# Stress-strain behaviour of unconfined and confined hybrid glass/steel fibre self-compacting concrete

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**Abstract.** An experimental study was conducted to investigate the effectiveness of transverse reinforcing bars of self-compacting concrete mix (PSCC) and hybrid glass fiber reinforced self-compacting concrete mix (HFRSCC) grade M 40 under monotonically increasing axial compression. was performed for cylinders enclosed in . The behavior of SCC cylinders surrounded by a circular ring and having different volume ratios and clearances was compared under axial compression. In this work, we present a mathematical model developed to predict the stress-strain behavior of SCC and FRSCC under constrained and unconstrained conditions and validate the model using experimental results. To develop SCC, Nan Su blending method based on filling rate 1.12 and 1.14, S/A ratio 0.50 and 0.57 is applied. The steel and glass fiber usage in the hybrid fiber reinforced SCC mixture is assumed to be 1% and 0.05% of the concrete volume respectively. M 40 grade plain self-compacting concrete mixes (PSCC) and hybrid glass/steel fiber reinforced self-compacting concrete mixes (HFRSCC) constrained to different volume ratios, stresses, strains, elastic moduli, plasticity ratios, ductility ratios, and unlimited strength ratios ) has been evaluated experimentally. The following conclusions can be drawn from the stress-strain diagram: 1) Maximum load-bearing capacity and strain at peak stress are higher for his HFRSCC than for PSCC. 2) The presence of steel and fiberglass increases the strength bearing capacity and allows it to withstand greater loads at peak loads. 3) If the containment is in the form of a lateral ring boundary, the effect of fibers is almost negligible. This clearly shows that HFRSCC has a stronger containment effect compared to his PSCC. The strength confinement factor is lower for HFRSCC, suggesting that HFRSCC offers a superior confinement factor compared with his PSCC.

**Keywords.** self-compacting concrete, hybrid fibre reinforced, Stress-strain, lateral confinement, modelling

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## 1 Introduction

Using the stress-strain test results, a mathematical model was developed to predict the stress-strain behavior of SCC and FRSCC in constrained and unconstrained conditions [1-2]. The proposed model is based on the mathematical equations of Saenz and Mansur. The Mansur model applies to finite and unconstrained fibrous and non-fibrous concrete[3]. We find that the model based on the Mansur equation is in good agreement with the experimental values as it includes fiber confinement parameters and lateral confinement effects [4]. The ductility modulus is the ratio of the strain at 85% of the ultimate stress on the descending portion of the curve to the strain on the ascending portion of the curve[5-7]. A quantitative measure of the increase in ductility when introducing different types of fibers is the ratio of the axial strain at 85% of the maximum axial stress to the axial strain at the maximum stress in the descending portion of the stress-strain curve. h is €0.85 Dsc/€0, called the plasticity ratio, given by Martinez (1984) [8-11].

## 2 Mix design

The following data is considered for the study:
1. Mix design based on Nan Su mix design criteria
2. Packing factors considered are from 1.12 to 1.18
3. Fine aggregates to total aggregates (s/a) ratio between 0.50 and 0.57
4. Types of SCC mixes considered are Plain SCC (PSCC) and Hybrid glass/steel fibred SCC (HFRSCC)
5. For confinement of concrete cylinders, 0, 3, 4, 5 and 6 hoops are used

## 3 Optimization of packing factor and s/a ratio

PSCC1 indicates the plain SCC mix made with packing factor 1.12 and s/a ratio 0.50 whereas PSCC2 indicates the plain SCC mix made with packing factor 1.14 and s/a ratio 0.57. The above two PSCC mixes yield maximum compressive strengths and are optimally chosen from various PSCC mixes made with various packing factors from 1.12 to 1.18 and s/a ratio from 0.50 to 0.57.

**Table 1.** Optimum mix quantities for M40 grade PSCC mixes

| Type | Packing Factor PF | s/a ratio | Cement kg/m$^3$ | Fly ash kg/m$^3$ | Fine aggregate kg/m$^3$ | Coarse aggregate kg/m$^3$ | Water L | Compressive Strength (in MPa) At 28 days |
|---|---|---|---|---|---|---|---|---|
| PSCC1 | 1.12 | 0.50 | 400 | 200 | 1084 | 756 | 224 | 51.69 |
| PSCC2 | 1.14 | 0.57 | 400 | 184 | 1056 | 712 | 212 | 53.28 |

## 4 Dosage of steel and glass fibre

For the PSCC1 or PSCC2 mixes, add various percentage of glass fibre by volume of concrete and determine the compressive strengths. The optimum dosage of steel fibre is the one which yields maximum compressive strength. Same procedure is adopted to determine the optimum dosage of glass fibre.

**Table 2.** Dosage of percentage of glass fibre for M40 grade mixes

| Glass fibre reinforced SCC designation | Percentage of Glass fibre by volume of Concrete | Glass fibre kg | Compressive Strength MPa |
|---|---|---|---|
| GFRSCC1 or GFRSCC2 | 0.01 | 0.91 | 46.50 |
| | 0.02 | 1.82 | 47.80 |
| | 0.03 | 2.43 | 48.40 |
| | 0.04 | 3.64 | 50.30 |
| | 0.05 | 4.47 | 53.60 |
| | 0.06 | 4.55 | 47.70 |

**Table 3.** Dosage of percentage of steel fibre for M40 grade mixes

| Steel fibre reinforced SCC designation | Percentage of Glass fibre by volume of Concrete | Steel fibre kg | Compressive Strength MPa |
|---|---|---|---|
| SFRSCC1 or SFRSCC2 | 0.4 | 108.1 | 47.09 |
| | 0.6 | 162.3 | 50.45 |
| | 0.8 | 216.7 | 52.67 |
| | 1.0 | 270.5 | 56.45 |
| | 1.5 | 324.3 | 50.35 |

The table 4 presents the mix proportions for M40 grade PSCC and HFRSCC mixes

**Table 4.** Final mix proportions for M40 grade PSCC and HFRSCC mixes

| Type | Steel kg | Glass kg | Compressive Strength MPa |
|---|---|---|---|
| PSCC1 | - | - | 51.69 |
| HFRSCC1 | 270.5 | 4.47 | 58.14 |
| PSCC2 | - | - | 53.28 |
| HFRSCC2 | 270.5 | 4.47 | 60.35 |

The table 5 presents the fresh properties of PSCC and HFRSCC mixes

**Table 5.** Fresh properties of PSCC and HFRSCC mixes

| Type | Fly ash % | Paste volume | Flow Properties | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Slump flow mm | J-Ring mm | V-Funnel $T_0$ sec | V-Funnel $T_5$ sec | U-Box mm | L-Box Blocking ratio |
| PSCC1 | 33.3 | 32.1 | 712 | 10 | 9.2 | 9.1 | 30 | 1.00 |
| HFRSCC1 | 33.3 | 32.1 | 674 | 8 | 9.6 | 10.2 | 27 | 0.96 |
| PSCC2 | 30.6 | 38.4 | 725 | 9 | 9.0 | 11.2 | 28 | 1.00 |
| HFRSCC2 | 30.6 | 38.4 | 712 | 8 | 9.3 | 10.1 | 27 | 0.97 |

## 5 Experimental Stresses and Strains

For M 40 grade plain self-compacting (PSCC) and hybrid glass/steel fibre reinforced self-compacting concrete (HFRSCC) mixes confined with different volumetric ratios, stresses, strains, modulus of elasticity, plasticity ratio, ductility ratio and confined to unconfined strength ratios are evaluated experimentally and are validated analytically. Figure1 show the details of transverse reinforcement provided in the specimens.

**Figure 1.** Transverse reinforcement in the form of circular hoops and test setup

**Table 6.** Stress -Strain characteristics of PSCC1 and HFRSCC1 mixes

| Type of SCC | Number of confinement hoops | Peak Stress (N/mm$^2$) | Strain at Peak stress | Initial Tangent Modulus ($E_{it}$) | Plasticity ratio | Ductility Ratio | Confined to unconfined strength ratio |
|---|---|---|---|---|---|---|---|
| PSCC1 | 0 | 34.83 | 0.0022 | 20368.76 | 1.2805 | 1.8100 | _- |
| | 3 | 38.62 | 0.0029 | 28311.44 | 1.3291 | 1.6535 | 1.134 |
| | 4 | 40.83 | 0.0031 | 32048.18 | 1.1647 | 1.5610 | 1.176 |
| | 5 | 42.78 | 0.0035 | 34056.45 | 1.2266 | 1.6667 | 1.233 |
| | 6 | 51.61 | 0.0042 | 36405.41 | 1.2105 | 1.5969 | 1.478 |
| HFRSCC1 | 0 | 41.23 | 0.0024 | 26310.86 | 1.1813 | 1.4442 | _- |
| | 3 | 45.62 | 0.0032 | 34161.63 | 1.2198 | 1.9917 | 1.140 |
| | 4 | 47.89 | 0.0034 | 38951.63 | 1.3154 | 1.8094 | 1.187 |
| | 5 | 48.05 | 0.0038 | 41423.52 | 1.3040 | 1.9561 | 1.185 |
| | 6 | 56.66 | 0.0048 | 42913.34 | 1.2951 | 2.1284 | 1.127 |

**Table 7.** Stress -Strain characteristics of PSCC2 and HFRSCC2 mixes

| Type of SCC | Number of confinement hoops | Peak Stress (N/mm$^2$) | Strain at Peak stress | Initial Tangent Modulus ($E_{it}$) | Plasticity ratio | Ductility Ratio | Confined to unconfined strength ratio |
|---|---|---|---|---|---|---|---|
| PSCC2 | 0 | 37.21 | 0.0022 | 20692.52 | 1.1367 | 1.6304 | - |
| | 3 | 41.67 | 0.0030 | 24746.11 | 1.3673 | 1.6544 | 1.144 |
| | 4 | 44.02 | 0.0033 | 32346.76 | 1.1919 | 1.6649 | 1.213 |
| | 5 | 47.83 | 0.0037 | 34753.01 | 1.2931 | 1.9732 | 1.284 |
| | 6 | 51.5 | 0.0040 | 39118.65 | 1.1681 | 1.1681 | 1.414 |
| HFRSCC2 | 0 | 43.82 | 0.0024 | 25688.69 | 1.3743 | 1.7274 | - |
| | 3 | 45.79 | 0.0031 | 35039.79 | 1.2835 | 1.7720 | 1.062 |
| | 4 | 50.22 | 0.0034 | 37592.77 | 1.2880 | 1.7201 | 1.141 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 53.14 | 0.0038 | 41423.52 | 1.3040 | 1.9561 | 1.228 |
| | 6 | 54.26 | 0.0041 | 39922.66 | 1.1934 | 2.0660 | 1.281 |

## 6 Theoretical Stresses-Strains

### a) Simplified Saenz Model

**Table 8.** Constants of Stress Strain equations ($Y=Ax/1+Bx^2$) of PSCC1 and HFRSCC1 for different Confinements

| Type of SCC | Number of confinement hoops | Peak Stress ($N/mm^2$) | Strain at Peak stress | Ascending | | Desending | |
|---|---|---|---|---|---|---|---|
| | | | | A | B | A | B |
| PSCC1 | 0 | 35.11 | 0.00210 | 1.41 | 0.41 | 5.54 | 4.54 |
| | 3 | 38.62 | 0.00290 | 1.27 | 0.27 | 4.67 | 3.67 |
| | 4 | 41.28 | 0.00318 | 1.36 | 0.3 | 24.10 | 23.10 |
| | 5 | 43.29 | 0.00360 | 1.53 | 0.535 | 5.44 | 4.44 |
| | 6 | 51.91 | 0.00390 | 1.50 | 0.50 | 6.43 | 5.43 |
| HFRSCC1 | 0 | 41.16 | 0.00240 | 1.19 | 0.19 | -38.69 | -39.69 |
| | 3 | 46.93 | 0.00286 | 1.97 | 0.97 | 4.73 | 3.73 |
| | 4 | 48.87 | 0.00331 | 1.43 | 0.43 | 4.03 | 3.03 |
| | 5 | 48.78 | 0.00358 | 1.64 | 0.64 | 3.57 | 2.57 |
| | 6 | 56.38 | 0.00406 | 1.75 | 0.75 | 4.45 | 3.45 |

**Table 9.** Constants of Stress Strain equations ($Y=Ax/1+Bx^2$) of PSCC2 and HFRSCC2 for different Confinements

| Type of SCC | Number of confinement hoops | Peak Stress ($N/mm^2$) | Strain at Peak stress | Ascending | | Desending | |
|---|---|---|---|---|---|---|---|
| | | | | A | B | A | B |
| PSCC2 | 0 | 37.21 | 0.00222 | 1.03 | 0.03 | -24.63 | -25.63 |
| | 3 | 42.21 | 0.00277 | 1.15 | 0.15 | 3.26 | 2.26 |
| | 4 | 44.02 | 0.00330 | 1.01 | 0.01 | 3.06 | 2.06 |
| | 5 | 47.83 | 0.00370 | 1.41 | 0.41 | 2.74 | 1.74 |
| | 6 | 51.50 | 0.00400 | 1.47 | 0.47 | 2.36 | 1.36 |
| HFRSCC2 | 0 | 43.82 | 0.00210 | 1.25 | 0.21 | 3.88 | 2.88 |
| | 3 | 45.79 | 0.00280 | 1.35 | 0.35 | 3.16 | 2.16 |
| | 4 | 50.22 | 0.00360 | 1.50 | 0.50 | 2.53 | 1.53 |
| | 5 | 53.14 | 0.00370 | 1.58 | 0.58 | 2.37 | 1.37 |
| | 6 | 56.60 | 0.00400 | 1.81 | 0.81 | 5.99 | 4.99 |

### b) M.A.Mansur, M.S.Chin and T.H.Wee Model

Stress Strain equations for Different Confinements
For ascending portion, stress strain equation is $y=\beta x/\beta-1+X^{\beta}$

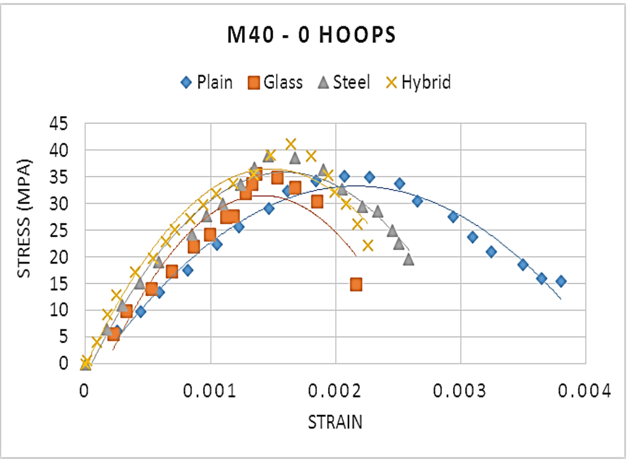
For descending portion, stress strain equation = $y=k1\beta x/1+k1\beta-1+(X)^{k2\beta}$ `

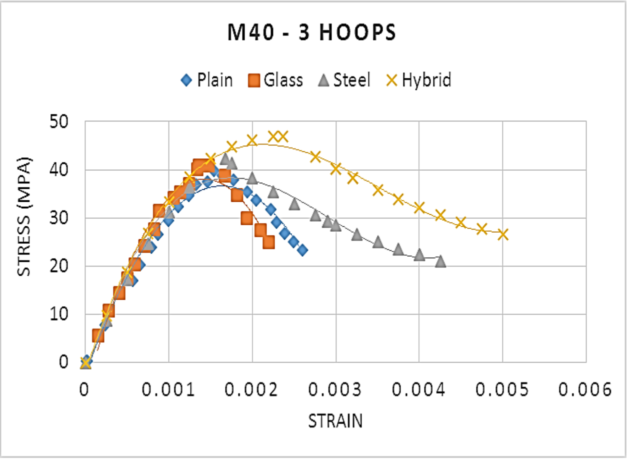
**Table 10.** Constants of Stress-Strain equations of PSCC1 and HFRSCC1 for different Confinements

| Type of SCC | Number of confinement hoops | Peak Stress ($N/mm^2$) | Strain at Peak stress | Ascending curve | Descending curve | |
|---|---|---|---|---|---|---|
| | | | | β | k1 | k2 |
| PSCC1 | 0 | 35.11 | 0.0021 | 5.47 | 1.0000 | 1.0000 |
| | 3 | 38.62 | 0.0029 | 4.78 | 0.3063 | 0.4407 |
| | 4 | 41.28 | 0.0033 | 3.71 | 0.3404 | 0.4572 |
| | 5 | 43.29 | 0.0036 | 2.94 | 0.3954 | 0.4840 |
| | 6 | 51.91 | 0.0041 | 2.57 | 0.4502 | 0.5107 |
| HFRSCC1 | 0 | 41.16 | 0.0022 | 3.89 | 1.0000 | 1.0000 |
| | 3 | 46.93 | 0.0028 | 5.84 | 0.1574 | 0.2944 |
| | 4 | 48.87 | 0.0032 | 5.84 | 0.0209 | 0.1866 |
| | 5 | 48.78 | 0.0035 | 2.88 | 0.0262 | 0.1907 |
| | 6 | 56.38 | 0.0040 | 3.05 | 0.0314 | 0.1948 |

**Table 11.** Constants of Stress-Strain equations of PSCC2 and HFRSCC2 for different Confinements

| Type of SCC | Number of confinement hoops | Peak Stress ($N/mm^2$) | Strain at Peak stress | Ascending curve | Descending curve | |
|---|---|---|---|---|---|---|
| | | | | β | k1 | k2 |
| PSCC2 | 0 | 37.21 | 0.0022 | 5.12 | 1.0000 | 1.0000 |
| | 3 | 42.21 | 0.0027 | 3.41 | 0.2856 | 0.4306 |
| | 4 | 44.02 | 0.0033 | 2.81 | 0.3404 | 0.4572 |
| | 5 | 47.83 | 0.0037 | 2.86 | 0.3954 | 0.4840 |
| | 6 | 51.5 | 0.0040 | 2.48 | 0.4502 | 0.5107 |
| HFRSCC2 | 0 | 43.82 | 0.0020 | 2.79 | 1.0000 | 1.0000 |
| | 3 | 45.79 | 0.0031 | 3.31 | 0.1498 | 0.2884 |
| | 4 | 50.22 | 0.0032 | 4.73 | 0.1993 | 0.3276 |
| | 5 | 53.14 | 0.0036 | 2.21 | 0.2491 | 0.3669 |
| | 6 | 56.60 | 0.0039 | 2.60 | 0.2986 | 0.4061 |


M40 - 0 HOOPS
Plain
Glass
Steel
Hybrid
STRESS (MPA)
45
40
35
30
25
20
15
10
5
0
0
0.001
0.002
0.003
0.004
STRAIN


M40 - 3 HOOPS
Plain
Glass
Steel
Hybrid
STRESS (MPA)
50
40
30
20
10
0
0
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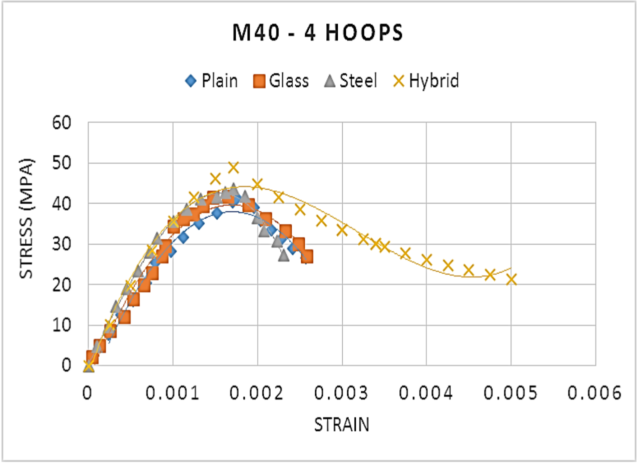
0.002
0.003
0.004
0.005
0.006
STRAIN


M40 - 4 HOOPS
Plain
Glass
Steel
Hybrid
STRESS (MPA)
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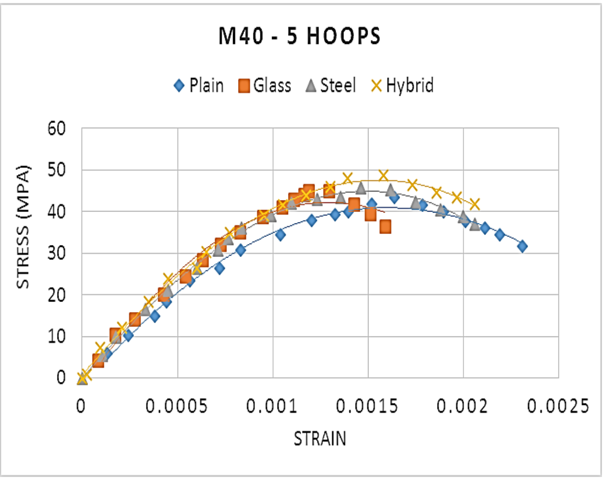
50
40
30
20
10
0
0
0.001
0.002
0.003
0.004
0.005
0.006
STRAIN



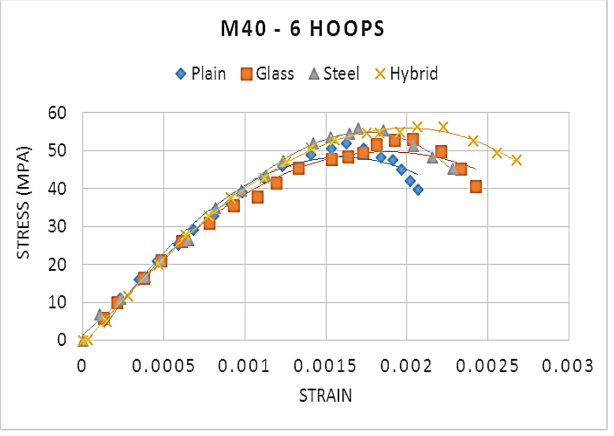
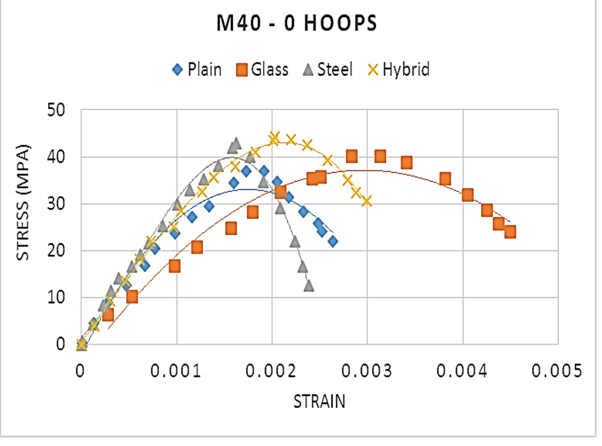
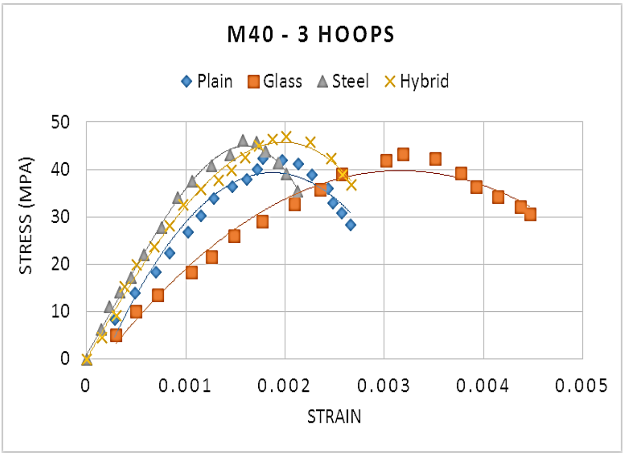




**Figure 2.** Stress strain curves of M40 grade PSCC, SFRSCC, GFRSCC and HFRSCC in unconfined (0 Hoops) and confined (3,4,5 and 6 Hoops) states for optimum combination of PF=1.12 and s/a=0.5




M40 - 3 HOOPS
Plain
Glass
Steel
Hybrid
STRESS (MPA)
STRAIN
0
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0.002
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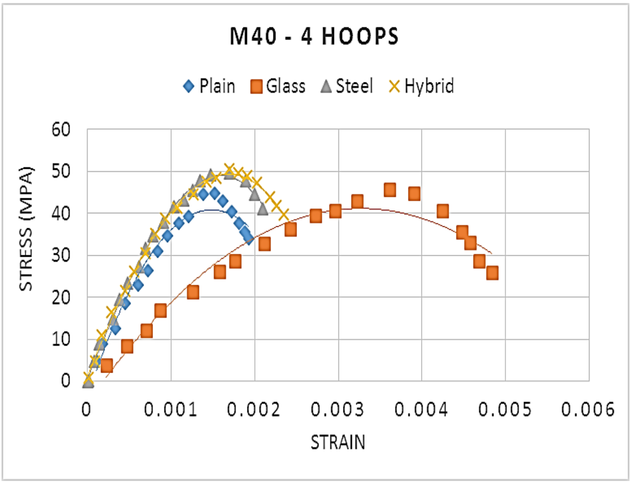
0.005


M40 - 4 HOOPS
Plain
Glass
Steel
Hybrid
STRESS (MPA)
STRAIN
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0.001
0.002
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0.004
0.005
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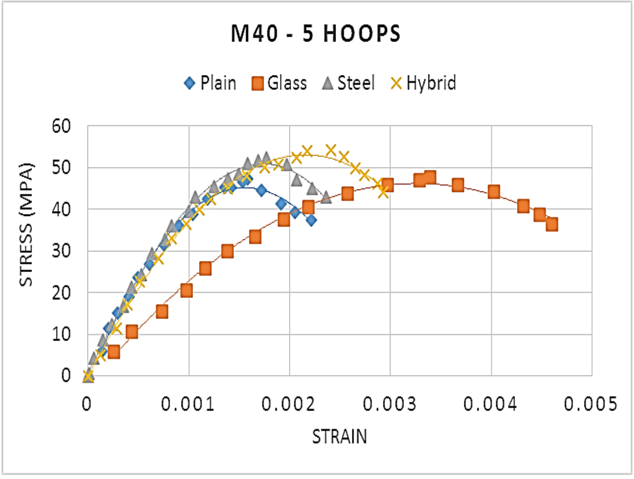
M40 - 5 HOOPS
Plain
Glass
Steel
Hybrid
STRESS (MPA)
STRAIN
0
10
20
30
40
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0.001
0.002
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 https://doi.org/10.1051/e3sconf/202339101214

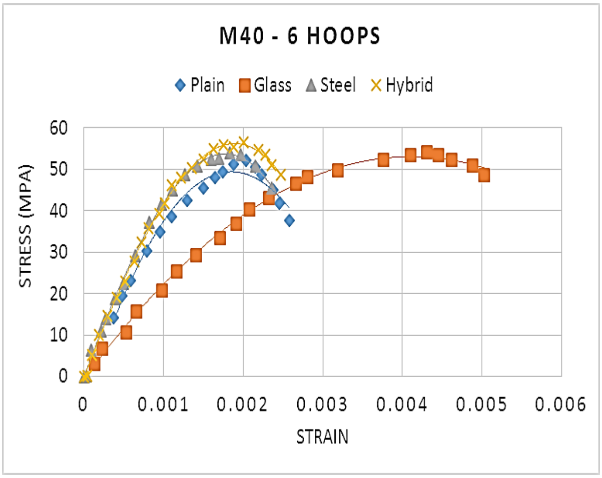


**Figure 3.** Stress strain curves of M40 grade PSCC, SFRSCC, GFRSCC and HFRSCC in unconfined (0 Hoops) and confined (3,4,5 and 6 Hoops) states for optimum combination of PF=1.14 and s/a=0.57

## 7 Discussions

As can be seen, the maximum working load limit and elongation at peak load are higher for HFRSCC than for PSCC. These figures clearly show that the use of steel and fiberglass improves strength-holding capacity and allows for higher load absorption at peak loads. This is likely due to the presence of small, discrete, high-dispersion glass fibers that inhibit cracking at the micro level and steel fibers that inhibit late failure. However, if the containment is in the form of lateral ring boundaries, the effect of the fibers is of little importance. This clearly shows that HFRSCC has a stronger containment effect compared to his PSCC. In both cases, fiber hybridization in SCC showed improvement in confined conditions using steel hoops.

The intensity inclusion parameter was found to range from 0.055 to 0.094 for various inclusion percentages. Strength increase rate, ie. H. The intensity ratio between trapped SCC ("fo") and untrapped SCC ("fo") is between 1.164 and 1.631. Moreover, the strength confinement factor of HFRSCC is lower, suggesting that HFRSCC has improved confinement compared to PSCC.

## 8 Conclusions

Transverse reinforcement to understand the effectiveness of shear bars on M 40 grade simple self-compacting concrete (PSCC) and hybrid glass/steel fiber reinforced self-compacting concrete (HFRSCC) mixtures under monotonically increasing axial compression. Study the cylinder bounded by . The following conclusions can be drawn from the stress-strain diagram:

1) The mathematical formulas proposed by Saenz and Mansur were validated to predict the stress-strain behavior of SCC and HFRSCC in constrained and unconstrained states.

2) To develop SCC, Nan-Su mixed construction method is applied based on filling rate 1.12 and 1.14 and S/A ratio 0.50 and 0.57.

3) For hybrid fiber-reinforced SCC mixtures, the loadings of steel and glass fibers are 1% and 0.05% of the concrete volume, respectively.

4) For M 40 grade simple self-compacting concrete (PSCC) and hybrid glass/steel fiber reinforced self-compacting concrete mix (HFRSCC) with different volume ratios, stresses, strains, elastic moduli, plasticity ratios and ductility ratios, unlimited The intensity ratio of is: evaluated experimentally. 5) Maximum load capacity and peak load are higher for HFRSCC than for PSCC. The presence of steel and glass fibers increases strength bearing capacity and allows it to withstand greater loads during peak loads.
5) If the confinement is in the form of a lateral ring confinement, the fiber effect is almost negligible. This clearly shows that HFRSCC has a stronger containment effect compared to his PSCC. The strength confinement factor is lower for HFRSCC, suggesting that HFRSCC offers a superior confinement factor compared to PSCC.

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