical, ranging in diameter from <1 µm up to 150 µm. The type of dust collection equipment used largely determines the range of particle sizes in any given fly ash.

Fly ashes exhibit pozzolanic activity. The American Society for Testing and Materials (ASTM) defines a pozzolan as "a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties." Fly ashes contain metastable aluminosilicates that will react with calcium ions, in the presence of moisture, to form calcium silicate hydrates.

More than 2000 years ago, Roman builders recognized that certain volcanic ashes were capable of forming effective cements when combined with lime. The Romans widely exploited this pozzolanic property of volcanic ashes, and many structures from the Roman period are still intact. The modern recognition that fly ash is pozzolanic has led to its use as a constituent of contemporary Portland cement concrete.

Typical characteristics of good quality fly ash are as follows:

1. Fineness (Blaine's): 32.62 m^2/N (Min.)
2. Lime Reactivity: 4.5 N/mm^2 (Min.)
3. Loss on ignition: 5% (Max.)

Table 1.2 Physical characteristics of VTPS fly ash:
(Obtained from Vijayawada Thermal Power station)

Characteristics	Experimental results
Fineness, m2/kg (Blain's permeability)	475
Lime reactivity	4
Compressive strength, 21 days	>80%of the Corresponding plain Cement mortar cubes
Drying shrinkage	% 0.08
Autoclave shrinkage	%/0.68

Table 1.3 Chemical composition of VTPS fly ash:
(Obtained from Vijayawada Thermal Power station)

Characteristics	Percentage
SiO_2 +Al_2O3+Fe_2O_3	86.7
SiO_2	54
MgO	0.1
Total sulfur as SO_3	0.11
Available alkali as sodium oxide (Na_2O)	2.16
Loss on ignition	2

c) Chemical Admixtures: A 'Chemical admixture' is any chemical additive to the concrete mixture that enhances the properties of the concrete in the fresh or hardened state. ACI-116R [2000] defines the term admixture as 'a material other than water, aggregates, hydraulic cement, used as an ingredient of concrete or mortar, and added to the batch immediately before or during its mixing'.

A number of types of Chemical admixtures are used for concrete. The general purpose chemicals include those that reduce water demand for a given workability('water reducers'),those entraining air in the concrete for providing resistance to freezing and thawing action('air entrainers'),and those chemicals that control the setting time and strength gain rate of concrete ('accelerators' and 'retarders').Apart from these chemicals, there are others for special purposes-namely, Viscosity Modifying Agents, Shrinkage Reducing Chemicals, Corrosion inhibiting admixtures, and alkali-silica reaction mitigating admixtures.

A 'water reducing chemical', as the name implies, is used to reduce the water content of a concrete mixture while maintaining a constant workability. The resultant effect of the reduced water content is the increased strength and durability of concrete. However, water reducers may also be employed to 'plasticize' the concrete, i.e., Make concrete flowable. In this case, the water content (or water to cement ratio) is held constant, and the addition of the admixtures makes the concrete flow better, while the compressive strength (which is a function of water to cement ratio), is not affected. Another use of water reducers is to low the amount of cement (since water is proportionally reduced) without affecting both strength and workability. This makes the concrete cheaper and environmentally friendly, as less cement is consumed.

Water reducers are classified broadly into two categories: Normal and High Range Water Reducers. The normal water reducers are also called 'plasticizers', while the high range water reducers are called 'superplasticizers. While the normal water reducers can reduce the water demand by 5-10%, the high range water reducers can cause a reduction of 15-40%.

i) Superplasticizer: In present days Superplasticizers are powerful enough to keep a concrete mix highly workable for more than one hour with much less water.

Dosage: The optimum dosage is best determined by site trails with the concrete mix which enables the effects of workability, strength gain or cement reduction to be measured. As a guide the rate of addition is generally in the range of 1 to 4 lit per cubic meter of concrete

ii) Viscosity modifying Agent (VMA): Today's concrete has to fulfill a wide range of requirements in both the fresh and hardened state. Concrete can be pumped both vertically and horizontally over a long distance even with high flow, self-compacting properties.

The use of a viscosity-modifying agent can suppress some of these variations to a certain extent.

The inclusion of VMA ensured the homogeneity and the reduction of the tendency of highly fluid mix to segregate Gelinium-2 VMA is used for this work. The use of a VMA gives more possibilities of controlling segregation when the amount of powder is limited.

GLENIUM-2 is a premier ready-to-use, liquid, organic, viscosity-modifying admixture (VMA) specially developed for producing concrete with enhanced viscosity and controlled rheological properties. Concrete containing **GLENIUM-2** admixture exhibits superior stability and controlled bleeding characteristics, thus increasing resistance to segregation and facilitating placement.
Typical Properties of **Glenium-2:**
Aspect: Colourless free flowing liquid
Relative Density: 1.01 ± 0.01 at 25°C
pH: > 6
Chloride ion content: < 0.2%
Dosage: GLENIUM-2 is dosed at the rate of 50 to 500 ml/100 kg of cementitious material. Other dosages may be recommended in special cases according to specific job site conditions.

iii) Glass Fibres: The glass fibres are of Cem-FIL Anti – Crack HD (High Dispersion) Glass Fibres with Modulus of Elasticity 72 GPa, Filament Diameter 14 Microns, Specific Gravity 2.68, Filament length 12 mm and having Aspect Ratio of 857: 1. The number of fibres per 1 kg is 212 million fibres.

On the basis of the experimental study, it was concluded that addition of Glass Fibres in concrete gives a reduction in bleeding. A reduction in bleeding improves the surface integrity of concrete, improves its homogeneity, and reduces the probability of cracks occurring where there is some restraint to settlement. The properties of Glass Fibres are shown below in table 2.0.

Table 1.4 Properties of Selected Glass Fibres

Trade Name	Cem FIL anti-crack High Dispersion Glass Fibres
1. Number of fibres	212 million/Kg
2. Aspect ratio	857:1
3. Specific surface area	$105m^2$/Kg
4. Typical addition rates	0.6 Kg/m^3 of concrete
5. Tensile strengths	1700 N/mm^2
6. Modulus of Elasticity	73 GPa
7. Corrosion resistant	Excellent
8. Specific gravity	2.6
9. Density	26 kN/m^3
10. Filament diameter	14 µm
11. Filament length	12mm

4.3 Water: This is the least expensive but most important ingredient in concrete. The water, which is used for making concrete, should be clean and free from harmful impurities such alkali, and acid etc. in general, the water is fit for drinking, should be used for concrete. Water confirming to IS 456-2000.

5. Processing of Methodology

5.1. Mix proportions

In the total experimental programme, M50 grade SCC mix was designed based on Indian Standard Recommended Method of Concrete Mix Design (IS 10262-1982), and was further modified by fine tuning the relative proportions of fine and coarse aggregate, filler material like fly ash, glass fiber along with super plasticizers and viscosity modifying agents. three phases are involved at first preparing the SCC mix M 50. In the second phase involving the casting of the specimens which is of standard sizes cubes for compressive strength, cylinders for split tensile strength and beams for flexural strength by varying the percentage of replacements as well as the confinements. And in the third phase conducting the tests on the hardened properties of the specimens to know its mechanical properties. Compression Tests will be carried out on hardened test cylinders, the cylindrical test specimens have a length equal to twice the diameter they are of 150 mm in diameter and 300 mm long. Compression test develops a rather more complex system of stress. Due to compression load, the cube or cylinder under goes lateral expansion owing to the position's ratio effect. The steel plates do not undergo lateral expansion to some extent that of concrete. With the result that the steel restrains the expansion tendency of concrete in the lateral direction. This induces a tangential force between the end surfaces of the concrete specimen and the adjacent steel plates of the testing machine. Cracks are developed on the surface of test specimen when it attains peak load in compression. On Central portion of test specimen, it observed that cracks are identified. This shows that failure of test specimen occurred due to insufficient cover to confined steel specimen.

Fresh SCC must possess the key properties including filling ability, passing ability and resistance to segregation at required level. To satisfy these conditions EFNARC has formulated certain test procedures. The fresh properties of SCC with glass fiber are shown in Table 6.8. Companion cube specimens of standard dimensions 100 mm x 100 mm x 100 mm were also cast and tested for the strength. The results of the compressive strength are also presented in Table 6.8. The corresponding compressive strength of cube specimens presented in Table 6.10. Thus, the optimum mix proportions for GFRSCC were arrived at the end of this phase of study.

5.2 Trail Mixes: Aim is to arrive the Mix Proportion for M50 Grade Self-Compacting Concrete. Hence Mix 1 to Mix 4 in the Trail Mixes for evaluating the Self-Compatibility of Concrete. In Mix 4, the material quantities are same as used in the above Mix including the quantity of super plasticizer, only reducing the dosage of VMA is changed. Here the Mix passed and the values are within limits. Thus, the Mix is considered as the final Mix.

Final Mix proportion: Cement: Fine Aggregate: Coarse aggregate 1: 1.642: 2.156 respectively. Cement is replaced by 33% with Fly ash.

Table 1.6 Mix design proportions of GFRSCC M50 grade

Material	Quantity (kg/m^3)
Cement	425
Fine Aggregate	794.93
Coarse Aggregate	(70%+30%) = 896.40
Water	190
Fly ash	209
Glass Fibres	0.60
Super plasticizer	85 ml (0.04132 m^3)
Viscosity modifying agent	3 ml

5.3 Development of Glass Fiber Reinforced Self-Compacting Concrete (GFRSCC):

Fresh SCC must possess the key properties including filling ability, passing ability and resistance to segregation at required level. To satisfy these conditions EFNARC has formulated certain test procedures. The fresh properties of SCC with glass fiber are shown in Table 1.7. Companion cube specimens of standard dimensions 100 mm x 100 mm were also cast and tested for the strength.

The results of the hardened properties of compressive strength for cylinders are also presented in Table 1.9. The corresponding compressive strength of cube specimens presented in Table 1.10 Thus, the optimum mix proportions for GFRSCC were arrived at the end of this phase of study.

5.4 Specimen Preparation for GFRSCC:

After satisfying the requirements GFRSCC in fresh state was poured in moulds of cubes & cylinders. Using 6 mm diameter. Mild steel rings as transverse reinforcement, five different types of cylinders of standard size 150 x 300 mm cast i.e., placing no rings, 3 rings, 4 rings, 5 rings and 6 rings. Specimens were prepared with varying percentages of Confinement. For GFRSCC mix 15 cylinders and GFSCC mix 14 cubes specimen size 100 mm x 100 mm x 100 mm were cast. After the concrete has set in moulds the cylindrical specimens which were to be tested in axial compression were capped with a thin layer of stiff neat Portland cement paste. After 24 hours of casting the specimens were de-moulded and placed in water for curing. After 28 days of curing the specimens were taken out from water and allowed the surfaces for drying.

Table 1.7 Concrete Specimen's Cylinders casting with different Confinements

Mix Identification	No of rings	Specimen's Size	No of Specimens
GFR SCC 0%	0	150 mm x 300 mm	3
GFRSCC 0.798%	3	150 mm x 300 mm	3
GFRSCC 1.062%	4	150 mm x 300 mm	3
GFRSCC 1.327%	5	150 mm x 300 mm	3
GFRSCC 1.591%	6	150 mm x 300 mm	3

5.5 Compressive Strength

Of the various strengths of concrete, the determination of compressive strength has received a large amount of attention because the concrete is primarily meant to withstand compressive stresses. Generally, cubes are used to determine the compressive strength. The cubes are usually of 100 x 100 x 100mm (or) 150 x 150 x 150 mm size. In the present investigation the size of 100 x 100 x 100 mm is used. In the compressive test, the cube while cleaned to wipe of the surface water, is placed with the cast faces in contact with the planes of the testing machine, i.e. the position of the cube then tested is at right angles to that as cast. The specimens were removed from the moulds and submerged in clean fresh water until just prior to testing. The temperature of water in which the cylinders were submerged was maintained at 27o C+2o C and 90% relative humidity for 24 hours. The specimens were cured for 28 days.

Table 1.8. Fresh properties of GFRSCC

Name of the test	Property	Unit	Result	Requirement as per of EFNARC Min	Max
Slump flow	Filling Ability	mm	675	650	800
T_{50} cm Slump Flow	Filling Ability	sec	308	2	5
V- Funnel	Filling Ability	sec	6	6	12
V- Funnel 5 minutes	Seg. Resistance	sec	9	0	15
L- Box	Passing bility	H_2/H_1	0.8	0.8	1

6. Results & Discussion

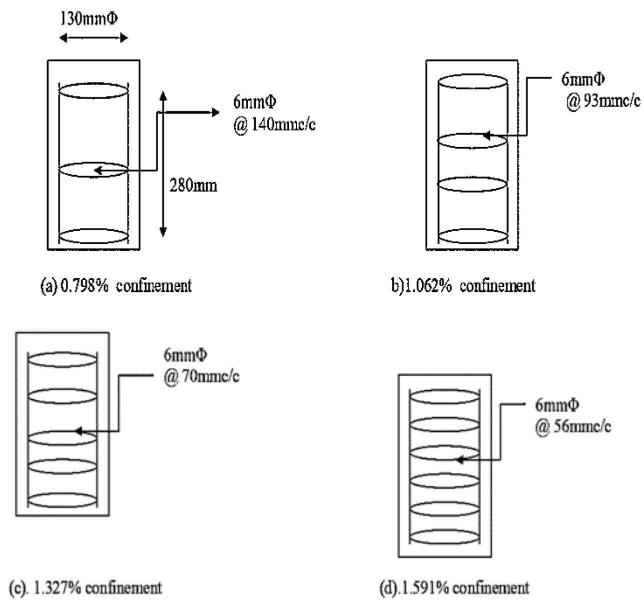
In the present investigation the size of 100 x 100 x 100 mm is used. In the compressive test, the cube while cleaned to wipe of the surface water, is placed with the cast faces in contact with the planes of the testing machine, i.e., the position of the cube then tested is at right angles to that as cast. The specimens were removed from the moulds and submerged in clean fresh water until just prior to testing. The temperature of water in which the cylinders were submerged was maintained at 27o C+2o C and 90% relative humidity for 24 hours. The specimens were cured for 28 days.

6.1 Stress-strain behaviour of GFRSCC

A stress-strain curve is a graph derived from measuring load versus strain. In order to get the strain values, we cast cylinders of standard size 150 x 300 mm. In the present investigation, Cylinders with different confinements were tested in compression using 1000 kN capacity computer controlled UTM under strain rate control as per IS 516:1959 to get for assessing as well as deformation and strain characteristics of concrete cylinders while undergoing compression testing. Compressive strength tests were carried out on cubes of 100 mm size using a compression testing machine of 1000 kN capacity as per IS 516:1959.

A stress-strain curve is a graph derived from measuring load versus strain. In order to get the strain values, we cast cylinders of standard size 150 x 300 mm we provided confinement to the cylinders at different percentages. As a section we using 1000 kN capacity computer controlled UTM under strain rate control is utilized for assessing as well as deformation and strain characteristics of concrete cylinders while undergoing compression testing. The stress-strain behaviour of concrete is a vital parameter which is essential in designing and toughness of concrete. An entire stress-strain curve required for the design and examination of a concrete structure during the severe weather conditions to and difficulty in concrete repair.

6.1.1 Cylinder with different confinements



6.2 Stress-strain values of 0 % confinement at 28 days

In order to find the stress-strain curves for concrete, we used to test cylinder specimen under strain control. The rate of strain 0.02 mm per second and measures at every 20 KN. And also, here peak stress is 43.0072 N/mm2 and the peak strain is 0.0026. in order to conclude the values of normalized stress, we consider actual stress to the peaks stress. Similarly in case of normalized strain actual strain to the peak strain. And here the most extreme strain is 0.0385. the stress and normalized stress graphs are given below in Fig 1.0 & Fig 1.1. The graphs are given below.

Table 1.9 Stress-Strain values of cylinder 0% confinement

SL No	Stress N/mm²	Strain	Normalized stress N/mm²	Normalized strain
1	1.13177	0.0000333	0.03	0.01
2	2.26354	0.0000650	0.05	0.02
3	3.39531	0.0000900	0.08	0.03
4	4.52707	0.0001167	0.11	0.04
5	5.65884	0.0001583	0.13	0.06
6	6.79061	0.0002000	0.16	0.07
7	7.92238	0.0002417	0.18	0.09
8	9.05415	0.0002667	0.21	0.1
9	10.1859	0.0003083	0.24	0.11
10	11.3177	0.0003500	0.26	0.13
11	12.4495	0.0003917	0.29	0.14
12	13.5812	0.0004333	0.32	0.16
13	14.713	0.0004917	0.34	0.18
14	15.8448	0.0005333	0.37	0.19
15	16.9765	0.0005833	0.39	0.21
16	18.1083	0.0006333	0.42	0.23
17	19.2401	0.0006667	0.45	0.24
18	20.3718	0.0007167	0.47	0.26
19	21.5036	0.0007667	0.50	0.27
20	22.6354	0.0008000	0.53	0.29
21	23.7671	0.0008500	0.55	0.30
22	24.8989	0.0009000	0.58	0.32
23	26.0307	0.0009667	0.61	0.35
24	27.1624	0.0010167	0.63	0.36
25	28.2942	0.0010833	0.66	0.39
26	29.426	0.0011667	0.68	0.42
27	30.5577	0.0012250	0.71	0.44
28	31.6895	0.0013333	0.74	0.48
29	32.8213	0.0014083	0.76	0.50
30	33.9531	0.0015000	0.79	0.54
31	35.0848	0.0015917	0.82	0.57
32	36.2166	0.0016667	0.84	0.60
33	37.3484	0.0017667	0.87	0.63
34	38.4801	0.0018667	0.89	0.67
35	39.6119	0.0019667	0.92	0.70
36	40.7437	0.0021500	0.95	0.77
37	41.8754	0.0023333	0.97	0.84
38	43.0072	0.002792	1	1
39	41.8754	0.0031667	0.97	1.13
40	40.7437	0.0033000	0.95	1.18
41	39.6119	0.0034333	0.92	1.23
42	38.4801	0.0035667	0.89	1.28
43	37.3484	0.0036833	0.87	1.32
44	36.2166	0.0037500	0.84	1.34
45	35.0848	0.0038167	0.82	1.37
46	33.9531	0.0038500	0.79	1.39

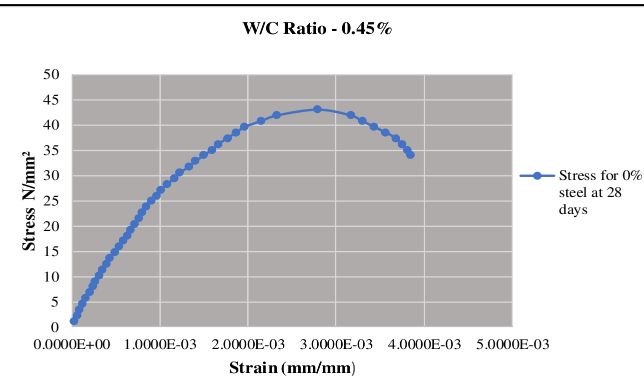


Fig 1.0 Stress-strain behaviour of M50 grade GFRSCC at 0% confinement

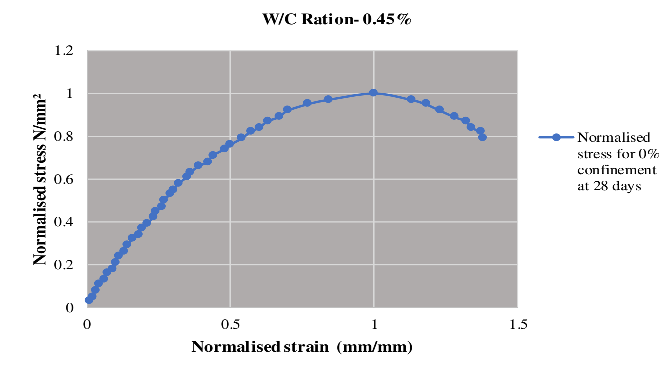


Fig 1.1 Normalised stress- Normalised strain curve for M50 grade GFRSCC at 0% confinement

6.3 Stress strain calculations for 0.798 % confinement

The stress-strain computations for 0.798% steel at 28 days. The stress-strain curve and normalized stress – strain curve of 0.798% was given beneath. The peak stress is 45.271 N/mm² and peak strain is 0.002417 and maximum strain is 0.005083. similarly, peak stress & peak strain was calculated from the actual stress to the peak stress. Comparison of the normalized stress & strain values graphically presented in Fig 1.2 & Fig 1.3. The graphs are given below.

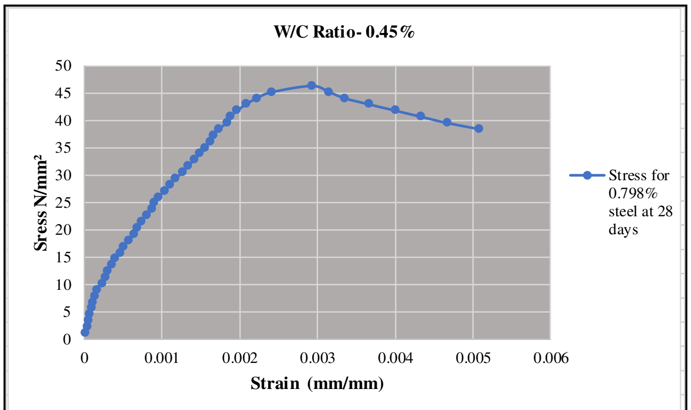


Fig 1.2 Stress -strain behaviour of M50 grade GFRSCC at 0.798% confinement

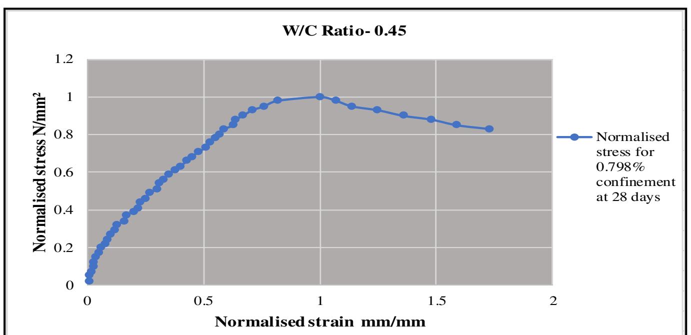


Fig 1.3 Normalised stress - Normalised strain curve of M50 grade GFRSCC at 0.798% confinement

6.4 Stress-strain calculations for 1.062 % steel for 28 days

The specimen readings along with the stress-strain computations for 1.062% steel at 28 days was given beneath. The stress-strain curves and standardized stress-strain curves for confinement 1.062% given beneath. Peak stress is 48.1 N/mm² and strain at peak stress is 0.004. The extreme strain is 0.05833. similarly, peak stress & peak strain was calculated from the actual stress to the peak stress. Comparison of the normalized stress & strain values graphically presented in Fig 1.4 & Fig 1.5. The graphs are given below.

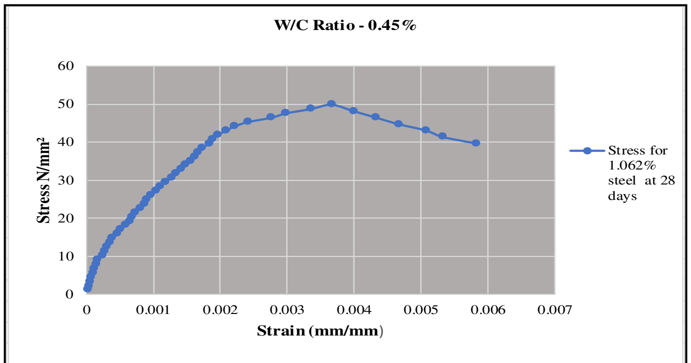


Fig 1.4 Stress-Strain behaviour of M50 grade GFRSCC at 1.062% confinement

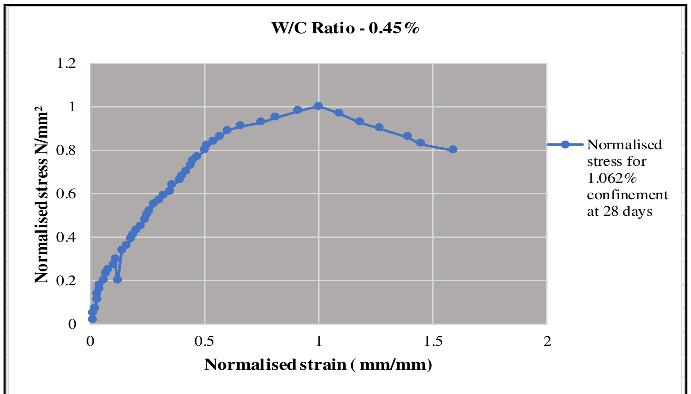


Fig 1.5 Normalised stress - Normalised strain curve of M50 grade GFRSCC at 1.062% confinement

6.5 Stress- strain calculations for 1.327% steel for 28 days

The stress-strain computations for 1.327% steel at 28 days. The stress-strain curve and normalized stress – strain curve of 1.327% was given beneath.

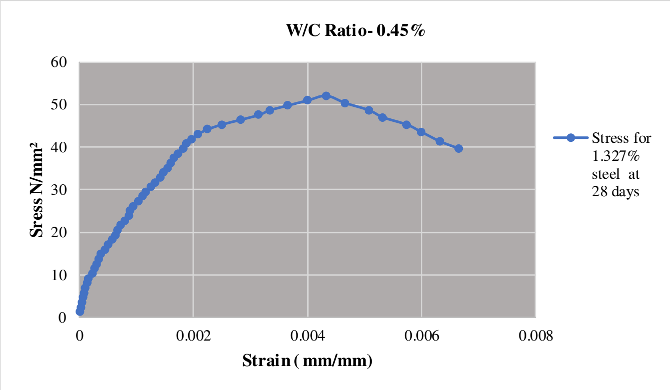


Fig 1.6 Stress-Strain behaviour of M50 grade GFRSCC at 1.327% confinement

The peak stress is 52.061 N/mm^2 and peak strain is 0.004333 and maximum strain is 0.006667. similarly, peak stress & peak strain was calculated from the actual stress to the peak stress. Comparison of the normalized stress & strain values graphically presented in Fig 1.6 & Fig 1.7. The graphs are given below.

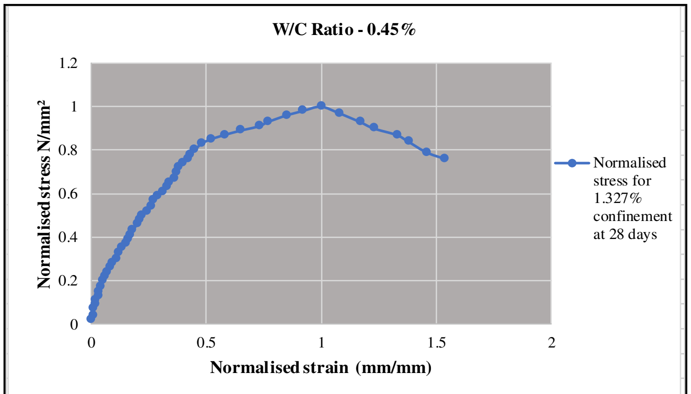


Fig 1.7 Normalised stress - Normalised strain curve of M50 grade GFRSCC at 1.327% confinement

6.6 Stress- strain calculations for 1.591% steel for 28 days

The stress-strain computations for 1.591% steel at 28 days. The stress-strain curve and normalized stress – strain curve of 1.591% was given beneath. The peak stress is 57.7202 N/mm^2 and peak strain is 0.004833 and maximum strain is 0.007667. similarly, peak stress & peak strain was calculated from the actual stress to the peak stress. Comparison of the normalized stress & strain values graphically presented in Fig 1.8 & Fig 1.9. The graphs are given below.

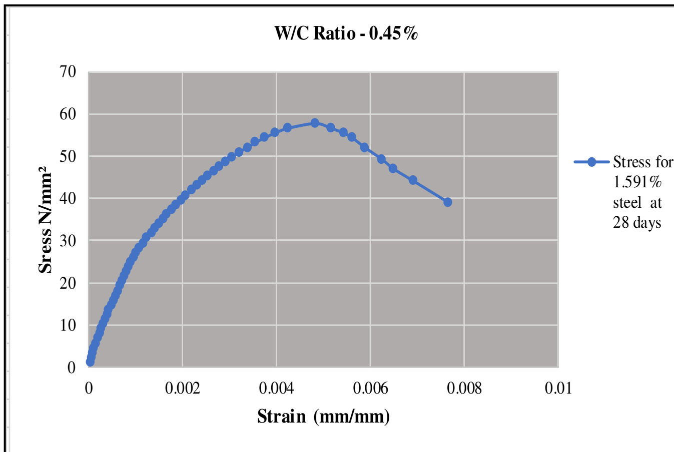


Fig 1.8 Stress-Strain behaviour of M50 grade GFRSCC at 1.591% confinement

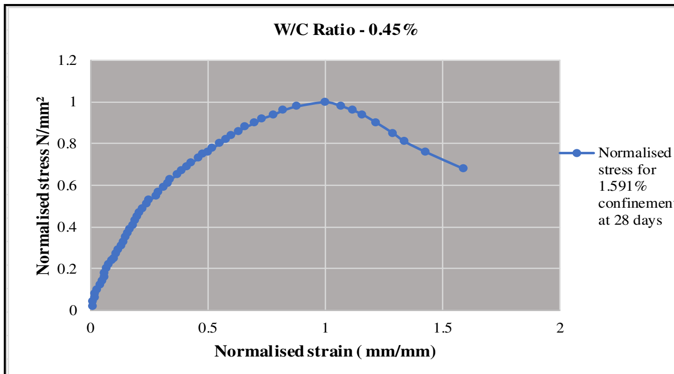


Fig 1.9 Normalised stress- Normalised strain curve of M50 grade GFRSCC at 1.591% confinement

6.7 Typical Stress-strain behavior of (M50 Grade GFRSCC) with different confinement at 28 days

The typical stress-strain curves of M50 GFRSCC at 28 days under compression. The ascending part of stress-strain curve is more linear and steeper as the compressive strength of concrete increases is graphically presented in 1.10, that there is increase in compressive strength with increasing tie confinements and also it shows that the peak strain increases slightly with increasing compressive strength. There is not much difference in the initial portion of stress – strain curves for confined and unconfined state. Since the confinement provided by lateral circular-hoop reinforcement, is a reaction to the lateral expansion of concrete, lateral reinforcement becomes effective only after considerable deformation in the axial direction. The graphs are given below.

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Table 1.10 Compressive strength of Concrete Cubes tested in 28 days

Sl No	Designation	Compressive Strength in N/mm^2
1	GFSCC Plain	61.17
2	GFSCC Plain	58.77
3	GFSCC Plain	58.96
4	GFSCC Plain	58.81
5	GFSCC Plain	58.86
6	GFSCC Plain	58.34
7	GFSCC Plain	59.80
8	GFSCC Plain	58.92
9	GFSCC Plain	59.10
10	GFSCC Plain	59.96
11	GFSCC Plain	58.35
12	GFSCC Plain	58.79
13	GFSCC Plain	58.69
14	GFSCC Plain	64.03

Table 1.9. Hardened properties of M50 grade GFRSCC at 28days

Designation	Volume of Confinement reinforcement %	Cylindrical Compressive Strength in N/mm^2 (MPa)	Strain at Peak Stress
GFSCC p	0	43.0072	0.002792
GFRSCC (3R)	0.798	46.4025	0.002933
GFRSCC (4R)	1.062	49.7980	0.003667
GFRSCC (5R)	1.327	52.0614	0.004333
GFRSCC (6R)	1.591	57.7202	0.004833

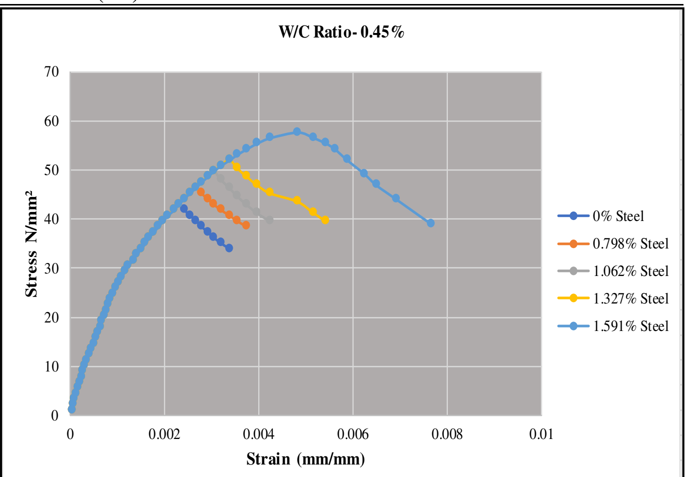

Fig 1.10 Typical stress-strain behaviour of M50 grade GFRSCC with different confinement at 28 days

6.8 Compressive strength of Cubes

The Compressive strength of Cubes of all the 14 Specimens is more than 50 N/mm^2, which is more than the required strength are shown in Table 1.10.

6.9 Secant Modulus

The term Young's Modulus of elasticity can strictly be applied only to the straight part of the Stress-Strain Curve. In case of concrete, since no part of the graph is straight line is drawn connecting a specified point on the Stress-Strain Curve to the origin of the curve. Slope of this line is referred as Secant Modulus. In this case Secant Modulus ant E_{sec} obtained at 39% Stress level is shown in Table 1.11. It shows there is an increase in Secant Modulus with Confinement. The value of Secant Modulus obtained for SCC without confinement is 28294.25 N/mm^2. This is found to be about 24.95 % less than normal concrete of similar strength (35355.339 N/mm^2). An equation relating young's modulus (EC) of GFRSCC and its compressive strength (f_{ck}) is obtained as EC = $5000\sqrt{f_{ck}}$. The Secant modulus of GFRSCC with confinement follows the relationship $E_{sec} = 5132\sqrt{f_{ck}}$. The high elastic modulus and high density of steel may be responsible to increase the E_{sec} of GFRSCC.

Table.1.11 Secant Modulus of GFRSCC

Designation	Secant Modulus N/mm^2
GFSCC P	28294.25
GFRSCC (0.798 %) 3R	29958.82
GFRSCC (1.062%) 4R	31383.02
GFRSCC (1.327%) 5R	33419.29
GFRSCC (1.591%) 6R	33657.99

6.10 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 is shown in table 1.12. There is an improvement of energy absorption capacity from 36.12% to 101.82% due to confinement.

6.11 Ductility

Ductility is a mechanical property of materials that measures the degree of plastic deformation the material can sustain prior to 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.

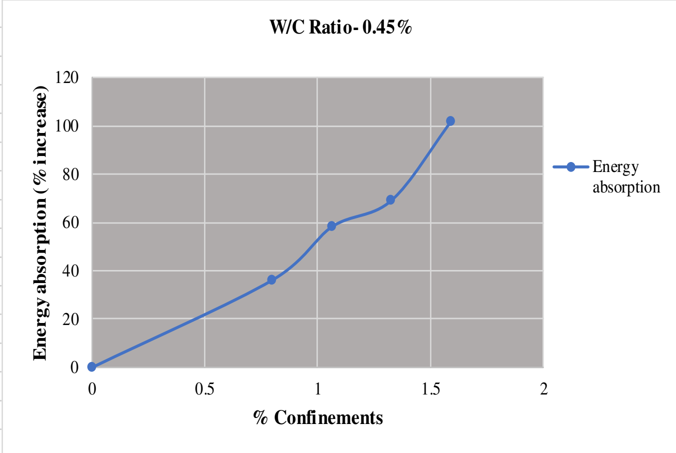

Fig 1.11 Graphical representation of increase in Energy Absorption (%increase) with different confinements

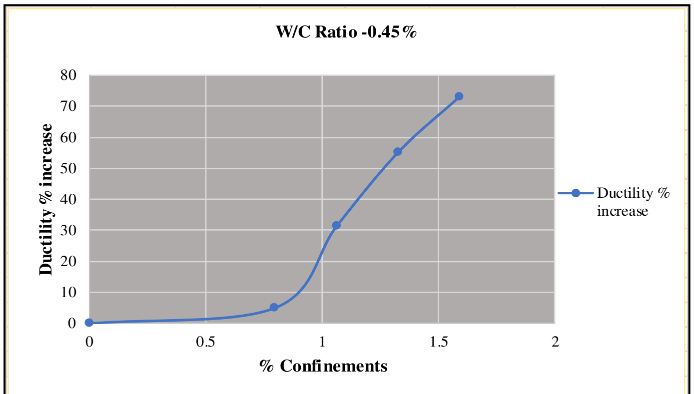

Fig 1.12 Graphical representation of increase in ductility (%increase) with different confinements

Table 1.13 different confinements vs Improvement in compressive strength (%)

Designation	Peak stress N/mm^2	Improvement in compressive strength (%)
GFSCC P	43.0072	7.52
GFRSCC (0.798 %) 3R	46.4025	16.00
GFRSCC (1.062%) 4R	49.798	24.50
GFRSCC (1.327%) 5R	52.0614	30.15
GFRSCC (1.591%) 6R	57.7202	44.30

Table 1.12 Energy absorption, and ductility values for GFRSCC with different confinements

Designation	Energy Absorption (% increase)	Ductility (% increase)
GFSCC P	-	-
GFRSCC (0.798 %) 3R	36.12	5.05
GFRSCC (1.062%) 4R	58.18	31.33
GFRSCC (1.327%) 5R	69.16	55.19
GFRSCC (1.591%) 6R	101.82	73.10

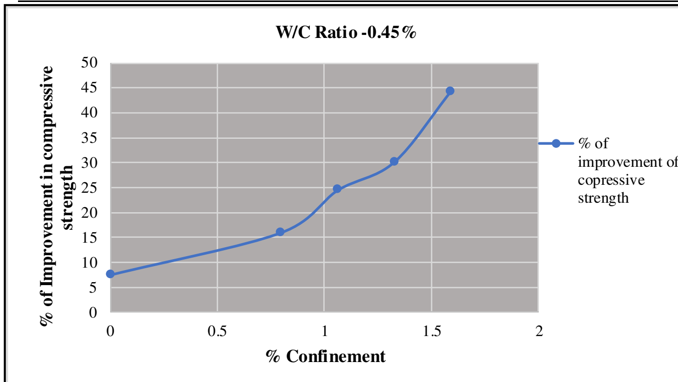

Fig 1.13 % of Different Confinements Vs % of Improvement of Compressive Strength

7. Conclusions

Experimental Investigation of 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 non-fibrous and fibrous concretes. There is a marginal increase in 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 descending portion. The improvements in strains are pronounced than improvement in strength.

3. The experimental values compared well with analytical model developed. A nondimensionalized stress–strain equation proposed in this investigation can be used to predict the behaviour of Glass Fiber Reinforced Self-Compacting Concrete (GFRSCC). The stress block parameters presented in this paper can be used to determine the ultimate moment and corresponding curvature of GFRSCC.

4. Confinement of concrete has increased the strengths at 28 days from 7.52% to 44.30% in compression.

5. The value of secant modulus (E_C) obtained for M50 grade SCC without confinement is 24.95% less than normal concrete of similar strength.

6. The value of secant modulus (E_C) obtained for M50 grade GFRSCC with confinement is 2.64% more than ordinary concrete and follows the relationship $E_C = 5132\sqrt{f_{ck}}$

7. It observed that the peak stress and corresponding strain at peak stress increases with the increase in the percentage of confinement.

8.The energy absorption was increased by 101.82% when the percentage of confinement is 1.591%.

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