Influence of ultra-fine steatite powder on the fresh and hardened properties of self-compacting concrete

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Abstract. Being one of the globally used construction material, upgrading in the concrete has always become the cardinal motif for the researchers inducing the advancements in the same. Self compacting concrete being one such special concrete has eased much of the work for the constructors in many aspects. Steatite powder (Hydrated magnesium silicate powder) is introduced as an additive in the self compacting concrete in this experimental study. The fresh properties of self-compacting concrete such passing ability, filling ability flowing ability and segregation resistance along with the hardened concrete studies such as compressive strength as well as split tensile strength were studied. An entire powder content of 530Kg/m3 and a water/powder ratio of 0.43 were adopted throughout the study for the mix proportions. Different percentages of Ultra Fine Natural Steatite Powder (UFNSP) were incorporated to the complete weight of the OPC at 0%, 5%, 10%, 15%, 20% and 25% as an additive. The flow properties of the SCC developed with UFNSP were noted to be within the permissible limits of the European guidelines for SCC. Whereas on the other side, the mechanical properties remain elevated up to 20% of addition of UFNSP by developing optimum strength at 15% of UFNSP owing to the finer particle size of the UFNSP along with the presence of Mg in the SCC mixes thus developed.

Keywords: Fresh Properties, Ultra Fine Natural Steatite Powder, Super Plasticizer, Viscous Modifying Agent, hardened properties, self-compacting concrete.

1. Introduction
Improper compaction in concrete being the key factor that vastly varies the strength of the concrete [1], which adversely get affected in special conditions like the beam column joint as well as in the locations with concentrated reinforcements. Since the SCC gets compacted by itself due to the self weight without an external compaction[2], this can be implemented in above mentioned special conditions to overcome the difficulty and therefore additional cement content is required[3,4] for developing the SCC making the section uneconomical. Which in turn also develops higher autogenous shrinkage along with a higher heat of hydration. Fly ash and Steatite were included in this study as mineral admixtures which consequently minimizes the emission of the CO₂ henceforth developing a balanced eco system (5-7). India (Author’s Native) serves as the second largest source in the availability of the steatite. This mineral encompasses talc as the major component enabling it to have a higher percentage of magnesium. The enormous availability and better durability performance under high temperature enabled the material to easily gain the attention of the researchers. Initial studies on the influence of UFNSP in Concrete with high performance were already initiated in fewer studies [23,24]. However, the study on the steatite mineral by the researchers were inadequate when compared with the study on the other mineral
admixtures [8-22]. The strength parameter and the setting time [25] on the other hand were noted to increase with a weakening in the flow properties in the earlier studies. In this experimental investigation, steatite is involved as a filling material in the SCC mix as it does not abide with the pozzolanic necessities (CaO+SiO₂+Al₂O₃ > 70%). Consequently, it cannot be practically incorporated as an ideal choice of replacing cement in concrete construction. Viscous modifying agents and super plasticizers were added in the SCC developed in this study. These chemical admixtures enable to minimize the segregation and bleeding in fresh concrete thus improving the workability and permeability of the fresh concrete [22,26].

The micro size (5 microns) of the UFNSP enables to diminish the permeability [24] by filling the voids in the cement, thus acquiring a denser concrete. Six sets of samples were cast in this study with UFNSP of varying percentage of 0%, 5%, 10%, 15%, 20% and 25% of total cement weight in the concrete mix. Both the fresh concrete and hardened concrete properties were experimentally tested and analysed for SCC in this study. To validate the fresh concrete properties of thus developed self compacting concrete, L-Box test, V-Funnel test, Slump Cone test, Slump cone T₅₀₀ tests and column segregation test were carried out. On the other side, Compressive strength test and Split tensile test were carried out to corroborate with the implications assimilated in the fresh concrete studies.

2. Experimental study

Ultra fine natural steatite powder (UFNSP) is acquired from the industrial market in southern part of India which contains 63% of silica (Si), 32% of magnesium (Mg) and 5% of H₂O [24]. OPC (Ordinary Portland cement) of 53 grade as per the standards of IS-12269[27] is used for developing SCC. Coarse aggregates of angular shape with particle size of 10mm to 12.5mm and a specific gravity of 2.7 were used. M sand with specific gravity of 2.65 and fineness modulus of 2.623 as per the standards of IS 383:1970[28] were used. CERA HYPERPLAST XR-W40(Polycarboxylic based) is used as superplasticizer to obtain the apt workability along with Mastermatrix VMA 362 as the viscous modifying agent.

2.1. Mix Proportion

In this experimental investigation, SCC mix is developed in reference with the European guidelines for self compacting concrete[30]. Trial and error method [Table 1] is implemented for the production of SCC which is presented in Table 2 with their respective inferences. A water powder ratio of 0.43 is used throughout the study for 530 Kg/m³, 805.6Kg/m³, 784.4Kg/m³ of cement, fine aggregate and coarse aggregate respectively. The UFNSP is varied as 0%, 5%, 10%, 15%, 20% and 25% for the weight of the OPC and thus 6 sets of samples were cast for each % variation. The mix were represented as SCC_0, SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 for 0%, 5%, 10%, 15%, 20% and 25% respectively. The mix proportions thus obtained were presented in Table 2.

| Trial | Mix ratio | W/C ratio | Identified Fault            | Implemented action to eradicate the fault according to EFNARC (as per Table C.2)          |
|-------|-----------|-----------|-----------------------------|------------------------------------------------------------------------------------------|
| 1     | 1:1.52:1.52 | 0.48      | Rapid loss of workability   | Use different superplasticiser, use slower reacting cement type                          |
| 2     | 1:1.52:1.52 | 0.48      | Segregation                 | Increase the mortar volume, Reduce the water content                                        |
| 3     | 1:1.52:1.48  | 0.4       | viscosity too high          | Increase the water content                                                               |
| 4     | 1:1.52:1.48  | 0.43      | Nil                         | _                                                                                         |

Table 1. Trial and error method for SCC production
Table 2. Mix proportion developed for self-compacting concrete

| Mix ID | Cement content (kg/m³) | Steatite content (kg/m³) | Amount of Water (lit/m³) | Superplasticizer content (kg/m³) | Viscous modifying agent content (kg/m³) | Fine aggregate content (kg/m³) | Coarse aggregate content (kg/m³) |
|--------|------------------------|--------------------------|-------------------------|-------------------------------|------------------------------------------|-------------------------------|-------------------------------|
| SCC0   | 530                    | 0                        | 227.9                   | 10.6                          | 2.12                                     | 805.6                         | 784.4                         |
| SCC5   | 530                    | 26.5                     | 239.3                   | 11.13                         | 2.22                                     | 805.6                         | 784.4                         |
| SCC10  | 530                    | 53                       | 250.7                   | 11.66                         | 2.33                                     | 805.6                         | 784.4                         |
| SCC15  | 530                    | 79.5                     | 262                     | 12.19                         | 2.44                                     | 805.6                         | 784.4                         |
| SCC20  | 530                    | 106                      | 273.5                   | 12.72                         | 2.54                                     | 805.6                         | 784.4                         |
| SCC25  | 530                    | 132.5                    | 283.6                   | 13.19                         | 2.64                                     | 805.6                         | 784.4                         |

2.2. Mixing Procedure

To obtain the similar homogeneity and consistency every developed mixes of SCC, the mixing procedure suggested by Khayat [29] is implemented in this work, since the mixing time period and mixing sequence plays the key role in the production of SCC. The same is presented in the below flow chart (Figure 1)

Figure 1. flowchart representing the mixing sequence for the production of SCC.
3. Observations and Discussions

3.1. Fresh concrete studies

3.1.1. Slump flow test
Initially when the flowability of SCC were studied with slump flow test. The recorded slump values (Figure 2) were noted to be between 620mm and 700mm. The flowability of the concrete slump is noted to decrease upon the addition of the UFNSP in the SCC [23,24], owing to the finer nature of the UFNSP, therefore increasing the water demand. Thus SCC_20 and SCC_25 was classified as SF1 [30] conforming to the EFNARC guidelines. On the other hand, SCC_5, SCC_10 and SCC_15 was classified as SF2. The highest slump flow of 700mm and lowest slump flow of 625mm were recorded for SCC_0 and SCC_25 respectively.

![Figure 2. Slump flow test results](image)

3.1.2. T500 flow time
In view of the test results from the T500 flow test in figure 3, all the SCC mixes developed in this investigation were classified under VS2[30]. For the T500 flow test with lower UFNSP, the mix SCC_0 is noted to have a flow time of 2.9 seconds whereas, the SCC mix with higher % of the UFNSP SCC_25 showcased a flow time of 5.7 seconds. The other mixes SCC_5, SCC_10 and SCC_20 was noted to have flow time of 3.3 seconds, 4.4 seconds, 4.8 seconds and 5.3 seconds respectively. Thus, the flowability in T500 flow test for the SCC mix developed with UFNSP is noted to be enhanced better.

![Figure 3. T500 flow test results](image)
3.1.3. V funnel flow time
In case of the V funnel test results(Figure 4), based on the EFNARC guidelines, the SCC mix thus developed with the UFNSP is categorized as VF1 whereas, SCC_5, SCC_10, SCC_20 and SCC_25 were classified as VF2. A minimal flow time of 7.9 seconds is recorded for SCC_0, and a maximum flow time of 11.8 seconds is noted for SCC_25(maximum UFNSP%). On the other side, SCC_5, SCC_10, SCC_15 and SCC_20 was observed with a flow time of 8.4 seconds, 9.3 seconds, 10.5 seconds and 11.3 seconds respectively. The test results are visibly clear that higher percentage of UFNSP increased the flow time in the V funnel flow time test. Therefore, it is concluded that, the usage of UFNSP reduced the flowability of SCC, however the viscous modifying agents and superplasticizers are incorporated in the mix that allows the same to be within the limits of EFNARC guidelines.

![Figure 4. V-Funnel test results](image)

3.1.4. L- box test
Since the L-box height ratio is limited between 0.8 and 1 conforming to the EFNARC guidelines, the recorded results in this experimental study were noted to abide the same by having 0.9 as the L-box height ratio for the mix SCC_0. Also, the SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 were noted to have a L-box height ratio of 0.92, 0.88, 0.86, 0.85 and 0.82 respectively. The 3 No’s of rebars in the L-box puts all the mix under PA2 class. Therefore, all these mixes were feasible for the constructions with a spacing of 60mm to 80mm in the reinforcement. These results (Figure 5) also throws light on the reduction of fluidity of SCC upon the addition of UFNSP. Henceforth a correlation of $H_2/H_1=0.0088(T_{500})^2 − 0.1281 + T_{500} +1.27112$ is obtained between the $T_{500}$ flow test and L box test for the mixes, with a co-efficient of $R^2=0.9833$ for this experimental analysis.

![Figure 5. L-Box test results](image)
3.1.5. Column segregation test

This standard method for studying the static segregation of SCC involving column technique is adopted in this study. The mixes were graded into three categories according to the ASTM 1610 standards as BSR (Border segregation resistance), MSR (Medium segregation resistance), and HSR (High segregation resistance). Out of which, SCC_0 and SCC_5 come under BSR. The mixes SCC_10 and SCC_15 were categorized as MSR. Under the HSR category, the mixes SCC_20 and SCC_25 were classified. These grading(Figure 6) depicts the better segregation resistance in the SCC mixes as the % of UFNSP increases revealing the intrusion of finer UFNSP particles when the water demand increases in the SCC mixes. Thus SCC_25 is observed to develop highest segregation resistance for the maximum percentage of replacement with UFNSP owing to the uniformly graded - cohesive mix developed in this experimental study.

![Column Segregation Test](image)

* HSR - High Segregation Resistance; MSR - Moderate Segregation Resistance; BSR - Border Segregation Resistance

Figure 6. column segregation test results

3.2. Hardened concrete studies

3.2.1. Compressive strength

The compressive strength of the different mixes was analysed for 28 days, 56 days and 90 days. A maximum of 33.19 N/mm², 33.62 N/mm² and 34.58 N/mm² is noted for SCC_15 at 28 days, 56 days and 90 days respectively (Figure 7). At 28days, the % increase in compressive strength was noted to be maximum for SCC_15. The maximum later age strength (56 days and 90 days) were recorded as 33.41% and 37.22% higher when compared with the control specimen for SCC_15. The strength gain upon the addition of UFNSP is due to the finer particle size of the same along with the presence of Mg which allows the finer particles to intrude into the cement matrix [31,32]. Consequently, the higher hydration rate imparts the early age strength for the specimens of SCC with UFNSP [33]. The 28 days strength for SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 developed strength gain of 6.83%, 15.63%, 31.63%, 22.50% and 1.03% respectively (Figure 8). In case of 56 days of curing, the specimens of SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 were noted to showcase rise in the compressive strength values of 8.06%, 17.38%, 33.41%, 24.21% and 2.82%. The later later age strength attainment at 90 days of curing were noted to be higher when compared with the 28 days curing strength and 56 days curing strength. Increased values of 11.19%, 22.62%, 37.22%, 27.02% and 6.32% when compared with the control specimen were developed in for SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 respectively. Thus the addition of UFNSP in SCC tend to increase the compressive strength of the hardened concrete with a maximum rise for SCC_15 mix, after which a considerable decline is noted in the % of strength attainment compared with that of the control specimen. Nevertheless, SCC_25 showcased a compressive strength almost slightly elevated than the control specimen indicating the high feasibility of including UFNSP in the production of SCC.
3.2.2. Split tensile strength

In order to render the split tensile strength results (Figure 9), three replicate cylinders of 300mm length and 150mm of diameter were casted and tested on 28 days, 56 days and 90 days of curing for every mix. A maximum of split tensile strength is recorded for SCC_15 mix at 28 days, 56 days and 90 days with a split tensile strength of 4.72 N/mm$^2$, 4.79 N/mm$^2$ and 4.83 N/mm$^2$ respectively depicting the simultaneous rise in split tensile strength along with the compressive strength of the SCC mixes developed with UFNSP. At 28 days of curing, increase in the split tensile strength is recorded as 7.37%, 17.63%, 24.21%, 20.26% and 2.89% when compared with the control specimen for SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 respectively (Figure 10). Similarly, the split tensile strength is noted to be 3.42%, 18.42%, 26.05%, 21.32% and 4.74% of rise is observed for SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 respectively when the samples are tested after 56 days of curing. The later age strength of 90 days concrete also showed similar results as of 28 days and 56 days with an increased value of 9.47%, 20%, 27.11%, 23.16% and 6.5% than the control mix for SCC_5, SCC_10, SCC_15, SCC_20 and SCC_25 respectively.
4. Conclusion

- The SCC developed by adopting the method suggested by Khayat [29] were experimentally tested for fresh and hardened properties of SCC after the inclusion of UFNSP at various percentages of replacement.

- The slump test, $T_{500}$ slump flow test, V Funnel test and L-Box test results depict that maximum workability is obtained with SCC_15 mix when compared with SCC_5, SCC_10, SCC_20 and SCC_2. Whereas the column segregation test results reveal the tendency of UFNSP to limit the excess water in SCC due to its finer particle size. Thus a gradual rise is noted in the segregation resistance of the concrete along with the rise in the percentage of UFNSP in SCC.

- The compressive strength of the SCC developed with UFNSP were noted to rise steadily with a maximum compressive strength value of 34.58N/mm$^2$ for SCC_15 at 90 days. After which it is noted to decline for SCC_20 and SCC_25, however these values were slightly more than the control specimen denoting the high chance of including the UFNSP for the production of SCC efficiently.
The split tensile strength values showcased similar pattern as that of the compressive strength test results having higher split tensile strength for SCC_15 in the later age (90 days) as 4.83 N/mm² after which the split tensile strength reduced for SCC_20 and SCC_25 owing to the increased percentage of Mg in these two mixes.

Based on the experimental results, it is clearly evident that inclusion of UFNSP in SCC emerged out as an ideal replacement choice that gives the concrete better facets.

5. Conflicts of Interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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