FRESH AND HARDENED STATE PROPERTIES OF TERNARY BLEND SELF COMPACTING CONCRETE USING SILICA FUME AND GROUND GRANULATED BLAST FURNACE SLAG

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In the present research, ternary blended Self Compacting Concrete (SCC) was prepared to evaluate the performance by replacing cement with the Silica Fume (SF) from 5% to 20% and ground granulated blast furnace slag (GGBS) from 20% to 60% in the total percentage of the weight of the cement. An attempt was made to study the performance of fresh concrete by slump flow test, T-500, U-box and L-box test, and the hardened properties of concrete by cube compression and cylinder split tensile test. The superplasticizer and stabilizer were added in optimum dosages to prevent the segregation and bleeding of fresh concrete. More powder content, say 60% GGBS and varying SF from 5% to 20%, as cement replacement for ternary blended SCC has obtained better fresh property behaviour. But lower content of GGBS, say 20% blended with SF 10% and SF 15% obtained higher split tensile and compressive strength, respectively.

Keywords: *Self Compacting Concrete, Silica Fume, GGBS, EFNARC, Compressive strength*

1. Introduction

Self Compacting Concrete was emerged out into the construction industry when there was an unskilled labour problem in Japan. The casting of the structural element using SCC does not require any vibrator for compaction and could be pumped to an elevation of about 600 m for concreting. Three methods did the production of SCC, powder type, which contains more fines (size < 0.125 mm), Viscosity Modifying Agent (VMA) type, which contains viscous fluid that prevents bleeding and segregation and a combination of both. The significant type of SCC application was based on structure type, construction sites, locally available materials, and constraint over the concrete plant production process. Usually, for small scale products, combination type SCC was prepared in the laboratory because the mineral and chemical admixtures were effectively employed. SCC as a special concrete has advantages like less construction time, pump ability, noise control, compact on its own in congested type reinforcement, formwork subjected to less fatigue and can be re-used in many scaffolding forms. The primary application of SCC was in bridges, box culverts, concrete-filled tubes and columns (CFT's), tunnels, water tanks, basements, rafts and trenches. In particular, SCC had wide application in the manufacturing of prefabricated and precast concrete structures.

Hassan and Adnan [1] researched SCC using a high volume of supplementary cementitious materials as cement replacement. In SCC, the silica fume content within 10% increases the SCC compressive strength in ternary and quaternary blends. Watcharaponget al.[2] investigated the compressive strength by employing high-level fly ash and silica fume as a ternary blend. It was found that high strength SCC was obtained since the value of compressive strength exceeds 60 MPa. Ramanathan et al. [3] studied the SCC behaviour by employing different mineral admixtures. They obtained that limiting water/powder ratio= 0.35 by weight because if this value increases or decrease, it would cause segregation and blocking tendency in SCC mixes. Vejmelkovaet al.[4] made research on SCC using metakaolin and slag. It was found that metakaolin obtained early age strength than slag. But at 28 days, both the strength was similar. Kabay et al. [5] employed pumice powder for SCC by conducting fresh and mechanical properties. In the slump test, the flow value decreases due to the addition of pumice powder. The obtained compressive strength was less at early ages and increased strength gain at later ages. Jalal et al. [6] studied the SCC behaviour using Class F Fly Ash, Nano silica and Silica Fume. In fresh property tests, namely, slump flow, the values were in the range of 640– 910 mm and its flow time was less than 2.4 seconds. The less discharging time of 2.5 seconds obtained (for emptying funnel) for Fly Ash 10% and Fly Ash 15%. But for Silica Fume, 10% + Nano Silica 2% mixture had the maximum flow time of 12 seconds. Khalid et al. [7] investigated SCC using cement kiln dust which decreased the slump flow value in fresh test and at 30% cement replacement obtained acceptable strength.

Nuruddin et al. [8] researched SCC using incinerated rice husk ash, silica fume and fly ash as ductile self-compacting concrete mixes. The workability values were within the acceptable range for all mixes. It was noticed that low initial strength gained and improved later due to SiO_2 content in

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the mixes. Ruza et al. [9] made a study on real-time applications of SCC [9]. Anjali et al. [10] made an experimental study on metakaolin based SCC to obtain flow and compressive strength characteristics. Vivek and Dhinakaran [11] made a research on SCC using GGBS, SF and MK to study the fresh and mechanical properties. Vivek and Dhinakaran [12] performed research on durability characteristics of SCC by conducting the tests namely, water absorption, sorptivity, porosity and resistance against acid and sulphate attack. Prasanna Venkatesh et al. [13] researched SCC mortar cubes using electric oven curing methods to study the early age strength attainment characteristics. Vivek et al. [14] performed research on flexural behaviour on ternary SCC beams using SF, MK and GGBS. The authors reported the test on fresh properties conducted and the flexural strength was higher than the conventional concrete of the same grade. Lakman Prabu et al. [15] had performed the comparative analysis of load-deflection behaviour of ternary blended SCC beams using the four-point loading method of testing. The experimental results were compared with ANSYS software and a similar behaviour was inferred. Lakman Prabu et al.[16] studied the behaviour of mechanical properties of SCC using steel fibre and stainless steel scrap in hybrid combinations. It was inferred that fresh properties got reduced and mechanical properties had an increasing trend by the addition of fibres in SCC. Vivek and Prablini [17] researched SCC using natural fibre namely coconut fibre with and without treatments. It was reported that treated coconut fibres had shown improved mechanical properties while the reduction in flow properties. Heba [18] researched binary and ternary blended SCC using fly ash (FA) and silica fume (SF) as a partial cement replacement to investigate the rheological and mechanical properties. The author concluded that partial cement replacement by 10% FA and 10% SF had shown improved mechanical properties. Mostafa et al. [19] performed research on binary and ternary blended SCC using silica fume, nano-silica, and class F fly ash as partial cement replacement. In the fresh state, the viscous property was observed in the mix containing SF and nano-silica in both binary and ternary forms. The authors concluded that mineral admixtures in combinations have developed high-performance SCC. Celine et al. [20] researched SCC using MK in a slurry form combined with LSP to investigate the strength and durability aspects. The authors concluded that SCC in the ternary blended form: cement+ MK+ limestone filler had influenced the pore size refinement, by the addition of two particles and the pozzolanic activity. Nehdi et al. [21] researched SCC using a high-volume replacement with binary, ternary, and quaternary cement using SF, RHA, class F fly ash, and slag to investigate the rheological, mechanical and durability properties. The authors reported that SCC in quaternary and ternary blended forms using high-volume cement replacement has shown improved rheology, mechanical and durability properties namely, low sulphate attack and very low chloride ion penetration depth. Bhanja and Sengupta [22] have performed research on the tensile strength of HPC using SF from 0% to 30% as cement replacement. Here the water-binder ratio used from 0.26 to 0.42. The tests performed at hardened state include, compressive, flexural and split tensile strength at early ages. The authors have reported that the optimum replacement of SF from 5% to 10% and 15% to 25% has improved the tensile and the flexural strength at early ages. By regression analysis techniques, authors have developed the relationship between different strength parameters and estimated statistical parameters. Dinakar et al. [23] have performed SCC mix design by cement replacement with GGBS from 20% to 80%. It was inferred that SCC mixes by cement replacement levels with high volume GGBS has reduced strength and low volume has yielded high strength. Salem [24] has researched SF based SCC from 3% to 9% as cement replacement to investigate the rheological and strength properties. The author concluded that in SCC mix 6% SF could be limited by the mass of the powder content.

The novelty of the present research paper is aimed to produce ternary SCC using SF and GGBS as a partial substitute for cement. The partial substitution of cement by mineral admixtures having pozzolanic nature could reduce CO_2 emission in the concrete batching plant since the volumetric batching was carried out. This would lead to the sustainable development of the environment while producing SCC in the batching plant.

It was inferred that from the available literature, many research works were carried out on SCC using binary blended forms. Hence, minimal research was carried out on ternary blended SCC, especially SF and GGBS combinations. In this research paper, when cement was replaced by GGBS kept constant namely 20%, 40% and 60% has been blended with silica fume varies from 5% to 20%. The cement replacement levels in the ternary SF & GGBS blended combinations range from a minimum of 25% to a maximum of 80%. Thus sincere effort was made in this research paper to study SCC by high volume replacement levels. The basic material properties tests were conducted. The experimental investigations on the prepared ternary blended SCC mixes were tested on fresh state and hardened state properties.

2. Experimental investigations

2.1. Materials used

For the experimental programme, the constituent of materials used in SCC are shown in Table 1. ASTM Type I cement was used in the

Table 1

Materials required in kg per m^3 of concrete

Materials (kg/m^3)	**CVC**	**GGBS**			**Silica fume**			
		20%	40%	60%	5%	10%	15%	20%
Cement	600	-	-	-	-	-	-	
GGBS	-	120	240	360	-	-	-	
Silica fume	-	-	-	-	30	60	90	120
Water	240	240	240	240	240	240	240	240
Water/Powder ratio	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Fine aggregate	412	834	834	834	834	834	834	834
Coarse aggregate	1113	686	686	686	686	686	686	686
Super plasticizer (1.5% wt. of cement)	-	9	9	9	9	9	9	9
VMA (0.15% wt. of cement)	-	0.9	0.9	0.9	0.9	0.9	0.9	0.9

Table 2

Properties of materials

Fine aggregate	Fineness modulus: 2.6
Coarse aggregate	Bulk density:1288 kg/m^3
Cement(ASTM Type 1)	Initial setting time:29 minutes
	Std. consistency:29%
	Specific gravity:2.91 (no unit)
Silica fume (SF)	Specific gravity :2.25 (no unit)
GGBS	Specific gravity : 3.40 (no unit)

in the present work. River sand and crushed granite stones were used as fine aggregate and coarse aggregate, respectively. The specific gravity of fine aggregate and coarse aggregate was 2.60 and 2.65, respectively. The nominal maximum size of coarse aggregate used was 12.5 mm downsize.The superplasticizer, namely naphthalene formaldehyde sulphonate chemical-based, namely Conplast SP430 G8, was employed. Aura mix V100 was used as a viscosity modifying admixture (VMA) to reduce segregation and bleeding. The combination type of ternary blended SCC was prepared by the cement, aggregates, mineral and chemical admixtures with a water to powder ratio of 0.4 (arrived from laboratory trials). The proportions of fine aggregate and coarse aggregate were adjusted by keeping a constant water-powder ratio along with the optimum dosages of SP and VMA to obtain the flowability, passing and filling ability of SCC since it was mandatory for SCC mixes.

2.2. Concrete mix proportions

The conventional normal strength concrete mix was prepared according to the ACI 211[25] code of practice.

The mix design prepared for SCC was adjusted according to fresh state properties like flow, passing and filling characteristics by fresh property tests. Initially, the fine aggregate and coarse aggregate were mixed with equivalent proportions by adding 50% on cement proportions, i.e. (1:1.5:1.5). SF and GGBS replaced cement in combinations by weight. The proportions of fine aggregate and coarse aggregate were adjusted to obtain the required flow properties laid by EFNARC guidelines. Final normal strength SCC mix proportion was obtained with water to powder ratio of 0.4. Since fresh state trials attained it in the laboratory by varying in the range from 0.35 to 0.40 in parallel, superplasticizer and stabilizer dosages were also added to obtain a homogeneous conglomerated cohesive SCC mix with the flow passing, filling, segregation resistance, etc.

Table 2 shows the material properties of the constituents used in the preparation of SCC.

Here cement was replaced by GGBS 20%, 40 %, and 60%, but SF was substituted from 5% to 20% (with an increment of 5%), respectively. Therefore 12 SCC ternary blended mixes were cast with one conventional vibrated concrete as a control mix. According to ASTM standards, the fresh property tests were carried out for each SCC mixes per EFNARC guidelines as shown in Table 3 and hardened state by testing cube and cylindrical specimens as shown in Fig.3.

Fig. 1 shows the fresh properties tests performed in the laboratory as per EFNARC guidelines.

3. Fresh properties of SCC

European Federation of National Associations Representing for Concrete (EFNARC) guidelines [26 & 27] were adopted especially for studying the behaviour of SCC. The parameters include the selection of suitable pozzolanic materials, mix design preparation and conducting the fresh state properties test, namely slump flow, T500 time, V-funnel, L-box and U-box tests as per the specifications laid by EFNARC. EFNARC also laid the specifications based on the range of values obtained for each type of fresh property tests. EFNARC had classified the fresh state requirements into flowability through slump-flow SF 3 classes, viscosity VS or VF 2 classes, passing ability PA 2 classes and segregation resistance SR 2 classes. In the present paper, all fresh property tests were conducted by the

Table 3

Acceptance criteria for SCC (as per EFNARC 2002 & 2005 guidelines)

Method	**Unit**	**Typical range of values**	
		Minimum	**Maximum**
Slump Flow Test	mm	650	800
T-500 Test	s	2	5
V-Funnel Test	s	6	12
L-Box Test	H_2/H_1 ratio	0.8	1.0
U-Box test	H_2-H_1 (mm)	0	30

Fig. 1 a Slump Flow Test.

Fig. 1b V-Funnel Test.

Fig. 1c L- Box Test.

Fig. 1d U-Box Test.

Fig. 1 - SCC fresh properties tests.

Fig. 2 - Casting of Cubes and Cylindrical specimens in the wooden mould.

Fig. 3 - Testing of Cubes and Cylindrical specimens in DCTM.

number of test trials in the laboratory until the obtained values were satisfied by EFNARC guidelines as shown in Table 3 and Fig.1 (Fig.1a to Fig.1d). The repeatability and reproducibility of the tests were conducted to meet the given range of values.

4. Tests on hardened SCC properties

4.1. Casting and curing of test specimens

After conducting the test on fresh state behaviour of SCC, it was poured on the wooden mould of inner dimensions 100 mm x 100 mm x 100 mm using a trowel and ensuring that it should be leakproof at corners. Otherwise, SCC will flow out and escape away from the mould. The cube specimen was de-moulded after 24 hours and then immersed in the water tank for curing. Similarly, the cylinder of internal dimensions having 100 mm diameter and 200 mm height was cast and cured before the age of testing as shown in Fig.2.

4.2. Compressive strength on concrete cubes

After curing for 28 days, the concrete cube specimens were kept in the atmosphere for 2 hours and placed on the automatic digital compression testing machine. Once the machine is switched on, the uniaxial load was applied gradually to the cube specimens until it fractures. Compressive strength was calculated by dividing the Peak load by the cross-sectional area of the cube specimens as shown in Fig. 3.

4.3. Split tensile test on cylinders

The split tensile test was conducted as per ASTM C496 [28]. A concrete cylinder was placed by keeping its axis in the horizontal direction, and the load was applied through the strip until failure occurs as shown in Fig.3. Then, tensile stress was calculated by the equation $2P/ \pi DL$.Where P = the axial compressive load on the cylinder, L = length of the cylinder and D = diameter.

5. Results and discussion

From the above experimental programme, ternary blended SCC was obtained by replacing cement with mineral and chemical admixtures, namely, ground granulated blast furnace slag (GGBS) (20%, 40% and 60%) and silica fume (SF) (5%, 10%, 15% and 20%), along with SP and VMA in optimum dosages by the percentage of the weight of cement. The fresh property and hardened property test results were discussed below.

5.1. Effect of SF and GGBS in Fresh properties

The SCC fresh properties test, namely, slump flow & T500, L-box, V-funnel and U-box test, were conducted with water to powder ratio of 0.4 and the superplasticizer & stabilizer's dosages were used 1.5% 0.15% by weight of cement.

From Table 4, the fresh property results obtained by keeping 20% GGBS constant and mixed with silica fume varying from 5% to 20% (increment of 5%) as total cement replacement. In the slump flow & T500 tests, the values were well within the range laid by EFNARC guidelines i.e. 650 to 800 mm. There was a slight increase and decrease in trend in the L-box test due to 10% SF and 20% SF when blended with 20% GGBS. The reason could be the presence of SF in higher percentages has restricted the flow properties. The difference in height between the two limbs H2-H1 was observed in the U-box test. The mix consisting

Table 4

Test on fresh properties- Cement+ GGBS 20% with SF 5% to 20%

Fresh property tests on SCC	**Mix 1: C+ 5 SF+ GGBS20**	**Mix 2: C+10SF +GGBS20**	**Mix 3: C+15SF +GGBS20**	**Mix 4: C+ 20SF +GGBS20**	**As per EFNARC**
Slump flow (mm)	670	652	680	705	650 – 800
T 500 (s)	2	2.5	3	4	2 – 5
L – box (H_2/H_1)	0.93	0.8	0.85	1.1	0.8 – 1.0
V – Funnel (s)	9	12	14	10	8 – 12
U – box ($H_2 – H_1$) (mm)	26	28	30	31	0 – 30

Table 5

Test on fresh properties-Cement + GGBS 20% with SF 5% to 20%

Fresh property tests on SCC	**Mix 5: C+ 5SF + GGBS40**	**Mix 6: C+ 10SF + GGBS40**	**Mix 7: C+ 15 SF + GGBS40**	**Mix 8: C+20SF+ GGBS40**	**As per EFNARC**
Slump flow (mm)	654	685	722	750	650 – 800
T 500 (s)	2.5	3	4	3.5	2 – 5
L – box (H_2/H_1)	0.8	0.9	0.8	0.85	0.8 – 1.0
V – Funnel (s)	10	11.5	9	12	8 – 12
U – box ($H_2 – H_1$) (mm)	28	33	26	44	0 – 30

Table 6

Test on fresh properties-Cement+GGBS 60% with SF 5% to 20%

Fresh property tests on SCC	**Mix 9: C+ 5SF + GGBS60**	**Mix 10: C+ 10SF+ GGBS60**	**Mix 11: C+15SF+GGBS60**	**Mix 12: C+20SF+ GGBS60**	**As per EFNARC**
Slump flow (mm)	665	681	756	738	650 – 800
T 500 (s)	2.8	3.4	4.3	3.2	2 – 5
L – box (H_2/H_1)	0.82	0.86	0.99	0.85	0.8 – 1.0
V – Funnel (s)	10	12	9	12	8 – 12
U – box ($H_2 – H_1$) (mm)	26	28	21	24	0 – 30

of SF20% and 20% GGBS had a slight increase in height difference between the two limbs. A time lag of 2 seconds in the V-funnel test in filling ability of SCC was observed in the mix containing 20% GGBS + 15%SF. It was mainly because of the rapid initial setting due to the addition of more fines on the SCC mix.

From Table 5, the fresh property results obtained by replacing cement by maintaining constant 40%GGBS and mixing with SF from 5% to 20%. The maximum cement replacement by this ternary SCC combination was up to 60%. The fresh property results namely, slump flow &T500, V-funnel test results were well within the permissible EFNARC range. But in L-box and U-box test, there was a blockage of concrete flow was analogous to that of viscous fluid flow. Since the specific gravity of three distinct pozzolanic materials could the reason for the blockage effect.

From Table 6, the fresh property was prepared by keeping 60% GGBS, and SF was added with an increment of 5% up to 20%, respectively. Hence total cement replacement by SF and GGBS combination increases up to 80%. All fresh property tests were well within the permissible limit because of the addition of more powder content. Hence, the substitution of more powder content had improved the fresh or rheological properties.

The conducted test results on fresh properties of 12 ternary SCC mixes were classified according to EFNARC guidelines. The slump flow values obtained has a range from 660 mm to 750 mm belonged to the SF2 category. It could be feasible for normal applications like walls and columns. From the V-funnel test results, the time values were in the range between 9 and 25 s belonged to the VF2 category. Similarly, the VS2 category was observed for the T500 test since the time values were more than 2 s. From the L-box test, the passing ability class belonged to PA2 since the height ratios were more than 0.80.

5.2. Results on Hardened state Properties

5.2.1 Effect of SF and GGBS on SCC Compressive strength

The compressive strength of 12 SCC mixes and one conventional concrete are shown in Fig.4.

The comparison of strength between the ternary SCC mixes in respect to conventional concrete has been discussed by the percentages of variations. The highest compressive strength was obtained for the ternary SCC mix consisting of cement replaced by 15% SF and 20% GGBS. The conventional concrete had shown a decrease in compressive strength of about 95.33% when compared with ternary SCC mix containing cement replaced by 15% SF and 20% GGBS. This was due to the presence of optimum percentages of pozzolanic materials namely SF and GGBS in the SCC mix.

The ternary SCC mixes containing cement replacement with constant GGBS 20% with the range of SF from 5% to 20% the compressive strength is shown in Fig.4. It was inferred that cement replacement by 20% SF and 20% GGBS had shown a strength reduction of about 8% concerning the conventional concrete. The reason could be the low early strength gain because of the higher replacement of mineral admixtures by 40%. The obtained low strength could be gained at later ages due to the pozzolanic reaction exhibited

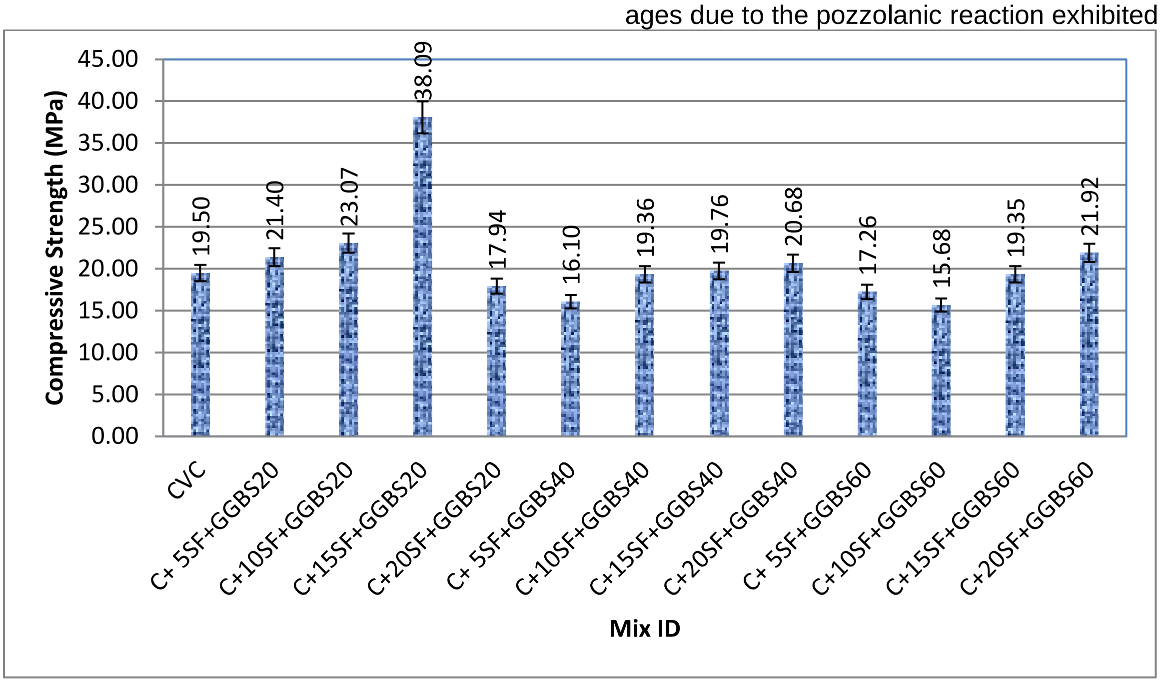

Fig. 4 - Cube compressive strength at 28 days.

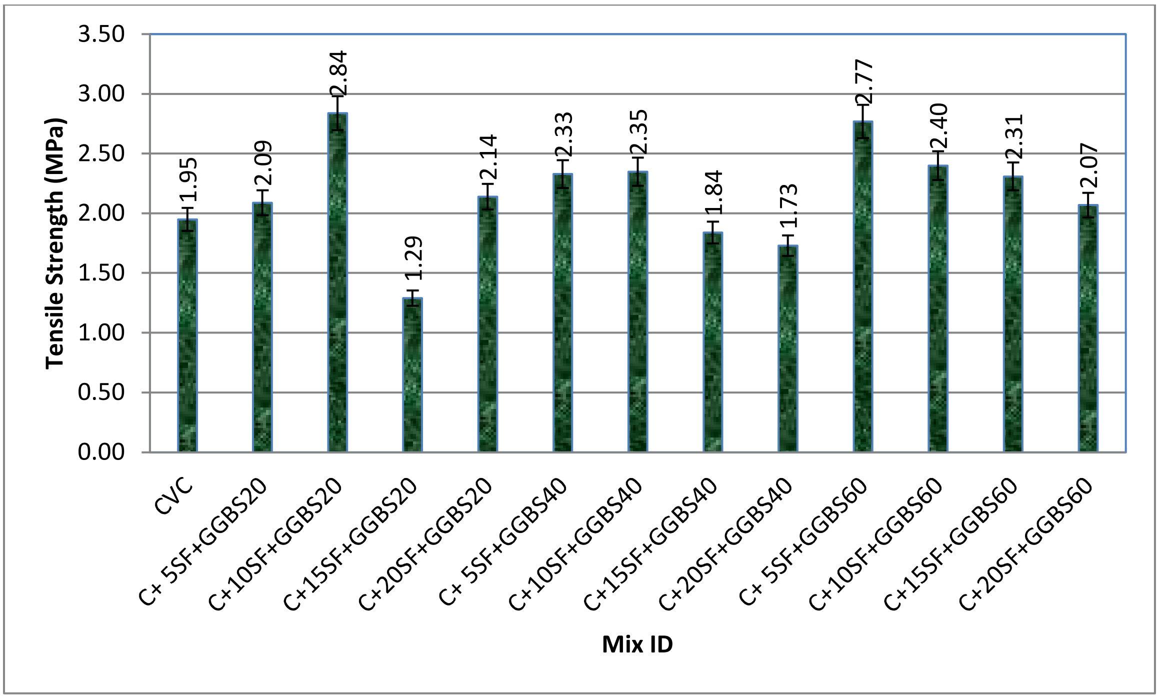

Fig. 5 Cylinder split tensile strength at 28 days.

between cement and the presence of chemical compounds of mineral admixtures. Since in the present research, the strength was tested at 28 days.

For ternary SCC mixes compressive strength consisting of cement replacement with constant GGBS 40% along with SF range from 5% to 20% is shown in Fig.4. When the cement was replaced with constant GGBS 40% along with SF 5% had shown strength reduction of about 17.44% in respect to conventional concrete.

The high volume of cement replacements was carried out by replacing cement with 60% GGBS along with SF from 5% to 20%. The total cement replacement ranges from 65% to 80% with an increment of 5%. As we increase the percentage of replacement with a 5% increment, the strength has increased by about 12.41% in respect to conventional concrete. The reason could be the higher presence of SF and GGBS in the SCC mix lead to strength gain at early ages. The results obtained were in agreement with the reported results of Dinakar et al. [23]

Hence among ternary SF and GGBS based SCC mixes from 25% to 80%, when GGBS content added 40% and 60% kept constant along with SF ranging from 5%, 10%, 15%, and 20% in SCC, had shown the decrease in the compressive strength values. Whereas GGBS 20% with the blend of SF from 5% to 20% had shown better performance among all ternary SCC mixes and conventional concrete mix. The reason was due to the addition of more fines or powder content in the SCC mix had improved the rheology of SCC, but it drastically decreased the compressive strength.

5.2.2 Effect of SF and GGBS on SCC tensile strength

The compressive strength is an important mechanical property of concrete materials. Similarly, tensile strength also an equally important type of mechanical property. The tensile strength was en route to the study on flexural behaviour of beams, slabs, prisms, etc. SCC ternary mixes tensile strength results are shown in Fig. 5.

Bhanja and Sengupta [22] had researched the tensile properties in concrete. It was reported that compressive strength values are directly proportional to the tensile strength values in lesser magnitudes. In the present research, the ratios between compressive strength to the tensile strength of the SCC mix ranges from 6.23 to 29.53.

Among all SCC ternary blended mixes, the mix containing partial cement replacement by 10% SF and 20% GGBS had the highest tensile strength which was about 45.64% higher than the conventional concrete. The obtained strength result was in agreement with the results reported by Hassan and Adnan [1] and Jalal et al.[6]. The ternary SCC mixes performed better in compressive strength has shown a descending trend in the tensile strength test was inferred from the test results. These contradictory results were due to the size and shape effect of the cube and cylinder specimens when tested. The effect of lateral restraint also had a significant effect on the tested specimens. The self-compactibility also influenced the test results values when pouring SCC on the different types of moulds and the drop height also.

When cement replaced by GGBS 40% had kept constant with SF from 5% to 20%, the tensile strength of the mix containing 10% SF and 40% GGBS has shown an increase in strength of about 20.51% in respect to conventional concrete. When the cement was replaced by 60% GGBS with 5% SF has shown a 42.05% increase in tensile strength when compared to conventional concrete.

6.Conclusions

From the experimental investigations carried out on the ternary blend of SCC mixes, the following conclusions were obtained.

- The basic material properties were tested for the constituents of concrete and adopted when the stipulated range has been met.
- The mix proportions were obtained by the number of slump flow test trials until the attainment of EFNARC satisfactory limits.
- 12 SCC ternary mixes were subjected to slump flow, T500, V-funnel, L-box and U-box tests. Due to its more viscous nature, some of the results of mixes having low powder content namely 20% and 40% constant GGBS blended with SF from 5% to 20% fell at the minimum range of L-box and U-box values.
- In compressive strength, the ternary SCC mix containing cement replacement by 15% SF and 20% GGBS had shown the highest strength concerning to ternary SCC group of mixes and conventional vibrated concrete mix.
- In tensile strength, the ternary SCC mix containing cement replacement by 10% SF and 20% GGBS had shown the highest strength concerning to ternary SCC group of mixes and conventional vibrated concrete mix.
- It was suggested that the percentage of cement replacement levels would increase flow properties whereas the reduction in mechanical properties took place.
- The SCC ternary mixes flowability, passing ability and filling ability was obtained without bleeding and segregation with the optimum dosages of SP (1.5%) and VMA (0.15%) along with the constant water to powder ratio of 0.40.

Hence ternary blend SCC mixes could be employed at an optimum level of powder content as cement replacement of 35% to gain more strength.

REFERENCES

[1] Hassan, E.C., Adnan.S, Properties of self-consolidating concrete made with high volumes of supplementary cementitious materials, J Mater Civ Eng, 2013, **25**,1579.

[2] Watcharapong, W., Pailyn,T., Athipong, N., Arnon,C., Compressive strength and chloride resistance of self compacting concrete containing high level fly ash and silica fume, Mater Des, 2014, **64**,261.

[3] Ramanathan, P., Baskar, I., Muthupriya, P., Venkatasubramani, R., Performance of self-compacting concrete containing different mineral admixtures, KSCE J Civ Eng, 2013, **17**,465.

[4] Vejmelkova, A.E., Keppert, A.M., Grzeszczyk, S.B., Skalin, B.B., Properties of self-compacting concrete mixtures containing metakaolin and blast furnace slag, Constr Build Mater, 2011, **25**,1325.

[5] Kabay, N., Mansur, T., Ahmet B.K., Didem, O., Properties of concrete with pumice powder and fly ash as cement replacement materials, Constr Build Mater, 2015, **85**,1.

[6] Jalal, M., Alireza, P., Omid, F.H., Davoud, J., Comparative study on effects of class F fly ash, nano silica and silica fume on properties of high performance self compacting concrete, Constr Build Mater, 2015, **94**,90.

[7] Khalid, B.N., Zaher, S.M., Using of cement kiln dust as a mineral admixture to produce sustainable self-compacting concrete, IEEE 2014, **74**, 126.

[8] Nuruddin, M.F., Kok, Y.C., Norzaireen, M.A., Workability and compressive strength of ductile self compacting concrete with various cement replacement materials, Constr Build Mater, 2014, **55**, 153.

[9] Ruza, O.B., Self-compacting concrete and its application in contemporary architectural practice, Spatium Int Rev, 2009, **20**,28.

[10] Anjali, D., Vivek, S.S., Dhinakaran, G., Compressive strength of metakaolin based self-compacting concrete, Int J ChemTech Res, 2015, **8**(2), 622.

[11] Vivek, S.S., Dhinakaran, G., Fresh and hardened properties of binary blend high strength self compacting concrete, Eng. Sci. Technol. an Int. J., 2017, **20** (3),1173.

[12] Vivek, S.S., Dhinakaran, G., Durability characteristics of binary blend high strength SCC, Constr Build Mater., 2017, **146**, 1.

[13] Prasanna Venkatesh, G.J., Vivek, S.S., Dhinakaran, G., Study on compressive strength of self compacting mortar cubes under normal & electric oven curing methods, IOP Conf. Ser.: Earth Environ. Sci., 2017, **80**, 012002.

[14] Vivek, S.S., Narayanan R.S., Dhinakaran, G., Comparative study on flexural behaviour of RCC beam and SCC ternary beams with mineral admixtures, Constr Build Mater., 2017, **152**, 57.

[15] Lakman Prabu, P.S., Vivek, S.S., Analytical and Experimental study on load-deflection characteristics of Ternary blend SCC beams, IOP Conf. Ser.: Mater. Sci. Eng., 2020**,** **872**, 012108.

[16] Lakman Prabu, P.S., Rambharath, S., Vivek, S.S., Mechanical behaviour of self compacting concrete with hybrid fibres, IOP Conf. Ser.: Mater. Sci. Eng., 2020, **872**, 012152.

[17] Vivek, S.S., Prabalini, C., Experimental and microstructure study on coconut fibre reinforced self compacting concrete (CFRSCC), Asian J. Civ. Eng., 2021, **22**, 111.

[18] Heba, A.M., Effect of Flyash and Silica fume on compressive strength of SCC under different curing conditions, Ain Shams Eng. J., 2011, **2**, 79.

[19] Mostafa, J., Esmaeel, M., Mohammad, S., Ali, R.P., Mechanical, rheological, durability and microstructuralproperties of high performance self-compacting concrete containing SiO2 micro and nanoparticles, Mater Des, 2012, **34**,389.

[20] Céline, P., Patrick, R., Sylvain, D., Slurry of metakaolin combined with limestone addition for self-compacted concrete. Application for precast industry, CemConcr Compos, 2013, **44**, 50.

[21] Nehdi, M., Pardhanb, M., Koshowski, S., Durability of self-consolidating concrete incorporating high-volume replacement composite cements, CemConcrRes, 2004, **34**, 2103.

[22] Bhanja, S., Sengupta, B., Influence of silica fume on the tensile strength of concrete, CemConcr Res, 2005, **35**, 743.

[23] Dinakar, P., Kali, P.S., Umesh, C.S., 'Design of self-compacting concrete with ground granulated blast furnace slag, Mater Des, 2013, **43**, 161.

[24] Salem, A., Influence of silica fume on the properties of self compacting concrete, World Acad Sci Eng Technol., 2013, **7**, 399.

[25] ACI 211, Standard practice for selecting proportions for normal, heavyweight and mass concrete, 1991, American Concrete Institute, Farmington Hills, MI, USA.

[26] EFNARC. Specification and guidelines for self-compacting concrete. February 2002.

[27] EFNARC. Specification and Guidelines for self-compacting concrete. May 2005.

[28] ASTM C496/C496 M-11, Standard test method for splitting tensile strength of cylindrical concrete specimens, American Society for Testing and Materials; West Conshohocken, PA.

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