Study on Flexural Behaviour of Ternary Blended Reinforced Self Compacting Concrete Beam with Conventional RCC Beam

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Abstract. The conventional concrete when used for structures having dense congested reinforcement, the problems such as external compaction and vibration needs special attention. In such case, the self compacting concrete (SCC) which has the properties like flow ability, passing and filling ability would be an obvious answer. All those SCC flow behavior was governed by EFNARC specifications. In present study, the combination type of SCC was prepared by replacing cement with silica fume (SF) and metakaolin (MK) along with optimum dosages of chemical admixtures. From the fresh property test, cube compressive strength and cylinder split tensile strength, optimum ternary mix was obtained. In order to study the flexural behavior, the optimum ternary mix was taken in which beam specimens of size 1200 mm x 100 mm x 200 mm was designed as singly reinforced section according to IS: 456-2000, Limit state method. Finally the comparative experimental analysis was made between conventional RCC and SCC beams of same grade in terms of flexural strength namely yield load & ultimate load, load- deflection curve, crack size and pattern respectively.

Keywords: Self compacting concrete, silica fume, metakaolin, flexural strength, cracks, load and deflection

1. Introduction
In recent developments of concrete technology many special concrete were developed ensuring high strength and high performance characteristics. In that scenario, self compacting concrete (SCC) was developed in 19th century in Japan to cater the durability aspects because of unskilled labour in the placement of concrete in bridge construction. It has a dynamic behaviour such as flow, passing and filling ability in the desired form. SCC had vast field applications in construction, repairs and rehabilitation of structures in countries such as Japan, Switzerland and European countries. European Federation of Nationalised Association Representing Concrete (EFNARC) made guidelines on conducting the test on SCC in fresh state and recommended the range of values for the tests such as slump flow, V-funnel, U-box and L-box test. SCC could be prepared as powder type and combination type. On SCC, the use of slag to understand the rheology was developed and found that 15% slag was optimum [1]. The research on fly ash addition in high strength SCC with reduced segregation potential enhances later age compressive strength (i.e. after 28 days) [2]. The addition of nano-silica and mineral admixtures (fly ash & silica fume) improved the pore space denser and the rheology of high performance SCC [3]. In SCC, the increase of w/c ratio from 0.35 to 0.7 decreases the compressive and tensile strength by 66% and 51% respectively [4]. Research on SCC using GGBS
and RHA by conducting axial compression and flexure tests reveals that the GGBS efficiency was improved from 0.7 to 1.8 at 28 days, obtained from Bolomey’s empirical expression [5]. After structural assessment of corroded SCC beams on durability properties such as half-cell potential, cracks, corrosion control, etc., beams prepared by SCC mix was superior to normal concrete [6]. The analytical & experimental study on rehabilitation of RC beams using SCC jacket was found that the structure was recovered completely in terms of strength and ductility property and the good correlation exhibits between analytical and experimental results [7]. The experimental investigation on the flexural characteristics of SCC pre-tensioned bridge girders was studied at high early age compressive strength after 16 h and at later ages, SCC obtained higher strength than conventional concrete [8]. The SCC flow behaviour and mechanical properties by 10% SF as cement replacement performed better was investigated [9]. Using 15% MK as cement replacement in SCC, fresh properties test and compressive strength was determined [10]. The simplest mix design was developed for SCC mixes [11]. The research was carried out on SCC using cement replacement by MK [12]. The mix design of SCC and its fresh properties test was conducted according to EFNARC guidelines [13-14].

In present study, the combination type (mineral & chemical admixtures) of SCC was developed. The powder content of SCC consists of mineral admixtures namely Silica Fume (SF) and Metakaolin (MK). The chemical admixtures include the dosages of super plasticizer (SP) and viscosity modifying agent (VMA). The ternary blend SCC mix was prepared and studied by conducting fresh properties test, compressive strength on cubes, split tensile strength on cylinders and flexural behaviour of beams.

2. Material used
Cement: Ordinary Portland cement 53 grade ASTM Type I [16] was used.
Mineral Admixtures: Silica Fume (SF) and Metakaolin (MK) were used as per ASTM C 1240-99 [15, 18].
Coarse Aggregates: For Self Compacting Concrete, the coarse aggregate was used as per ASTM C 127-12 [19]. Hence the property of fluidity was developed.
Fine aggregates: Natural river sand (< 4.75 mm) grading Zone III of ASTM was used. The physical properties were determined as per ASTM 127 and their particle size distributions confirmed to the requirements of ASTM C33 [17].
Chemical Admixtures: Super plasticizers and stabilizers play a major role in workability of concrete particularly for SCC.

3. Mix design
The mix design was developed according to conventional M60 grade concrete. By laboratory test trials, the fine and coarse aggregate proportions were adjusted and with addition of optimum water-powder ratio (0.4), dosages of super plasticizers (1.25% weight of cement) and stabilizers-VMA (0.1% weight of cement) SCC mix were prepared (Table 1). Then the prepared mix was subjected to fresh properties test according to EFNARC guidelines.

2. Material used

| MIX       | C/kg m$^3$ | SF/kg m$^3$ | MK/kg m$^3$ | FA/kg m$^3$ | CA/kg m$^3$ | Water/l m$^3$ | SP/l m$^3$ | VMA/l m$^3$ | w/p ratio |
|-----------|------------|-------------|--------------|-------------|-------------|---------------|-----------|-------------|-----------|
| CVC       | 600        | -           | -            | 396         | 1074        | 198           | -         | -           | 0.33      |
| C+10% SF+ 20%MK | 420 | 60 | 120 | 810 | 660 | 240 | 7.5 | 0.6 | 0.4 |
| C+5% SF + 20%MK | 450 | 30 | 120 | 810 | 660 | 240 | 7.5 | 0.6 | 0.4 |
| C+20%SF + 5%MK | 450 | 120 | 30 | 810 | 660 | 240 | 7.5 | 0.6 | 0.4 |
4. Experimental Programme

The experimental programme includes conducting test on basic materials to understand their physical properties and test on SCC fresh properties. In hardened state, the mechanical properties were studied by the preparation of cube, cylinder and beam specimens at 28 days of testing.

4.1 Basic test on materials
Before undergoing mix preparation, the quality of materials was found by conducting corresponding tests such as specific gravity, fineness modulus, bulk density, etc., for cement, fine aggregate and coarse aggregate, silica fume (SF) and metakaolin (MK).

4.2 Test for fresh properties of concrete
The SCC fresh property test namely slump flow test & T500, L box test, U box test and V funnel test was conducted for each mix and done according to EFNARC guidelines.

4.3 Preparation of mould and Casting of specimens
Once fresh properties test were conducted on each of those prepared mixes, the cube mould prepared from wooden material of inner dimensions 100 mm x 100 mm x 100 mm, cylinder mould of PVC material having inner diameter 100 mm and 200 mm height, SCC was poured. From the optimum results obtained from cube compressive strength and cylinder split tensile strength, beam specimen was prepared (Figure 1 & 2). Two beams were cast with the wooden mould of inner dimensions 1200 mm x 100 mm x 200 mm size.

4.4 Curing of specimens
The cube and cylinder specimens were removed from the mould and normal water curing was done for the duration of 28 days. But for the beams, the formwork of beams were de-moulded after 24 hours of casting and then cured in gunny bags with ponding of water for the age of 28 days. Finally the specimens were taken out from water tank after curing; its surfaces were made dry in normal atmosphere temperature for 3 hours before testing in laboratory.

4.5 Testing of specimens
The cube and cylinder specimens were tested in the Universal Testing Machine (UTM) to determine compressive and split tensile strength. For testing of beams, the self supporting frame was used (Figure 3). The load & deflection was measured using digitized recorder and LVDT’s were used for measuring deflection at mid span (L/2) and under the load (L/3).
5. Results and discussion

5.1 Results
The results obtained from the experimental programme were categorized into three stages. Stage 1 includes results from basic properties of materials and SCC fresh properties test. Stage 2 includes test on compressive and split tensile strength on cubes and cylinders. Stage 3 includes results obtained by conducting test on beams.

| MIX                  | Fresh properties test      |
|----------------------|----------------------------|
|                      | (As per EFNARC guidelines) |
|                      | Slump flow test (mm)       |
|                      | T 500 (s)                  |
|                      | V-funnel test (s)          |
|                      | L-Box test (H2/H1)         |
|                      | U-Box test (H2-H1) (mm)    |
| C+10% SF +20%MK      | 675                        |
|                      | 3                          |
|                      | 10                         |
|                      | 0.84                       |
|                      | 25                         |
| C+5% SF +20%MK       | 660                        |
|                      | 3.5                        |
|                      | 11                         |
|                      | 0.91                       |
|                      | 28                         |
| C+20%SF +5%MK        | 655                        |
|                      | 2.5                        |
|                      | 9                          |
|                      | 0.87                       |
|                      | 27.5                       |
| Accepted Range       | 650 to 800                 |
|                      | 2 to 5 s                   |
|                      | 6 to 12 s                  |
|                      | 0.8 to 1                   |
|                      | 0 to 30                    |

Table 2. Basic test on materials.

| Fine aggregate | Fineness modulus: 3.16 |
|----------------|------------------------|
|                | Specific gravity: 2.547 |
| Coarse aggregate | Fineness modulus: 7.02 |
|                | Specific gravity: 2.74  |
| Cement (OPC)   | Initial setting time: 33 minutes |
|                | Std. consistency: 31%   |
|                | Specific gravity: 3.14  |
| Metakaolin (MK) | Specific gravity: 2.5   |
| Silica fume (SF)| Specific gravity: 2.08  |

Table 3. Test on SCC fresh properties.
Table 4. Test on cube compressive strength.

| MIX          | Cube Compressive Strength (MPa) |
|--------------|---------------------------------|
|              | 3 days | 7 days | 28 days |
| CVC          | 12.35  | 33.6   | 55.94   |
| C+10% SF +20%MK | 15.2   | 38.3   | 65.5    |
| C+5% SF +20%MK | 13.7   | 36.5   | 60.3    |
| C+20%SF +5%MK  | 13.1   | 34.5   | 58.1    |

Table 5. Test on cylinder split tensile strength.

| MIX          | Cylinder Split tensile strength (MPa) |
|--------------|---------------------------------|
|              | 7 days | 28 days |
| CVC          | 2.15   | 3.55    |
| C+10% SF +20%MK | 2.37   | 4.01    |
| C+5% SF +20%MK | 2.28   | 3.84    |
| C+20%SF +5%MK  | 2.19   | 3.6     |

Figure 4. Cube compressive strength (MPa) Vs Age (Days).
Figure 5. Cylinder split tensile strength (MPa) Vs Age (Days).

Figure 6. Load Vs Deflection Curve of CVC beam.
5.2 Discussion

5.2.1 SCC fresh properties. SCC rheology was studied by conducting fresh properties test according to EFNARC guidelines (Table 3). In SCC ternary blend type, two different heterogeneous materials (SF & MK) were used to replace cement. The conglomeration of SCC mix was obtained by the addition of chemical admixtures namely SP and VMA. The determination of water powder ratio was done by conducting laboratory test trials. First the control over aggregate proportions was developed and on the next stage water content, dosages of SP and VMA were optimized. In such a way the flow was developed with w/p ratio 0.4, SP 1.25% weight of cement and VMA 0.1% weight of cement. It should also be noted that the over dosages of w/p ratio and chemical admixtures leads to less strength and segregation of mix. The slump flow & T500 test measures flow ability of SCC mix, all ternary SCC mixes were attained minimum spread diameter of 650 mm. The reason of SCC flow behaviour was due to addition of powder content namely MK and SF used up to 25% and 30% in the ternary mix. Similar trend was obtained for L-box, U-box and V-funnel test which determines the filling ability of SCC in the field applications such as dense congested reinforcement. Hence all SCC fresh properties test were well within the range of EFNARC guidelines and found satisfactory.

5.2.2 CVC and SCC mechanical properties. The hardened state properties of CVC and ternary SCC mixes were studied by conducting cube compressive strength and cylinder split tensile strength at the age of 28 days (Table 4 & 5). The cement replacement by two mineral admixtures namely 10%SF and 20% MK plays a significant role in improving mechanical properties was shown (Figure 4 & 5). It reveals that optimal cement replacement confines the interfacial transition zone (ITZ) and it makes denser in ternary SCC mixes. Here out of 3 ternary SCC mixes, two mixes were replaced up to 25% and one having maximum cement replacement of 30% respectively. Hence increase of fines in the form of powder content develops higher strength in the ternary form, which resembles that in binary form pozzolonic activity was less whereas in the ternary form combined reaction takes place. The above statement could be correlated with the composite behaviour of materials with fibres and matrix form. In this study, due to above highlighted reasons, SCC ternary form shown higher mechanical properties than conventional vibrated concrete (CVC).

5.2.3 Flexural behaviour of CVC and SCC beam. The structural behaviour of any concrete materials could be studied by flexure or axial compression test. In present study the beams were cast with CVC and ternary SCC type. The beam test set up (Figure 3) comprises of two point loading system in which
the corresponding deflection was measured at the position of L/2 and L/3 of beam simply supported span (L). The initial crack obtained for CVC was obtained at 40 kN whereas in ternary SCC (C+10%SF+20%MK) was 50 kN. The maximum load obtained by ternary SCC was 71 kN with a maximum displacement at L/2 was 8.52 mm was relatively a better performance with CVC beam (Figure 6 &7). The wider cracks say 1.5 mm were found in CVC beam than SCC of 1mm. The failure modes of beams were under flexure only. Hence SCC beam performed better than CVC on flexure study.

6. Conclusion
Based on experimental investigation on self compacting concrete with cement replacement by SF and MK as ternary blend type the following important conclusions were made. By laboratory trials, optimum w/p ratio of 0.4 was achieved by conducting fresh tests with the dosages of Super plasticizer (1.25% by weight of cement) and Stabilizer (0.1% by weight of cement) respectively. The SCC fresh properties tests values were well within the recommended range of EFNARC guidelines. The compressive strength and split tensile strength values of ternary SCC mix was 15% and 12% higher than CVC mix. It was found that cement replacement by 10%SF and 20% MK performed better in terms of compressive strength and split tensile strength respectively. From the load–displacement curve between CVC and SCC, SCC beam were ductile in nature compared to CVC beam was observed on flexure study. The width, spacing and propagation of cracks were within the flexure zone was observed.

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