Experimental Study on the Presence of Mineral Admixtures and Steel Fiber on the Elastic Properties of Self-Compacting Concrete (SCC)

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ABSTRACT: The elastic properties like young’s modulus and poison’s ratio are critical issues in the design of concrete structures. This technical paper focuses on the influence of the mineral admixtures like flyash and condensed silica fume along with percentage of steel fibers on the compressive strength and elastic properties of self-compacting concrete (SCC). The flow ability, passing ability along with the segregation resistance tests were conducted. Designed the M40 grade of SCC as per American concrete institute (ACI) provisions. The cement is mingle with flyash(FA) at 20% and condensed silica fume(CSF) at 10% as partial replacement by weight. The steel fiber of diameter 1mm and aspect ratio of 40 mixed at 0.2, 0.4, 0.6, and 0.8 percentages by volume of the concrete. The Young’s modulus and Poisson’s ratio are resolved as per American standard for testing materials (ASTM) specifications. Based on the experimental investigation, conclusions drawn on the contribution of mineral admixtures and steel fiber on the compressive strength and elastic properties of SCC. A mathematical model developed and checked the validity of the equation with the experimental results.

Keywords: Aspect ratio, Condensed Silica Fume, Chemical admixtures, Poisson’s ratio, steel fibers, Young’s modulus.

1. Introduction

The structural strength of the concrete is mainly dependent upon the mix design, physical, and chemical properties of the ingredients. Compaction and curing also influence the hardened properties. Self-Compacting Concrete (SCC) defined as concrete material which doesn't require any external compaction for formation of dense mix. This type of special concrete is mainly used for placing in dense reinforcement where compaction is difficult. The SCC is also used in casting of thin concrete structural elements like plates and shells. SCC developed in Japan in late 90’s. Initially Okamura, Ouchi, and Ozawa investigated this special type of concrete. Later many researchers carried out the experimentation on the rheological behaviour, structural properties etc. The researchers also studied the influence of admixtures on the structural properties along with the addition of fibers in it. Basically concrete is strong in direct compression, by adding fibers in the concrete matrix the tensile and flexural strengths were improved. But the percentage of these fibers in SCC depends upon their physical properties. For steel fibers it is limited to a particular percentage of volume of the concrete, so as to avoid the obstruction of flow ability. By adding admixtures to the concrete, the properties in fresh stage are not only improved, but the strength properties in the hardened stage also enhanced. The chemical admixtures like superplasticizer (SP) improves the flow ability of the concrete. The viscosity modifying agent (VMA) modifies the segregation resistance. The percentage of these admixtures depend upon the properties of the ingredients used in the mix.

2. Literature review

In late 90’s Okamura.H, along with his team of scientists developed the ideology of SCC. This type of the concrete developed at that time for better strength and durability by using supplementary
cementitious materials (SCM) such as mineral admixtures. As per Okamura mix design is related to fine aggregate to mortar ratio to evaluate compatibility and flow ability. Nan Su et al (1), developed the easy mix design concept, which is based on the ratio of fine aggregate to total aggregate by mass. The authors concluded that the quantity of fine aggregate is more than the coarse aggregate in the complex of concrete, which can help the passing ability of the concrete through reinforcement bars easily. Okamura and Ouchi (2) reported the current and future perspectives of SCC to the world and given an outline way for the design mix of SCC incorporating the mineral admixtures at optimum dosages to satisfy the needs of the SCC. Turhan Bilir (3) did the experimentation for prognosticate of the elastic modulus for high grade concrete which incorporates the mineral admixtures such as silica fume and ground pumice. The author developed empirical formula for the material constant of the concrete. F. P.Zhou et al (4) investigated the affect of the coarse aggregate on the mechanical properties of the High performance concrete along with the Modulus of elasticity. D.Stefaniuk et al(5) did the experimentation for the determination of elastic properties of self-compacting concrete modified with nano particles. It was developed by multi scale approach.F.Demirt(6,7) did the experiments by using the artificial neural network, to prognosticate the modulus of elasticity for normal and high grade concretes. Ilker Bekir et al (8) did an attempt by using the composite material models for the estimation of modulus of elasticity of slag concrete. T.Noguchi et al (9) did the investigation for development of practical equation for the modulus of elasticity of concrete. H.Z.Cui et al(10) gave the analytical models for the compressive strength, and Modulus of elasticity. The authors also investigated the peak strain of structural lightweight aggregate concrete.Vijaya Kumar et al (11) developed the mathematical model for the compressive strength and elastic properties for the triple blended steel fiber self-compacting concrete. K.M.Lee,J.H.Park(12)did the investigation on the development of the numerical model for modulus of elasticity of concrete by considering interfacial transition zone.A.H.Gandomi et al(13) extracted the new design equations for modulus of elasticity of concrete using multi expression programming. "European Federation of National Associations Representing for Concrete-specifications for the self-compacting concrete”,EFNARC-2002(14) gave guidelines for Self Compacting Concrete. American Concrete Institute ACI-544 1R-960(15) gave the testing procedures for the determination of elastic properties. American Standards Testing of Materials (ASTM C 469-02)(16) gave the testing procedures for the determination of elastic properties.

3. Materials used for Experimentation:

3.1 Cement(OPC): 53 grade confirming to the IS:269-2019, used and all the properties such as its physical and chemical were examined as per the specifications.

3.2 Fine Aggregate: River sand confirming to Zone –II was adopted. Its modulus of fineness is 2.8.

3.3 Coarse aggregate(CA): Passing through 12 mm sieve and hold on on 10mm sieve used in experimentation, such that this type of the coarse aggregate is very easy to fulfil the rheological requirements. Shape of the coarse aggregate is the combination of rounded and angular. The modulus of the fineness is 6.8.

3.4 Mineral Admixture: F-type of flyash(FA) along with the condensed silica fume(CSF) is blended with the cement, the specific surface areas are 4000 and 150000cm²/gram respectively. The CSF has non-crystalline structure whereas FA is mostly globular. The CSF and FA has specific gravity 2.2 and 2.3 respectively.

3.5 Chemical Admixture: Glenium B 233 based on poly carboxylic ether (PCE) as superplasticizer along with Glenium-2 as VMA was used for this investigation.

3.6 Steel Fibers: Ordinary steel fiber of 1mm diameter and with an aspect ratio of 40 is used in the present investigations.

3.7 Water: water used for mixing, curing which is free from oil and any soluble salts.
4. Experimentation

4.1 Mix Design and Workability Tests:

M40 grade of SCC is developed based on the simple design approach by Nan Su[1]. The ratio of volume of the fine aggregate to the total aggregate content in the concrete is around 0.50 to 0.57 which depends on the packing factor (PF). In this experimentation, above ratio adopted as 0.62, by various trials to satisfy the needs of the SCC as per EFNARC guidelines. It basically depends upon the properties of the ingredients used in the SCC. Final mix design for the SCC along with the quantity of the materials are given in Tables 1 and 2.

Table 1. M40 Grade SCC-Mix Proportions

| S.No | Cement | Fine Aggregate | Coarse Aggregate | Water to cementitious ratio |
|------|--------|---------------|------------------|-----------------------------|
| 1    | 1      | 2.32          | 1.38             | 0.45                        |

Table 2. The Materials Adopted - M40 Grade SCC.

| S.No | Material             | Quantity for one cu.m |
|------|----------------------|-----------------------|
| 1    | Cement               | 320 Kg                |
| 2    | Flyash (FA)          | 92 Kg                 |
| 3    | Condensed Silica Fume (CSF) | 46 Kg  |
| 4    | Fine Aggregate (river sand) | 1056 Kg |
| 5    | Coarse Aggregate (12mm passing/10mm retained) | 628 Kg |
| 6    | Water                | 204 liter             |
| 7    | Superplasticizer (SP) | 234 ml               |
| 8    | Viscosity Modifying Agent (VMA) | 24 ml      |

The workability tests for SCC such as flow ability, passing ability and segregation resistance conducted on slump cone, V-funnel, and L-box respectively. These results are achieved when cement is partially blended with FA, and CSF at 20 and 10 percentages by mass of the cement. The SP and VMA were adopted at 1.0 and 0.15 percent by weight of the cement in the mix consistently for all the percentage of the steel fibers. Steel fibers were added at percentages of 0, 0.2, 0.4, 0.6, and 0.8. Details of the experimental results for the workability of the concrete for critical percentage of steel fiber (0.8) and maximum aspect ratio (40) are given in table 3.

Table 3. Workability Properties of Typical SCC

| S.No | Name of the test | units | Experimental value | Acceptance criteria |
|------|------------------|-------|---------------------|---------------------|
| 1    | Slump flow       | mille meter | 720              | 650-800            |
| 2    | V-Funnel         | seconds | 8                    | 6-12               |
| 3    | L-Box            | ratio  | 0.90                | 0.80-1.00          |

4.2 Number of mixes and specimens cast and tested:

The number of mixes adopted in this investigation were 5. For each mix 3 cubes, 6 cylinders were cast. For the determination of the compressive strength, a total of 15 number of cubes (150mm side) and a total number of 30 standard cylinders (150mm diameter and 300mm height) were cast for finding the failure load and the elastic properties. All the cubes are tested for compressive strength after completing 28 days of water curing. The 15 number of the cylindrical specimens are also tested for the compressive strength (failure load on the specimen), remaining 15 number of the cylindrical specimens are tested for the Young’s Modulus (E) and Poisson’s ratio (v) by applying compressive load at 40% of...
the failure load of the specimen, as per ASTM standards. The arrangement for measuring the dial gauges in longitudinal direction and lateral directions are shown in Figure 1 for noting the strain in both the directions. The testing setup for the cylindrical specimen is shown in Figure 2.

5. Results and Discussion

5.1 Compressive Strength and Material Constants:

The triple blended self-compacting concrete (TBSCC) with 20% FA and 10% CSF is recorded as 44.50MPa as compressive strength. The percentage of steel fiber is increased from 0.0 to 0.8 percent by volume of the concrete in four combinations(0.2,0.4,0.6,and 0.8) by maintaining maximum aspect ratio (40) in each percentage of steel fiber, it observed that the compressive strength of the triple blended steel fiber self-compacting concrete (TBSFSCC) is increased, the results are given in Table.4. The maximum compressive strength recorded for limiting percentage of steel fiber is 68.50MPa. Its variation shown in Fig 3.

| S.No | MIX CODE | Mix Abbreviation | Average Cube Strength in MPa |
|------|----------|------------------|----------------------------|
| 1    | M₁ 0.0 SF| Mix 1 for 0.0% of steel fiber | 44.50                      |
| 2    | M₂ 0.2 SF| Mix 2 for 0.2% of steel fiber | 49.80                      |
| 3    | M₃ 0.4 SF| Mix 3 for 0.4% of steel fiber | 54.00                      |
| 4    | M₄ 0.6 SF| Mix 4 for 0.6% of steel fiber | 60.75                      |
| 5    | M₅ 0.8 SF| Mix 5 for 0.8% of steel fiber | 68.50                      |

The triple blended Self-Compacting Concrete (with mineral admixtures and no fibers) is noted as 32,670MPa as its Young's Modulus value, which is 3.5% more than the standard Young’s modulus value for M40 grade of normal concrete(5000 √fₜₚ), which is due to the presence of admixtures in the concrete. As observed from the experimental results, with increase in the steel fiber percentages from 0.2 to 0.8, the elastic constant for E-Young’s modulus increased where as the Poisson's ratio decreased. There is an increase of nearly 34% for 0.8% of fibers compared to 0% fiber. The reason for increase in the Young’s modulus value is due to the presence of steel fiber, which makes denser compare to SCC without fiber. The strains are less in SFSCC due to locking of the fiber with ingredients in it enhancing
the strength. But in case of Poisson’s ratio, lateral strain is less for SFSCC compared to SCC without fiber. Hence, Poisson’s ratio is reduced with the increase in percentage of steel fiber (nearly 30%). The details of the experimental results shown in Table 5, and its variations shown in Fig 4 and 5.

Table 5. The Elastic Constants for the Steel fiber Self-Compacting Concrete (SFSCC) with triple blending. (20% FA and 10% CSF)- Aspect Ratio of steel fiber is 40.

| S.No | Mix   | E-Young’s modulus in MPa | ν - Poisson’s ratio |
|------|-------|--------------------------|-------------------|
| 1    | M₁₀.₀ SF | 32,670                   | 0.152             |
| 2    | M₂₀.₂ SF | 35,500                   | 0.133             |
| 3    | M₃₀.₄ SF | 37,200                   | 0.130             |
| 4    | M₄₀.₆ SF | 42,000                   | 0.117             |
| 5    | M₅₀.₈ SF | 44,900                   | 0.107             |

Fig 3. The compressive strength variation for TBSFSCC

Fig 4. The Young’s Modulus (E) variation in TBSFSCC with constant aspect ratio.
5.2 Correlation with mathematical models.

1) The mathematical model for the Young’s Modulus for the above SFTBSCC with aspect ratio of 40 is given by

\[ E = 30014 \, e^{0.0804 \, p} \]

E- Young’s Modulus in MPa;

p- percentage of steel content.

2) The mathematical model for the Poisson’s Ratio (\(\nu\)) for the above TBSFSCC with aspect ratio of 40 is given by

\[ \nu = -0.0085 \, p + 0.152 \]

\(\nu\) - Poisson’s ratio;

p- percentage of steel content.

6. Conclusions

The following conclusions were arrived at based on the experimentation done,

1. Optimum dosages are of the admixtures for getting better rheological characteristics of the Self-Compacting Concrete are 20% flyash, and 10% Condensed silica fume, due to calcium-silicate-hydrate(C-S-H) formation in the cement mortar.

2. The maximum percentage of steel fiber content in the SCC mix is limited to 0.8% of volume of the concrete. Beyond this percentage, the flow properties are interfered. The aspect ratio of the steel fiber is limited to 40 to facilitate smooth flow of S.C.C.

3. The Compressive strength of the basic SCC mix (without fiber) is increased by nearly 50% with 0.8% fiber content in the mix.

4. The Young’s Modulus of the TBSCC is 3.5% more than the Normal concrete of same grade, due to the affect of the mineral admixtures.

5. The steel fiber percentage increased from 0.0% to 0.8%, the Young’s Modulus [E] is enhanced by 34% compared to same SCC without steel fiber content due to more stiffness of the concrete.
6. The Poisson’s ratio has decreased by 30% for the optimum fiber content due to the increase in steel fiber content of SCC due to its more stiff behaviour.

7. The mathematical models for this concrete has showed good correlation to the elastic properties.

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