

Study of Stress – Strain Behaviour of Glass Fibre Self–Compacting Concrete With & Without Confinement

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ABSTRACT: 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 behaviour at early ages. However, there is a limit to the fluid behaviour 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 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 recently developed concept in which the ingredients of the concrete mix are proportioned in such a way that it can flow under its own weight to completely 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 concrete 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.

In this work an attempt has been made to study Stress – Strain behaviour of Glass fibre Self–Compacting Concrete 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 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..

I. INTRODUCTION

Development of self-compacting concrete (SCC) is a desirable achievement in the production enterprise in order to overcome issues related to cast-in-place concrete. Self-compacting concrete is not affected by the capabilities of people, the form and quantity of reinforcing bars or the association of a shape and, due to its high-fluidity and resistance to segregation it may be pumped longer distances (Bartos, 2000). The idea of self-compacting concrete changed into proposed in 1986 by professor Hajime Okamura (1997), however the prototype changed into first developed in 1988 in Japan, by using professor Ozawa (1989) on the University of Tokyo. Self-compacting concrete become advanced at that point to enhance the sturdiness of concrete structures. Since then, diverse investigations have been performed and SCC has been utilized in practical systems in Japan, specially through large production agencies. Investigations for organising a rational mix-design technique and self-compactability testing methods were accomplished from the point of view of making it a standard concrete. Self-compacting concrete is cast in order that no additional internal or outer

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vibration is important for the compaction. It flows like “honey” and has a completely easy floor level after putting. With regard to its composition, self-compacting concrete includes the same components as conventionally vibrated concrete, which can be 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-editing agents, which alternate the rheological properties of concrete. Mineral admixtures are used as an extra best cloth, besides cement, and in a few cases, they update cement. In this examine, 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.

Advantages of Self-Compacting Concrete

Compared to NVC, SCC possesses enhanced qualities, and its use improves productivity and working conditions (De Schutter et al., 2008; The Concrete Society and BRE, 2005). Because compaction is eliminated, 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 colour of the concrete (RILEM TC 174 SCC, 2000). Improved strength, durability and finish of SCC can therefore be anticipated.

II. 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

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when the coarse aggregate content was restricted to 46 percent instead of 50 percent tried by Okamura (1997). In the next series of experiments, the coarse aggregate content was fixed at 46 percent and the sand content in the mortar portion was varied from 36 percent to 44 percent on a solid volume basis in steps of 2 percent. Again, the water-powder ratio was varied from 0.3 to 0.7 and based on the U-tube trials a sand content of 42 percent was selected. In order to show the necessity of using a viscosity-modifying agent along with a superplasticizer, to reduce the segregation and bleeding, the mixture proportion developed by the two researchers was used to cast a few trial specimens. In these trials, viscosity-modifying agent was not used. The cast specimens were heavily reinforced slabs having 2400x600x80 mm and no vibration or any other method of compaction was used. However, careful qualitative observations revealed that the proportions needed to be delicately adjusted within narrow limits to eliminate bleeding as well as settlement of coarse aggregate. It was difficult to obtain a mixture that was at the same time fluid but did not bleed. This led to the conclusion that slight changes in water content or granulometry of aggregate may result either in a mixture with inadequate flowing ability, or alternatively one with a tendency for coarse aggregate to segregate. Therefore, it became necessary to incorporate a viscosity-modifying agent in the concrete mixture.

Viscosity-modifying agents can be a natural polymer such as guar gum, a semisynthetic polymer such as hydroxy propyl methyl cellulose, or water-soluble polysaccharides, including those derived from a microbial source such as welan gum. Experiments involving three types of gums were being carried out by the two researchers. One commonly used thickener in cement-based systems, namely hydroxy propyl methyl cellulose (HPMC), a low-priced gum known as guar gum and a special product called welan gum were selected for studying their suitability for use in self-compacting concrete.

III. DESIGN MIX ADOPTED M 30

In the present study, confinement in the form of hoops of **6mm** 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.

$$\frac{f}{f_u} = \frac{A1\left(\frac{\varepsilon}{\varepsilon_u}\right) + D1}{1 + B1\left(\frac{\varepsilon}{\varepsilon_u}\right) + C1\left(\frac{\varepsilon}{\varepsilon_u}\right)^2}$$

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.

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

$$\text{At } \frac{\varepsilon}{\varepsilon_u} = 0; \frac{f}{f_u} = 0; \text{ At } \frac{\varepsilon}{\varepsilon_u} = 1; \frac{f}{f_u} = 1; \text{ and At } \frac{\varepsilon}{\varepsilon_u} = 1; \frac{d\left(\frac{f}{f_u}\right)}{d\left(\frac{\varepsilon}{\varepsilon_u}\right)} = 0$$

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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 sideways 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.

1. Cement

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

2. Aggregates:

2.1. 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 quality of SCC will be sensitive to such changes. Particles smaller than 0.125mm are considered as Fines, which contribute to the fine content.

2.2. Coarse aggregate:

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

3. Admixtures:

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

3.1. Mineral Admixtures:

1. **Ground Granulated Blast Furnace Slag (GGBS):** GGBS, which is both cementitious, and pozzolonic 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 micron.

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.

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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 4080N/mm²

3.2. 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 m²/N (Min.)
2. Lime Reactivity: 4.5 N/mm² (Min.)
3. Loss on ignition: 5% (Max.)

4. Superplasticizer:

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

IV. EXPERIMENTAL TEST RESULTS

Specimens namely

GF SCC Plain (without any confinement)	: 3 specimens
GFR SCC with 0.798% Confinement	: 3 specimens
GFR SCC with 1.062% Confinement	: 3 specimens
GFR SCC with 1.327% Confinement	: 3 specimens
GFR SCC with 1.591% Confinement	: 3 specimens

1. 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.
2. The cylinders which were capped, were tested in compression using 1000kN capacity computer controlled UTM under strain rate control as per IS 516:1959 to get the stress strain characteristics.
3. Rate of Strain is 0.02mm/sec.

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Table 1. Hardened properties of M30 grade GFRSCC with & without Confinement at 28days (Cylinder):

Sl. No	Designation	Volume of Confinement reinforcement %	Cylindrical Compressive Strength in MPa	Strain at Peak Stress
1	GFSCC _p	0	43.0072	0.002792
2	GFRSCC _(3R)	0.798	46.4025	0.002933
3	GFRSCC _(4R)	1.062	49.7980	0.003667
4	GFRSCC _(5R)	1.327	52.0614	0.004333
5	GFRSCC _(6R)	1.591	57.7202	0.004833

Table 2 Compressive strength of Cubes tested at 28 days (without Confinement): Target strength 50 N/mm²

Sl. No	Designation	Compressive Strength of Cubes in N/mm ²
1	GFSCCP	61.17
2	GFSCCP	53.77
3	GFSCCP	52.96
4	GFSCCP	55.81
5	GFSCCP	52.86
6	GFSCCP	51.34
7	GFSCCP	55.80
8	GFSCCP	55.92
9	GFSCCP	55.10
10	GFSCCP	55.96
11	GFSCCP	58.25
12	GFSCCP	57.79
13	GFSCCP	58.69
14	GFSCCP	64.03

Compressive strength of Cubes of all the 14 Specimens is more than 50 N/mm², which is more than the required strength.

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Table 3: Stress -Strain Equations for Different Confinements of M30 Grade

% of Steel	Ascending	Descending
GFSCC _{plain}	A1= 2.395, B1= 0.724 , C1= 1.0, D1 =0.0	A1= 0.528, B1= -1.470 , C1= 1.0, D1 =0.0
	$\frac{f}{f_u} = \frac{2.395\left(\frac{\epsilon}{\epsilon_u}\right)}{1+0.724\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$	$\frac{f}{f_u} = \frac{0.528\left(\frac{\epsilon}{\epsilon_u}\right)}{1-1.470\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$
GFRSCC 0.798% (3R)	A1= 2.50, B1= 1.104 , C1= 1.0, D1 =0.0	A1= 1.336, B1= -0.611 , C1= 1.0, D1 =0.0
	$\frac{f}{f_u} = \frac{2.50\left(\frac{\epsilon}{\epsilon_u}\right)}{1+1.104\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$	$\frac{f}{f_u} = \frac{1.336\left(\frac{\epsilon}{\epsilon_u}\right)}{1-0.611\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$
GFRSCC 1.062% (4R)	A1= 2.771, B1= 1.245 , C1= 1.0, D1 =0.0	A1= 1.163, B1= -0.765 , C1= 1.0, D1 =0.0
	$\frac{f}{f_u} = \frac{2.771\left(\frac{\epsilon}{\epsilon_u}\right)}{1+1.245\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$	$\frac{f}{f_u} = \frac{1.163\left(\frac{\epsilon}{\epsilon_u}\right)}{1-0.765\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$
GFRSCC 1.327% (5R)	A1= 3.315, B1= 1.593 , C1= 1.0, D1 =0.0	A1= 0.641, B1= -1.345 , C1= 1.0, D1 =0.0
	$\frac{f}{f_u} = \frac{3.315\left(\frac{\epsilon}{\epsilon_u}\right)}{1+1.593\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$	$\frac{f}{f_u} = \frac{0.641\left(\frac{\epsilon}{\epsilon_u}\right)}{1-1.345\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$
GFRSCC 1.591% (5R)	A1= 3.338, B1= 2.217 , C1= 1.0, D1 =0.0	A1= 0.387, B1= -1.610 , C1= 1.0, D1 =0.0
	$\frac{f}{f_u} = \frac{3.338\left(\frac{\epsilon}{\epsilon_u}\right)}{1+2.217\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$	$\frac{f}{f_u} = \frac{0.387\left(\frac{\epsilon}{\epsilon_u}\right)}{1-1.610\left(\frac{\epsilon}{\epsilon_u}\right)+1.0\left(\frac{\epsilon}{\epsilon_u}\right)^2}$

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1) Stress-Strain values of Cylinder without confinement (M30 grade GFSCC)

Peak Load=760Kn; Compressive strength=43.0072 N/mm²

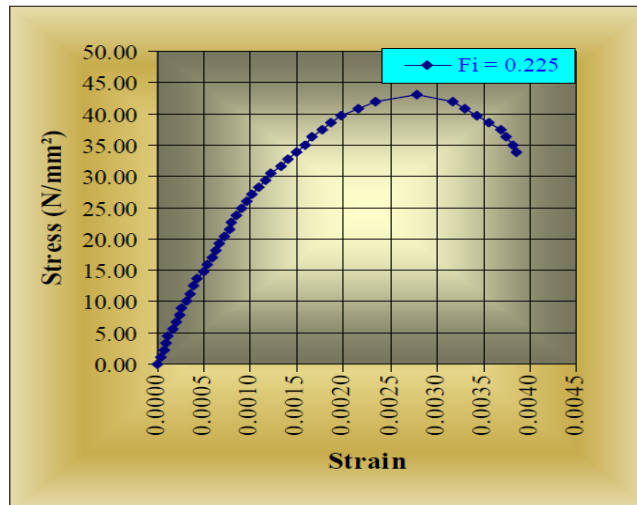


Fig:1 . Stress-Strain behaviour of GFRSCC without confinement

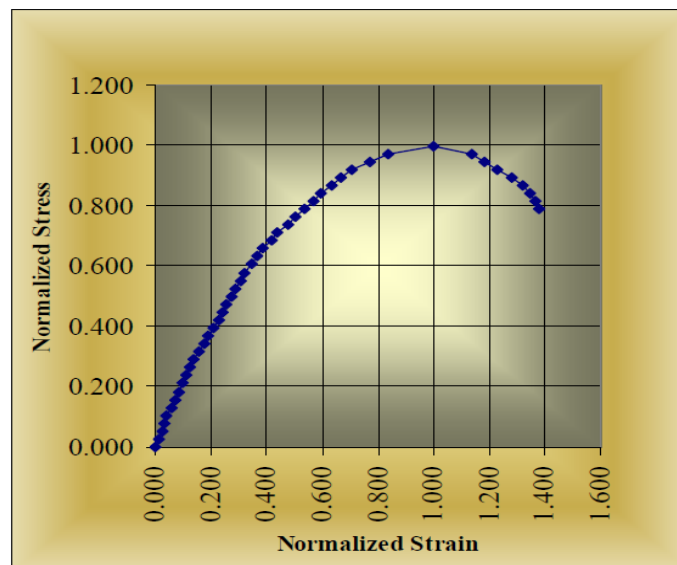


Fig:2 Normalized Stress- Normalized Strain Curve of GFRSCC without confinement

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2. Stress-Strain values of Cylinder with 0.798% confinement (M30 grade GFRSCC) Peak Load=820 KN; Compressive strength=46.4025N/mm²

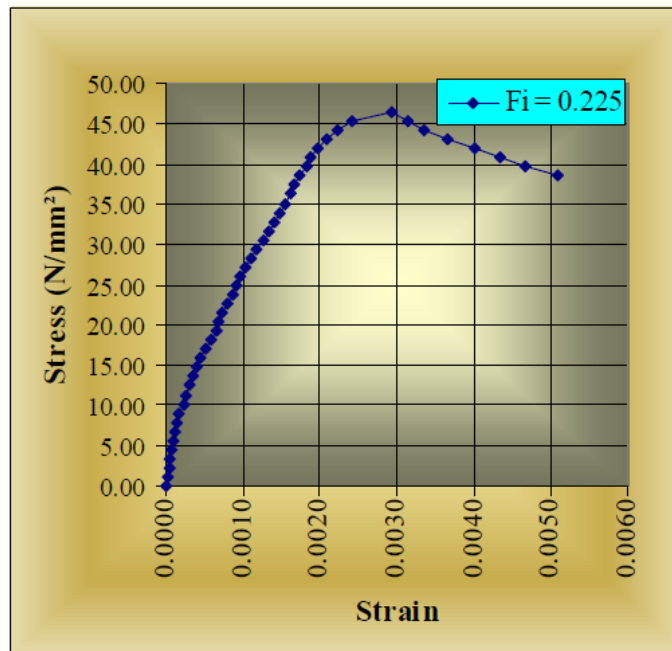


Fig: 3. Stress-Strain behaviour of GFRSCC (0.798% Confinement)

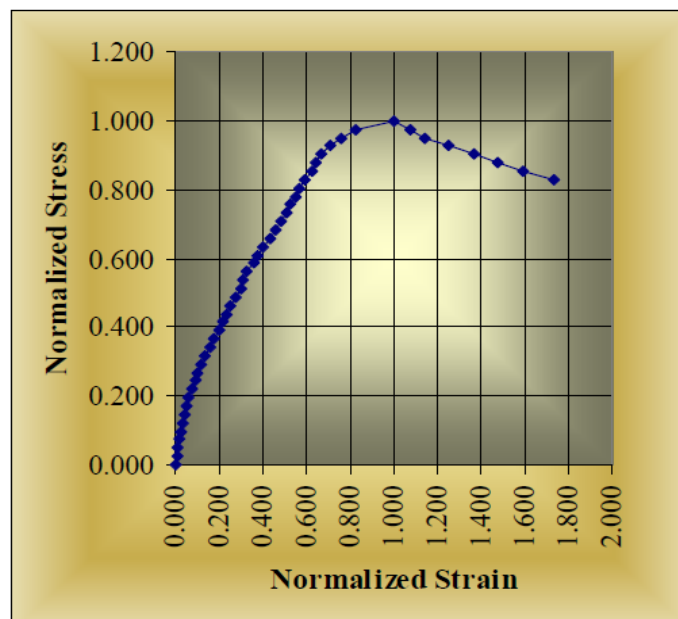


Fig:4 . Normalized Stress- Normalized Strain Curve of GFRSCC (0.798% Confinement)

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3. Stress-Strain values of Cylinder with 1.062% confinement (M30 grade GFRSCC)

Peak Load=880 KN ; Compressive strength=49.798 N/mm²

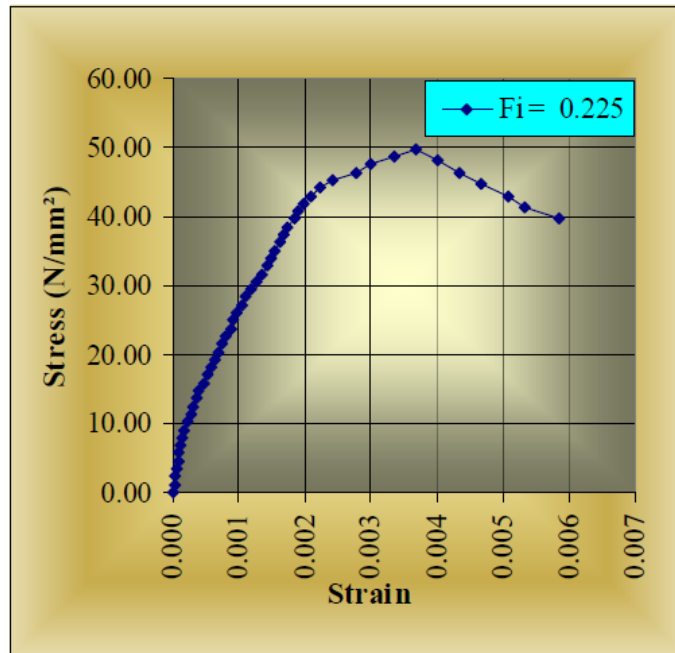


Fig. 5. Stress-Strain behaviour of GFRSCC (1.062% Confinement)

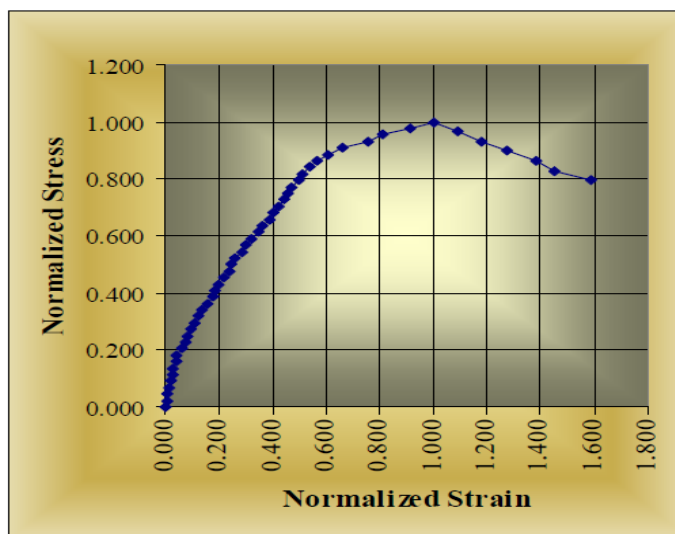


Fig. 6. Normalized Stress- Normalized Strain Curve of GFRSCC (1.062% Confinement)

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4) Stress-Strain values of Cylinder with 1.327% confinement (M30 grade GFRSCC)

Peak Load=920 KN ; Compressive strength=52.0614N/mm²

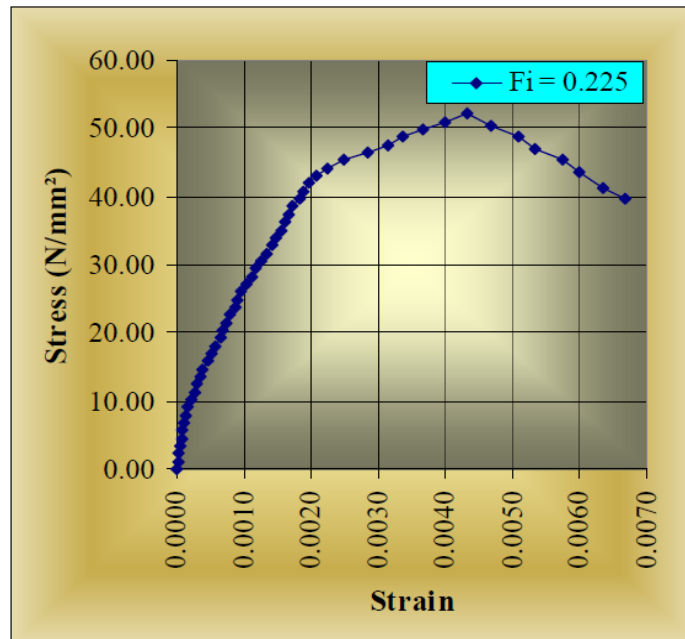


Fig: 7. Stress-Strain behaviour of GFRSCC (1.327% Confinement)

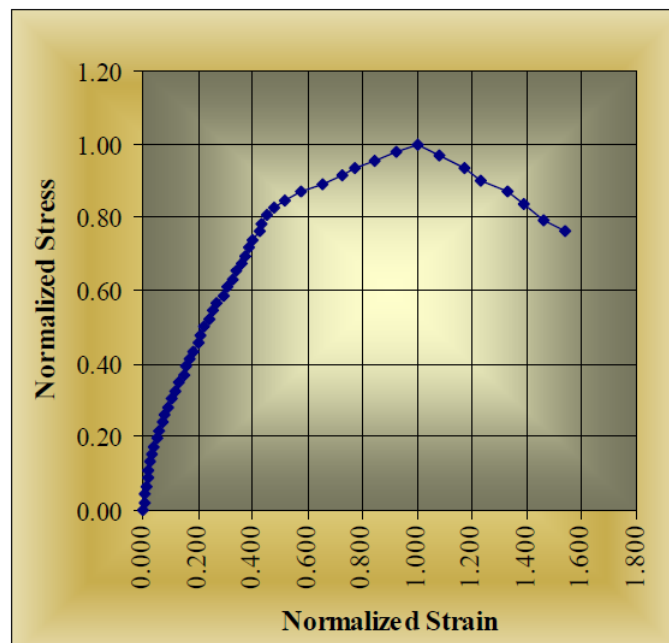


Fig:8 . Normalized Stress- Normalized Strain Curve of GFRSCC (1.327% Confinement)

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5. Stress-Strain values of Cylinder with 1.591% confinement (M30 grade GFRSCC)

Peak Load=1020 KN ; Compressive strength=57.720 N/mm²

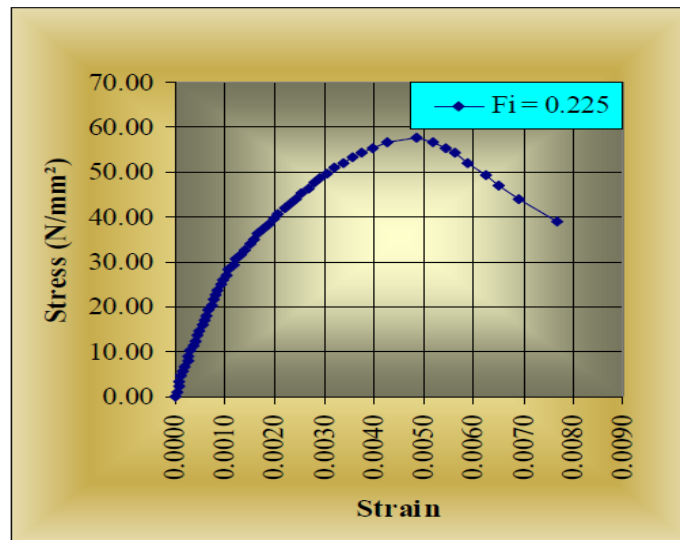


Fig 9: Stress-Strain behaviour of GFRSCC (1.591% Confinement)

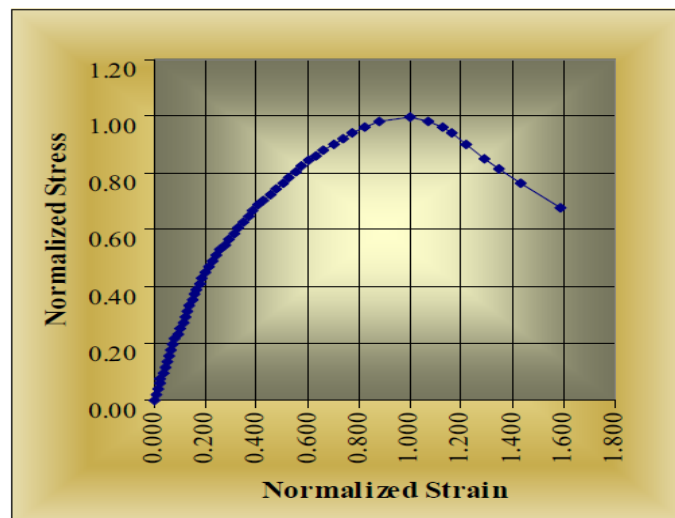


Fig: 10. Normalized Stress- Normalized Strain Curve of GFRSCC (1.591% Confinement)

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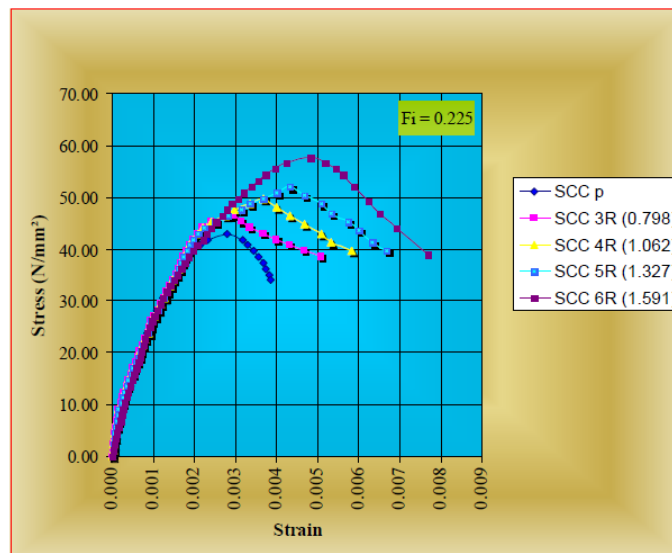


Fig.11 .Typical Stress-strain behavior of M30 grade GFRSCC with and without confinement at 28 days

V. CONCLUSION

The GFRSCC mix developed and satisfied the requirements of Self-compacting concrete specified by EFNARC guidelines. The properties like Modulus of Elasticity (E_c), Energy absorption capacity, Ductility and Stress-Strain behaviour 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 own 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 normal concrete, fact which led to a better bonding between aggregate and cement paste and to 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

In addition, self-compacting concrete has two big advantages. One relates to the construction time, which in most of the cases is shorter than the time when normal concrete is used, due to the fact that no time is wasted with the compaction through vibration. The second advantage is related to the placing. As long as SCC does not require compaction, it can be considered environmentally friendly, because if no vibration is applied no noise is made.

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