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# Computational Analysis of Bending Properties of Self-Compacting Concrete Reinforced With Steel Fibers

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**Abstract:** Self-compacting concrete is a highly-workable concrete that without any vibration or impact and under its own weight fills the formwork, and it also passes easily through small spaces between rebars. In this paper, the effect of steel fibers on beams and beam-column joints of SCC specimens, using three different fiber volume fractions (0.5%, 1% and 1.5%) were investigated. Mix design for strength of 20 MPa (low strength) was considered. The load-deflection curve, ductility, moment rotation curve and energy absorption parameters were studied and compared with analytical method using ANSYS.

The results revealed that the behavior of load-deflection, ductility and energy absorption was found to be more for the steel fibres having volume fraction 1.0% for SCC with partial replacement of cement with silica fume. SCC classes are reduced by increasing the steel fiber volume fraction, and using different forms of mineral admixtures. The results produced from the experimental work have also been proved with ANSYS.

**Keywords:** Self-compacting concrete; Mechanical performance; Steel fibers; Strength class

## I.INTRODUCTION

Self Compacting Concretes was designed initially in Japan around 1988 and since then several research papers have been published and tried out in different developed countries especially in Western Europe, Canada, Sweden and Netherlands. To produce SCC, the major work involves in designing an appropriate mix proportions and evaluating the properties of the concrete thus obtained.SCC shows good performance in compressive strength test and can fulfill other construction needs because its production was taken into consideration the requirements in the structural design. Self compacting concrete, a new kind of high performance concrete with excellent deformability and segregation resistance, was first developed in Japan in 1986. It is a special kind of concrete that can flow through and fill the gaps of reinforcement and corners of mould without any need for vibration and compaction during placing process. Though showing good performance, SCC is different from HPC developed in North America and Europe,which emphasizes on high strength and durability of concrete. In terms of workability, HPC nearly improves fluidity of concrete to facilitate placing; however it cannot flow freely by itself to pack every corner of moulds and all gaps among reinforcement. In other words, HPC still requires vibration and compaction in construction process.

The term Self-Compacting Concrete (SCC) refers to a “new” special type of concrete mixture,characterized by high resistance to segregation that can be cast without compaction or vibration. Self compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure and, due to its high-fluidity and resistance to segregation it can be pumped longer distances (Skarendahl, A., O. Petersson, 2000). Considering concrete as a composite material, it is usual to study the properties of the material from different levels of observation, i.e. micro-, meso-, and macro-levels.

## II.LITERATURE REVIEW

Ever since the first report of the development of SCC in Japan in 1988 by Ozawa et al using super plasticizer and viscosity agent and in 1922, they again identified the factors controlling self compactability namely coarse and fine aggregate content. They again developed test methods to check the self compactability and found that the water-powder ratio governs the self compactability.(1)

In 1996, Petersson et al identified three main criteria for the design of SCC namely construction criteria, void content and blocking criteria. They also suggested a theoretical model between blocking volume ratio of aggregate volume and ratio of clear spacing between the reinforcement to aggregate fraction size.(2)

Mortsell et al modeled fresh concrete as two-phase material with matrix of particles < 125 and particle phases composed of aggregates was developed an expression for workability parameter was also proposed.(3)

Okamura et al reported about he use of transparent polymer leads to simulate the movement of aggregate in SCC and they found the high w/p ratio, addition of SP and control of CA content minimizes shear stress and ensures good deformability and filling ability.(4)

In 2000 Okamura et al discussed the procedure for adjusting w/p and SP dosage to achieve desires properties. He found that for mortars, the ratio of slump flow index to funnel flow index to almost constant with respect to volume of powder ratio.(5)

In 2001, Saak et al suggested that inter particle separation is a critical parameter for design of SCC in addition to particle packing distance. They proposed a segregation control theory considering static and dynamic. They measured yield stress of cement pastes using a shear vane, and the test results shaved that concrete had the greatest fluidity at the lowest paste yield stress and viscosity, where segregation is avoided.(6)

In 2002 subramanian and chattopadhyay developed SCC with 50-60 Mpa strength using fly ash, SP, naphthalene formaldehyde/ acrylic polymer based SP, welan gum and locally available aggregates in India.(7)

## III.EXPERIMENTAL INVESTIGATION

### Materials and mix design

The studies were performed on the self-compacting concrete reinforced with steel fibers (SFR-SCC). The experimental investigation of SFR-SCC conducted by authors with SCC, SCC-SF, SCC-FAS, SCC-RHA and SCC-QD with various fibre volume fraction viz., 0.5%, 1% and 1.5% allows to properly adjust the ingredients of the mix in order to obtain the required workability and stability.

The trial mix were prepared for five classes of materials with various chemical and w/p ratio's conforming to EFNARC specifications and is presented in Table 1. To obtain comparable mechanical properties such as load-displacement, energy absorption, ductility and energy parameters were studied for various combinations and the experimental results were compared with ANSYS. The use of mixed cement eliminates the effect of different composition of Supplementary Cementing Materials (SCM) which causes variation of physical and chemical parameters of various combinations mentioned in Table 1.

**Table – 1 Ingredients of different mixes**

| Mix ID | Mixture ingredients (kg/m$^3$) | | | | | | | SP | w/c | w/p |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | FA | CA | SF | FAS | RHA | QD | (%) | (wt/wt) | (wt/wt) |
| CC | 420 | 710 | 1120 | - | - | - | - | 1.7 | 0.4 | 0.4 |
| SCC-SF | 380 | 841 | 864 | 47 | | | | 2.2 | 0.52 | 0.35 |
| SCC-FAS | 395 | 865 | 882 | - | 69 | - | - | 2.4 | 0.45 | 0.36 |
| SCC-RHA | 365 | 880 | 864 | - | - | 73 | - | 2.2 | 0.45 | 0.36 |
| SCC-QD | 380 | 846 | 874 | - | - | - | 74 | 2.5 | 0.46 | 0.35 |

FA – Fine aggregate; CA – Coarse aggregate; SF – Silica fume; FAS – Fly ash;

RHA – Rice husk ash; QD – Quarry dust; SP – Superplasticizer;

w/c – Water to cement ratio; w/p – Water to paste ratio

**Fibres Used:**
Corrugated Steel Fibre of Aspect Ratio: 30,60,90 and Volume Fraction of 0.5%, 1.0% and 1.5%

## IV. EXPERIMENTAL SETUP

The beam specimens where cast in cast-iron moulds and cured for 28 days. The inside of the mould were applied with oil to facilitate the easy removal of specimens. For obtaining the binder content sand and cement were mixed dry and kept separately. Then coarse aggregates and dry mix of cement and sand were kept in three layers and approximate amount of water was sprinkled on each layer and mixed thoroughly. Then, self-compacting agent is added to the mix as per the proportion homogeneously.

The testing arrangement is shown in figure1. Two point load is given to the beam and deflections under point load and at center is studied.

**Fig . 1 Experimental setup**

## V. RESULTS AND DISCUSSION

**Table – 2 Salient Points of Load-Displacement Curves (A/R-90)**

| Mix | Vf (%) | $P_{cr}$ | $\delta_{cr}$ | $P_y$ | $\delta_y$ | $P_u$ | $\delta_u$ |
|---|---|---|---|---|---|---|---|
| SCC | - | 5 | 2 | 20 | 10.5 | 25 | 21.75 |
| SCC-SF | 0.5 | 6 | 2.5 | 22.5 | 9 | 33.75 | 18.35 |
|  | 1.0 | 5.4 | 2.1 | 24 | 11 | 37 | 20.05 |
|  | 1.5 | 5 | 2.1 | 25 | 9.5 | 31.5 | 19.25 |
| SCC-FAS | 0.5 | 5.2 | 2.5 | 26 | 9.5 | 35 | 21.70 |
|  | 1.0 | 5 | 2.2 | 20 | 9 | 27.5 | 21.85 |
|  | 1.5 | 5.1 | 2.5 | 24 | 10.5 | 29 | 22.55 |
| SCC-RHA | 0.5 | 5 | 2.5 | 20 | 8 | 25 | 21.65 |
|  | 1.0 | 5.5 | 2.5 | 22.5 | 9 | 27 | 21.85 |
|  | 1.5 | 5.5 | 2 | 20 | 10 | 30 | 23.55 |
| SCC-QD | 0.5 | 5.2 | 2.5 | 21 | 10.25 | 32 | 21.45 |
|  | 1.0 | 5 | 2.25 | 22.5 | 10 | 29 | 21.35 |
|  | 1.5 | 5.1 | 2.5 | 24 | 11 | 33 | 23.40 |

The table -2 shows load – displacement results for various combinations of mixes with different fibre volume fractions viz., 0.5%, 1% and 1.5%. Here if we see that the resistance of first crack to the load seems to be more for SCC-SF for 0.5% than 1% and 1.5%. Similarly, the resistance of first crack for SCC-FAS and SCC-QD for 0.5% gives the same result. For SCC-RHA shows the highest resistance of load for 0.5%.

Now if we see that the deflection at the time of initial crack found to be slightly more for 0.5% but within the ultimate limit. The deflection result found to be same for SCC-FAS, SCC-RHA and SCC-QD for the fibre volume fraction 0.5%.

The ultimate load for SCC-SF found to give more strength for 1% Vf than 0.5% and 1.5% . But for other cases 1.5% Vf shows better results than 0.5% and 1%. From the maximum deflection results obtained it shows that SCC-SF gives better result for 0.5% Vf which is lesser than all other mixes and conventional concrete.

**Table – 3 Salient Points of Moment - Rotation Curves**

| Mix | Vf (%) | $M_{cr}$ | $\theta_{cr}$ | $M_y$ | $\theta_y$ | $M_u$ | $\theta_u$ |
|---|---|---|---|---|---|---|---|
| SCC | - | 1.5 | 6 | 6 | 22.5 | 7.5 | 34 |
| SCC-SF | 0.5 | 1.8 | 6 | 6.75 | 13 | 10.12 | 47 |
|  | 1.0 | 1.5 | 5 | 7.2 | 15 | 11.1 | 47 |
|  | 1.5 | 1.8 | 7 | 6.75 | 14 | 10.13 | 44 |
| SCC-FAS | 0.5 | 1.5 | 6 | 7.2 | 14 | 11.1 | 44 |
|  | 1.0 | 1.5 | 7 | 6 | 16 | 8.25 | 40 |
|  | 1.5 | 1.5 | 7 | 7.2 | 20 | 8.7 | 38 |
| SCC-RHA | 0.5 | 1.5 | 6.25 | 6 | 20 | 7.5 | 40 |
|  | 1.0 | 1.65 | 7 | 6.9 | 22 | 8.1 | 42 |
|  | 1.5 | 1.65 | 6 | 6 | 13 | 9 | 44 |
| SCC-QD | 0.5 | 1.5 | 6 | 6.3 | 12 | 9.6 | 46 |
|  | 1.0 | 1.5 | 7 | 6.75 | 19 | 8.7 | 46 |
|  | 1.5 | 1.5 | 6 | 7.5 | 21 | 9.9 | 47 |

The SCC-SF gives the better moment rotation capacity for Vf 1.0% than other combinations such as SCC-FAS, SCC-RHA and SCC-QD.

**Table – 4 Comparison of Experimental and FEA (ANSYS) Results**

| Mix | Vf (%) | $P_{cr\_FEA}$ | $P_{cr\_EX}$ | $P_{cr\_FEA}/P_{cr\_EX}$ | $P_{u\_FEA}$ | $P_{u\_EX}$ | $P_{u\_FEA}/P_{u\_EX}$ |
|---|---|---|---|---|---|---|---|
| SCC | - | 5 | 5 | 1 | 24 | 25 | 0.96 |
| SCC-SF | 0.5 | 5 | 6 | 0.83 | 30 | 33.75 | 0.89 |
|  | 1.0 | 4.5 | 5.4 | 0.83 | 33 | 37 | 0.89 |
|  | 1.5 | 4 | 5 | 0.8 | 27 | 31.5 | 0.86 |
| SCC-FAS | 0.5 | 4 | 5.2 | 0.77 | 24 | 35 | 0.69 |
|  | 1.0 | 5 | 5 | 1 | 32 | 27.5 | 1.16 |
|  | 1.5 | 4.5 | 5.1 | 0.88 | 26 | 29 | 0.90 |
| SCC-RHA | 0.5 | 5.4 | 5 | 1.08 | 27 | 25 | 1.08 |
|  | 1.0 | 4 | 5.5 | 0.73 | 36 | 27 | 1.33 |
|  | 1.5 | 4.8 | 5.5 | 0.87 | 28 | 30 | 0.93 |
| SCC-QD | 0.5 | 5.2 | 5.2 | 1 | 36 | 32 | 1.13 |
|  | 1.0 | 5 | 5 | 1 | 27 | 29 | 0.93 |
|  | 1.5 | 5 | 5.1 | 0.98 | 33 | 33 | 1 |

From the final results for the combinations of SCC-SF, SCC-FAS, SCC-RHA and SCC-QD, the Vf 1.0% gives better results experimentally and it has been compared with finite element software viz., ANSYS.

## VI. CONCLUSION

From the results discussed above from the table-2, it is concluded that SCC-SF having Vf 1.0% gives the better results than other fibre volume fractions and SCC-FAS, SCC-RHA and SCC-QD. The reason for these is due to the presence of more fineness in SCM like Silica fume than FAS, RHA and QD. These fineness particles will fill the micro pores in the concrete tends to make hardened concrete with low permeability. These hardened concrete makes to resist the high amount of load with limited slope and deflection.

For beams with SCC-SF class, the addition of steel fibers increases the maximum bending load. Addition of 1% of steel fiber volume fraction in SCC-SF causes the maximum bending loads to increase by 34.5%, 37%, 27% to that of SCC-FAS, SCC-RHA and SCC-QD respectively. The SCC-SF with 1.0% Vf will increase the bending strength by 48% compared with conventional SCC i.e., without replacement of cement with SCM. The main reason for this increase is the performance of randomly distributed steel fibers which provide bridging forces across micro-cracks and it resist the member from the crack formation. As a result, by increasing the fiber volume fractions from 0.5 % to 1.0% the bending load of beam specimens increases.

The Vf 1.0% for SCC-SF gives the better ductility and energy absorption results than other combination of mixes such as SCC-FAS, SCC-RHA and SCC-QD. Finally, the experimental result has been proved with analysis software viz., ANSYS.

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