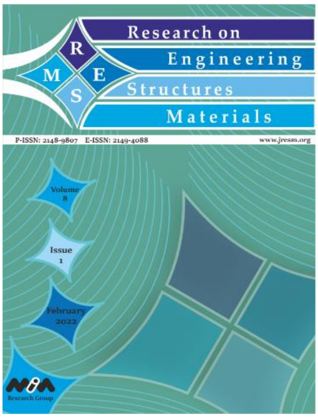
Research on Engineering Structures & Materials
journal homepage: http://www.jresm.org
Research Group



Properties of self-compacting concrete modified with ultrafine slag

Bode Venkata Kavyateja, Panga Narasimha Reddy, C. Arvind Kumar

Online Publication Date: 10 Jan 2022
URL: http://www.jresm.org/archive/resm2021.351st1008.html
DOI: http://dx.doi.org/10.17515/resm2021.351st1008

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article
Kavyateja BV, Reddy PN, Kumar CA. Properties of self-compacting concrete modified with ultrafine slag. *Res. Eng. Struct. Mater.*, 2022; 8(2): 371-384.

Research on Engineering Structures & Materials
journal homepage: http://www.jresm.org
Research Group

Research Article

Properties of self-compacting concrete modified with ultrafine slag

Bode Venkata Kavyateja[1,a], Panga Narasimha Reddy[*2,b], C. Arvind Kumar[3,c]

[1]*Department of Civil Engineering, Jawaharlal Nehru Technological University, Anantapur, Andhra Pradesh, India*
[2]*Department of Civil Engineering, Sri Venkateswara College of Engineering (Autonomous), R V S Nagar, Chittoor, Andhra Pradesh, India*
[3]*Department of Civil Engineering, Matrusri Engineering College, Hyderabad, Telangana, India*

Article Info

Article history:
Received 08 Oct 2021
Revised 23 Nov 2021
Accepted 25 Nov 2021

Keywords:

Self-compacting concrete;
Ultrafine slag;
Hardened properties

Abstract

Self- Compacting concrete (SCC) is a special type of concrete that is able to flow and compact under its own weight and can occupy all the spaces in the form without any vibration effect, and at the same time cohesive enough to be handled without bleeding or segregation. The required compaction properties are achieved by adding super-plasticizers and mineral admixtures such as fly ash, rice husk ash, silica fume, ultrafine slag etc. The utilization of these treated industrial by-products as cement replacement will not only help to achieve an economical SCC mix, but it is envisaged that it may improve the hardened properties, microstructure and consequently the durability of concrete. This provides solution to disposal problems and other environmental pollution issues created by these otherwise waste products. This paper presents the results of an experimental study aimed at producing SCC mixes incorporating constant dosage of fly ash (i.e., 30%) and varying dosage of ultrafine slag (i.e., 0-60%) as supplementary cementing materials. Also, this paper gives the comparison of these SCC mixes in terms of their properties like compressive, young's modulus and flexural strengths. The fresh concrete properties are also included in the study. Addition of constant dosage of fly ash (i.e., 30%) and ultrafine slag (i.e., 30%) showed a significant improvement in fresh and hardened properties of SCC.

1. Introduction

Self-Compacting Concrete (SCC) or Self Consolidating Concrete is the present-day concrete that is being adopted the world over. Self-Compacting Concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcements. The development of Self Compacting Concrete (SCC) is an important achievement in the construction industry for overcoming problems associated with conventional concrete. SCC is the improvised concrete that partly replaces the Ordinary Portland Cement (OPC) with suitable mineral admixtures and filler materials and yet retains the qualities of the conventional cement concrete [1]. SCC originated from Japan in the year 1986 by Professor Okamura of Kochi university of Technology and the prototype was first developed in 1988 in Japan by Professor Ozawa at the University of Tokyo.

SCC is segregation proof, able to flow and fill the remotest areas of the form work, cover all the reinforced sections without any voids or honeycombs and it is good enough to fill areas from considerable heights. Apart from enhanced durability properties of SCC, the homogenous and uniform distribution of constituent's materials of SCC are its pleasing

---

*Corresponding author: aryancivil.130@gmail.com; narasimha_07phd16@nitsri.ac.in
[a]orcid.org/0000-0003-3447-4741; [b]orcid.org/0000-0001-8856-9741; [c]orcid.org/0000-0003-3980-9088;
DOI: http://dx.doi.org/10.17515/resm2021.351st1008

aspects [2]. The high deformability of SCC and the elimination of vibration during compaction offer substantial benefits to the quality of concrete structures and in the construction process. The noise associated with mass concreting in conventional manner is eliminated. In Self Compacting Concrete the costs of vibration for compaction and the additional labour involved are less when compared to the conventional concrete [3]. It also reduces the construction time. Saving in labour cost might offset the increased cost due to chemical admixtures, but the use of freely available mineral admixtures could balance the excess demand of cement which results in cost saving. Thus, the total construction cost can be reduced for large-scale structures. Complicated repair works are possible due to easy handling of the concrete and provides access for automation. The SCC also serves in the precast industry thereby enabling mass concreting [4].

The main disadvantage of SCC is the high cost associated with the use of chemical admixtures such as super plasticizers, viscosity modifying agents and high volumes of cement content [5]. To obtain strength based concrete rich cement is to be adopted which leads to drying shrinkage and cracks are unavoidable. Increase in cement content results in more emission of Carbon dioxide (CO_2) apart from the requirement of skilled labour and the cost behind it. There is no generalized or specific mix design procedure for any grade of SCC. Country wise it would be different and various guidelines are followed for mix design, by trial-and-error method [6]. It is an inherent obstacle to widen the application of SCC and its rapid spread all over the world. The concrete mix design has to be repeated till the target strength of SCC is obtained, which may be an expensive and time-consuming process. To ensure the acceptable workability and mechanical properties, it requires manipulation of several mixture variables. So, the standard mix design procedure is yet to be established [7-10].

To keep the concrete more cohesive and achieve high flow ability, a proper design of Self Compacting Concrete possesses high powder content when compared to the conventional concrete [11]. Use of high volume of cement remarkably increases the cost of the concrete and also it is more vulnerable to drying shrinkage. Hence, it is necessary that SCC has to replace conventional concrete, but it should not be very expensive [12].

One of the alternatives to overcome these drawbacks is to use industrial by-products or waste materials which are finely divided materials added to concrete as partial replacement material in SCC. As these additives replace part of the OPC, the cost of SCC will be reduced. Addition of these materials will increase the workability, strength and durability properties of SCC [13].

Utilizing the waste mineral admixtures and filler materials as the substitute for cement in SCC will fulfil the expectations of providing greater sustainability in the construction industry. In order to reduce the time and cost involved in the design and production of SCC, a data driven solution is to be generated for predicting the mix proportion, flow properties and compressive strength of SCC [14]. The present research work is more focused on arriving the optimum mix proportions and mix design methods for SCC through experimental analytical study.

The choice of the quantity and stage of employing mineral admixtures and filler materials is very important for acquiring the strength and durability of SCC. The abundant availability of fly ash promises its utilization in the production of concrete. It is the most widely used supplementary cementitious material in concrete. It is recognized that the addition of fly ash has a beneficial effect on the rheological properties of cement paste and on the workability of fresh concrete [15].

Alccofine is a new generation, micro fine material of particle size much finer than other hydraulic materials like cement, fly ash, silica etc. being manufactured in India. Alccofine has unique characteristics to enhance 'performance of concrete' in fresh and hardened stages due to its optimized particle size distribution. It can be used as practical substitute for Silica Fume as it has optimum particle size distribution not too coarse, not too finer either per the results obtained by Counto Micro fine products Pvt. Ltd (A joint venture with Ambuja cement ltd and alcon developers). It is manufactured in the controlled conditions with special equipment's to produce optimized particle size distribution which is its unique property.

The need for the present study arises from the requirement to improve the overall utilization of these two mineral admixtures in correct proportions in SCC particularly to structures in the aggressive environment depending upon the requirements. The effect of those mineral admixtures towards the enhancement of the strength and durability of SCC needs to be researched. The significant objectives of this research work is to study the performance of SCC by carrying out experimental investigations on the fresh and hardened characteristics of SCC blended with mineral admixtures such as fly ash and ultrafine slag.

2. Research Significance

Ordinary Portland Concrete is a major component in conventional concrete to attain the strength properties. With the emergence of industrialization, industrial solid waste generation had increased in huge amount and the industries are facing difficulty in dumping and disposal of the solid waste generated. Non-engineered industrial waste disposal impacts the atmosphere, which in turns damages the environment. A lot of research is being performed to identify the ways to utilize the industrial solid waste in the construction industry. From the available research, it can be concluded that the industrial solid waste with pozzolanic nature can be used as a supplementary cementitious material. Efforts are being made to reduce the usage of cement by encouraging the use of industrial waste or by-products as admixtures or as a partial replacement of cement. There is no literature available investigating the effects of inclusion of alccofine along with fly ash in concrete and therefore it encouraged the authors to study the effects on various properties of alccofine concrete with the addition of constant dosage of fly ash. In the current research, an effort has been made to study the effects of alccofine with the addition of fly ash on the mechanical properties of concrete so that their scope to address environmental pollution induced by industrial by-products.

3. Experimental Investigation

3.1. Materials

The materials used in this study to produce the SCC were OPC53 grade cement fit in with the limits specified in IS-12269 [19] with the specific gravity of 3.15. Ultrafine slag is utilized as a mineral admixture, which is procured from Counto Micro fine products Pvt. Ltd. Goa, India, the specific surface area of ultrafine slag is 1200 cm^2/g and the chemical properties of cement and ultrafine slag obtained from the supplier are given in Table 1. Class F fly ash collected from Rayalaseema Thermal power Plant (RTPP), Muddanur, Andhra Pradesh, India and confirming to ASTM C 618. The physical properties and chemical composition of fly ash are represented in Table 2. The Scanning Electron Microscope (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) outputs of OPC 53grade and Ultrafine slag particles are shown in Figures 1 and 2, respectively. Figures 3 and 4 shows the chemical composition of cement and ultrafine slag, respectively. Apart from this Coarse aggregate of size ranges from 10 mm to 12.5 mm with the specific gravity 2.7 and for fine aggregate locally available river sand with the specific gravity of 2.65 and fineness modulus of 2.62 conforming with IS 383: 1970 [xx] is used. To improve the flow properties and to enhance the durability by means of reducing the water, chemical admixtures like BASF-Master Glenium sky 8233 is used conforming to BIS 9103, 1999. Figures 5 and 6 shows the grading of fine and coarse aggregates, respectively.

Table 1. Chemical Properties of OPC and Ultrafine Slag

Chemical composition (%)		
Component	Cement	Ultrafine slag
CaO	66.67	32.20
SiO_2	18.91	35.30
Fe_2O_3	4.94	1.20
Al_2O_3	4.51	21.40
SO_3	2.5	0.13
MgO	0.87	6.20
K_2O	0.43	-
Na_2O	0.12	-

Table 2. Physical Properties and Chemical Composition of Class F Fly ash

Particulars	Class F Fly ash	ASTM C 618 Class F Fly ash
Physical properties		
Fineness (m^2/kg)	360	Min 225
Specific gravity	2.23	-
Chemical composition (%)		
Silica	65.6	Silica + Alumina + Iron oxide
Iron oxide	3.0	>70
Alumina	28.0	
Magnesia	1.0	
Lime	1.0	
Sulphur trioxide	0.2	Max 5.0
Titanium oxide	0.5	
Loss on Ignition	0.29	Max 6.0

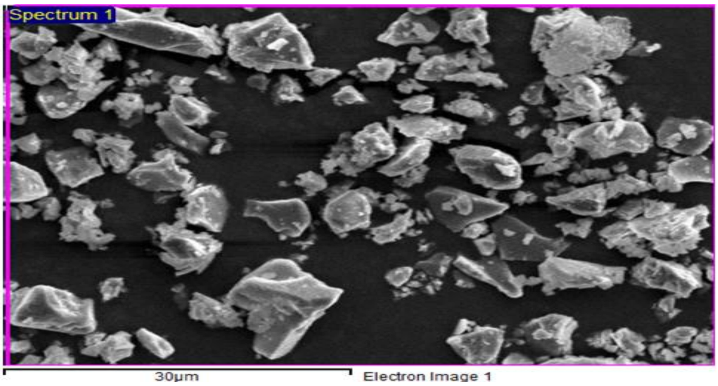


Fig. 1 SEM Image of Ultrafine Slag

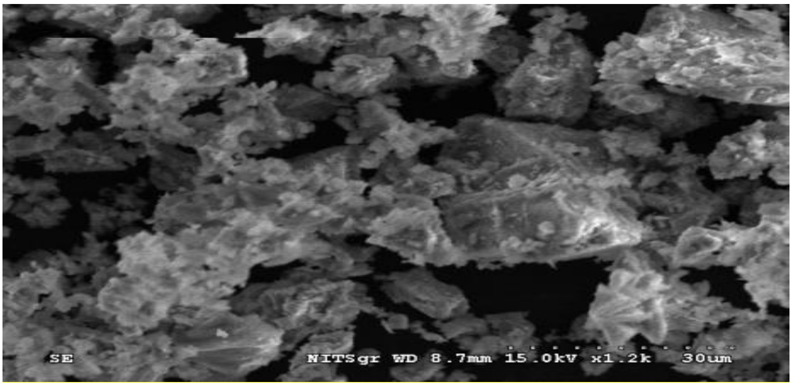
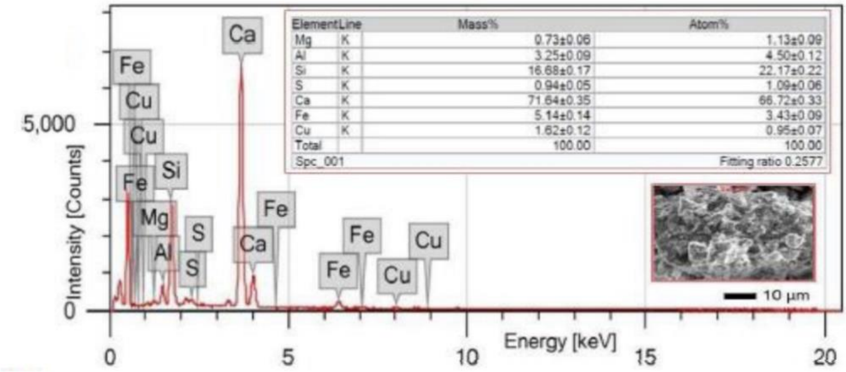
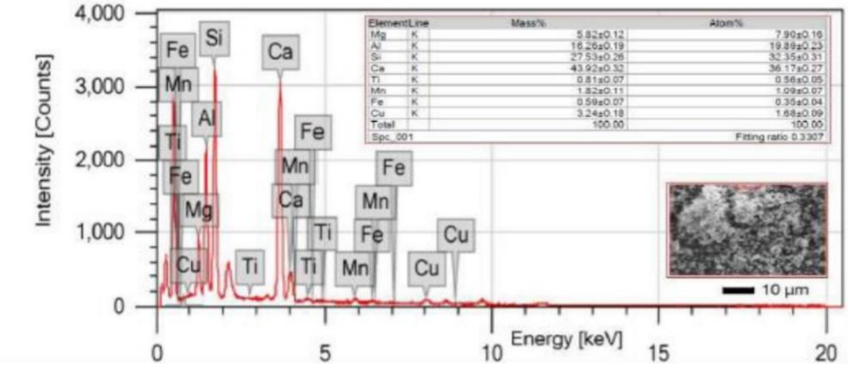


Fig. 2 SEM Image of Ultrafine Slag



ElementLine		Mass%	Atom%
Mg	K	0.73±0.06	1.13±0.09
Al	K	3.25±0.09	4.50±0.12
Si	K	16.68±0.17	22.17±0.22
S	K	0.94±0.05	1.09±0.06
Ca	K	71.64±0.35	66.72±0.33
Fe	K	5.14±0.14	3.43±0.09
Cu	K	1.62±0.12	0.95±0.07
Total		100.00	100.00
Spc_001			Fitting ratio 0.2577

Fig. 3 Chemical Composition Analysis of OPC 53 Grade Cement Energy Dispersive X-Ray Spectroscopy



ElementLine		Mass%	Atom%
Mg	K	5.82±0.12	7.90±0.16
Al	K	16.26±0.19	19.89±0.23
Si	K	27.53±0.26	32.35±0.31
Ca	K	43.92±0.32	36.17±0.27
Ti	K	0.81±0.07	0.56±0.05
Mn	K	1.82±0.11	1.09±0.07
Fe	K	0.59±0.07	0.35±0.04
Cu	K	3.24±0.18	1.68±0.09
Total		100.00	100.00
Spc_001			Fitting ratio 0.3307

Fig. 4 Chemical Composition Analysis of Ultrafine Slag Using Energy Dispersive X-Ray Spectroscopy

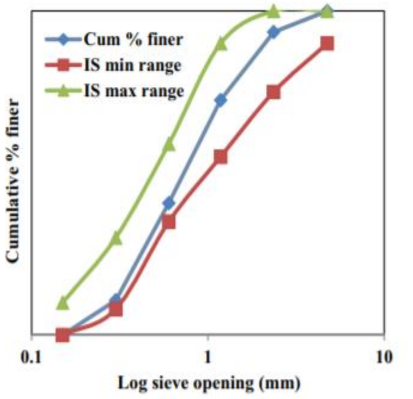


Fig. 5 Grading Curve of Fine Aggregate

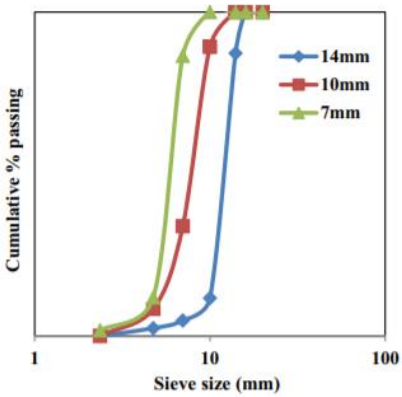


Fig. 6 Grading Curve of Coarse Aggregate

3.2. Mixture Proportions

Tests are conducted on the fresh mix as per EFNARC (2005) guidelines [xx] and reached at a mix proportion of SCC including Fly ash and ultra-fine GGBS (ALCCOFINE) as a replacement material for cement. The control SCC mix contained 325.5 kg/m^3 cement and constant dosage of fly ash of 139.5 kg/m^3 and cement is swapped with 0, 10, 20, 30, 40, 50 and 60% ultrafine slag by weight in the other SCC mixes. To acquire the SCC blend with required flow capacity tests are directed on crisp concrete according to EFNARC (2005) rules. The water to binder proportion is taken as 0.4 and SP measurement is fluctuated 4.65% of weight of binder at each substitution level. The blends that fulfilled the prerequisites of passing capacity, filling capacity and segregation resistance are set in moulds. After 24 hr examples are evacuated and curing is done till the date of testing. Seven SCC mixes replacing cement with ultrafine slag and fly ash are casted according to the obtained mix proportion to study the fresh and mechanical properties of SCC mixes which are shown in the Table 3.

Table 3. Mix Proportions of SCC (kg/m^3)

Mixture	Cement	Fly ash	Ultrafine slag	Fine aggregate	Coarse aggregate	Water	Superplasticizer
SCCA0	325.5	139.5	0	915	836	186	4.65
SCCA10	279	139.5	46.5	915	836	186	4.65
SCCA20	232.5	139.5	93	915	836	186	4.65
SCCA30	186	139.5	139.5	915	836	186	4.65
SCCA40	139.5	139.5	186	915	836	186	4.65
SCCA50	93	139.5	232.5	915	836	186	4.65
SCCA60	46.5	139.5	279	915	836	186	4.65

3.3. Testing of Fresh Concrete

To satisfy the workability of SCC as per European Federation of National Associations Representing for Concrete guidelines (EFNARC, 2005), fresh property tests (Slump flow, T50, V-Funnel and L-Box) are carried out.

3.3.1 Tests on Fresh Concrete

The slump flow test is a quick assessment of the flow ability of Self Compacting Concrete. This test was performed as per EFNARC (2005) guidelines. The apparatus used for the test comprises of slump cone, base plate, trowel, scoop, ruler and a stop watch. The slump cone is a truncated cone with 300 mm height, bottom 200 mm and top 100 mm diameter. The cone is placed over a metal plate of size 1000 × 1000 mm and has marking for placing the cone at the centre. Similarly, the 500 mm diameter circle is marked to measure the time taken for SCC to reach 500 mm diameter. The cone has two side handles on the periphery to lift and place materials on the plate.

About six litres of SCC was prepared for the test. The base plate and the interior of the cone need to be moist. The cone was placed over the base plate at the appropriate marking and the cone was centered on the base plate. Now concrete was filled up inside the cone from the top using the scoop. Once the cone gets filled up, a trowel was used to remove the excess concrete at the top of cone and to level the concrete. Now lifting of the cone and starting of a stop watch are to be simultaneously done.

The concrete will flow circumferentially after lifting the cone. T500mm is the time taken for the concrete to reach the 500 mm diameter circle marked on the base plate. The spread of concrete over the base plate is to be measured in two directions perpendicular to each. The mean value of these measures gives the slump flow diameter in mm. If flow diameter is more than 800 mm, the concrete might segregate and if its flow diameter is less than 650 mm, the concrete may have insufficient flow to pass through highly congested reinforcement. Figure 7 depicts the experimental test set up for slump flow test and the spread flow of concrete.

Fig. 7 Slump Flow Test

3.3.2 V-Funnel Test

V-funnel has a rectangular section of 490 mm x 75 mm at the top and the bottom with a section of 75 mm x 65 mm. The top and the bottom are connected with a hopper like portion for a length of 425 mm, from the top and the hopper connected to the bottom with a stem of 150 mm. Thus, the V-funnel stands to a height of 575 mm from the base and the base has a trap door to empty the contents. About 12 litres of concrete was prepared to conduct the test. The V-Funnel was set on the base and moistened inside with oil. The concrete was filled in the funnel using a scoop. The top of the funnel was levelled with a trowel and then a bucket of twelve litre capacity is placed at the bottom of the funnel.

Simultaneously a stop watch was started as and when the trap door was opened for the concrete to flow from the funnel into the bucket. The concrete was allowed to completely drain from the funnel and the time taken was noted. The dimensions of the equipment and the test set up of V-Funnel is shown in Figure 8.

Fig. 8 V-Funnel Test

3.3.3 L-Box Test

L-box test checks two aspects of SCC, one is the free flowing and another is the obstructed flow into the reinforced bars. The test equipment is a rectangular section configured in the shape of L. The vertical and horizontal sections are separated by a movable gate. At the point of change over from vertical to horizontal section, the reinforcement bars of particular size and spacing are fitted. The diameter of the bars and spacing can be altered depending on the requirement for the test. The vertical section is 600 mm in length with a cross-section of 100 mm x 200 mm and the horizontal section is 150 mm x 200 mm with a length of 800 mm. The vertical section was filled with concrete and then the gate was lifted to allow the concrete to flow into the horizontal section. When the flow was stopped, the height of the concrete H1 and H2 were measured. The ratio of H_2 / H_1 indicates the slope of the concrete at rest. This is an indication of passing ability. Figure 9 shows the equipment dimensions and also the picture taken during testing.

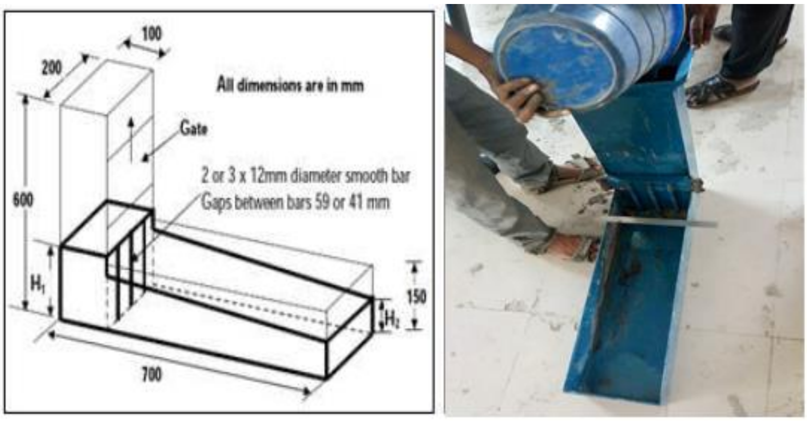


Fig. 9 L-Box Test

3.4. Testing of Hardened Concrete

To carry out necessary mechanical properties like Compressive strength, Modulus of rupture and modulus of elasticity for concrete it is essential to arrive the quantity of material as per [16-19]. The standard measurement of the cube is 150 mm x 150 mm x 150 mm, prism is 100 mm x 100 mm x 500 mm and Cylinder is 150 mm x 300 mm. For these measurements quantity for the specimens are arrived and batched. SCC is prepared in the concrete mixer machine. To maintain the adequate amount of cementitious material, initially fine aggregate and coarse aggregates are mixed in the mixing drum and then cement and ultrafine slag are added. The further required amount of water is added to some extent to achieve a certain degree of saturation for 3 minutes. The remaining water is mixed with superplasticizer and added to the mixer gradually then the entire mix is mixed for 3 to 5 minutes to gain the homogeneity. Specimens were cast without compaction other than its self-weight and demoulded after 24hours in an ideal temperature at 24 ± 2^0C and cured in the curing tank. From the date of casting 28 days compressive strength, modulus of rupture and young's modulus of concrete are calculated. Based on these results optimum mix is selected for beam casting.

4. Results and Discussion

4.1. Properties of Fresh Concrete

SCC's workability is determined by three basic tests: slump flow (flowability), V-funnel (filling ability), and L-box (passing ability). Flowability is initially assessed and measured. Slump flow values vary from 525 to 690 mm, with a T50 estimate of 4 to 8 seconds. Figure 10 shows diagrammatic representations of the slump flow and T50 for all mixes. The mixture begins to flow under its own weight when concrete is freed from the slump in a vertical direction, and the mean value is determined by measuring the flow horizontally in two directions. It was observed that in the ranges of 0% and 30%, the flow value gradually increased; furthermore, higher replacement caused in lower slump flow. Because of the significant lubricating behaviour between the finer particles, better flowability up to 30% replacement of ultrafine slag was achieved. The increase in the proportion of ultrafine slag resulted in a reduction in slump value because the additional finer particles demanded higher water content, resulting in sultry concrete. Effective hydration would be unattainable water shortage, and homogeneity would decline. In general, flow values are divided into three categories, denoted by the letters SF1, SF2, and SF3 in EFNARC. In the current work, the flow values have arrived under two categories SF1 and SF2.

The V-funnel method is used to determine the amount of time that elapses since the bottom shutter has been released and the funnel has been emptied. The suggested value by EFNARC for V-funnel is ≤8 and 9-25 sec. According to the test findings, the entire mixes meet the standards, with VF times ranging from less than 6 seconds for SCCA0 to SCCA30. For concrete to qualify as SCC, Khayat KH suggested a VF time of less than 6 seconds. SCC with VF timing of more than 15 seconds, in particular, would be more coherent and difficult to handle. Furthermore, a larger slag level might result in more viscous concrete, which would prolong the V-funnel duration.

This combined bar chart and line graph illustrates the slump flow values and Time required to reach 50cm diameter flow of SCC mixes SCCA0 to SCCA60. It helps to find the optimum mix using the maximum and minimum flow values and T50 time.

This line graph depicts the L-box ratio and V-funnel timings as ordinate individually with respect to the SCC mix proportion as abscissa. It makes visual understanding about acceptable range of passing ability and filling ability.

The ratio of height at the two extreme ends (h1 and h2) is computed in the L-box test, which indicates the SCC's passing ability. In the L-box test, the coarse aggregate size is usually more dominating. Because the maximum size of coarse aggregates might impair their passing ability, well-graded aggregates that pass through a 20mm sieve and are retained on a 4.75mm sieve are used. The passing ability ratio for all of the mixtures was determined to be in the range of 0.61 to 0.95 in the current scenario. EFNARC recommends an acceptable blocking ratio of ≥0.8. However, for SCC's higher filling capabilities, a ratio larger than 0.6 can be tolerated. There is no blockage during this test because the spacing between the L-box reinforcements is 41mm. The flow limitation, on the other hand, is related to the increased quantity of ultrafine slag replacement (SCCA50 & SCCA60). The graphical representation of V-Funnel timing and L-box ratio is shown in Figure 11.

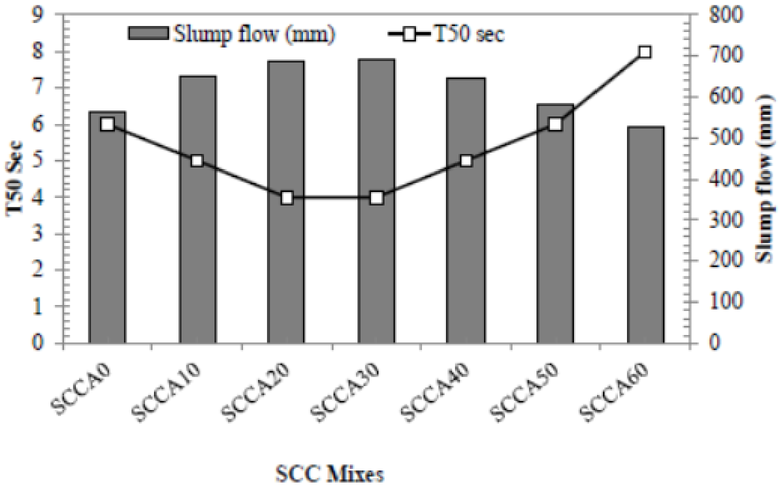


Fig. 10 Slump Flow and T50 Time of SCC Mixtures

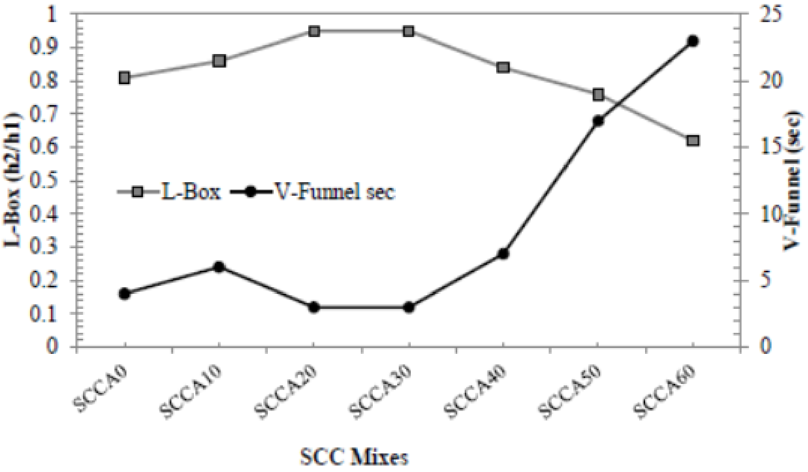


Fig. 11 V-Funnel and L-Box Ratio of SCC Mixtures

4.2. Properties of Hardened Concrete

Table 3 shows the mechanical characteristics of conventional and ultrafine slag-based mixes. Three specimens are examined for each mix to determine the average value. Test results of the mechanical properties showed varying strength at different amounts of ultrafine slag substitution. The attained compressive strength of 28 days varies from 30.69 N/mm^2 to 48.13 N/mm^2. The mix SCCA30 has an optimal compressive strength of 48.13 N/mm^2, which is 56% greater than

conventional SCC. The compressive strength values of all the mixes are shown in Figure 12. When comparing Ultrafine slag-based SCC to conventional SCC, it can be seen that Ultrafine slag-based SCC has a higher strength. Ultrafine slag was utilized as an SCM in normal concrete and SCC with a varied combination of admixtures in various studies, and the results were optimal with 10-15% replacement. However, in this study, the best results were obtained when ultrafine slag was replaced by 30%. This is due to the binary blend and moderate cement usage (465 kg/m3). One cause for the increase in compressive strength was the existence of more Calcium, Silica, and Alumina in Ultrafine slag. Because of the development of additional C-S-H gel, it was obvious that the ultrafine slag added concrete microstructure is denser. Ultrafine slag's fineness would minimize air content by filling pores, resulting in a higher unit weight of fresh concrete. Concrete with a higher unit weight has a better strength, which may be attained by adequate constituent material packing. Furthermore, the increase in strength with the substitution of ultrafine slag was attributed to higher packing density and the acceleration of cement hydration.

The modulus of rupture results at 28 days are varying from 3.20 N/mm^2 to 8.24 N/mm^2that is diagrammatically represented in Figure 12. The pozzolanic reaction is responsible for the increased flexural strength with the replacement of ultrafine slag. This reaction enhances the bond between the binder material and the aggregate, resulting in increased strength in the Interfacial Transition Zone (ITZ). Following the failure of these specimens, a single fracture appeared along with the depth of the specimen during the loading period. The fracture began at the interface zone due to the tensile strain generated by the compressive load, and subsequently propagated into the concrete composites. Cracks begin in the interfacial area at low stress and propagate to the concrete matrix at increasing stress during flexural loading, contributing to the specimen's collapse at ultimate load.

This combined bar chart and line graph exemplifies the 28 days compressive strength values and flexural strength values of SCC mixes SCCA0 to SCCA60 respectively based on cubes and prisms testing. The optimum percentage replacement of Ultrafine slag can be found easily from this diagram.

This graph shows the stress stain curve of SCC mixtures that are obtained by testing the cylindrical specimens with compressometer in compression testing machine. This curve is used to find the modulus of elasticity values.

The Young's modulus of concrete is a combined mechanical parameter that indicates how elastically the concrete material may deform (Bradu et al., 2016). The results of young’s modulus of concrete are ranging between 8 N/mm^2 to 33.33 N/mm^2. The optimum result obtained for SCCA30 is 33.33 N/mm^2, 45% higher than conventional SCC. The values generated by the mixes SCCA0 to SCCA30 gradually increased, while the remaining mixes generated values that were lower than conventional SCC. The type and volume of coarse aggregate and paste content influence young's modulus values in general. SCC produces more paste and has more deformability, lowering the stiffness of the concrete and reducing the volume of aggregate content. Initial Tangent Modulus determines the young's modulus of concrete for all mixes as a slope from the origin to the ultimate strength of concrete in stress-strain curves, as illustrated in Figure 13.

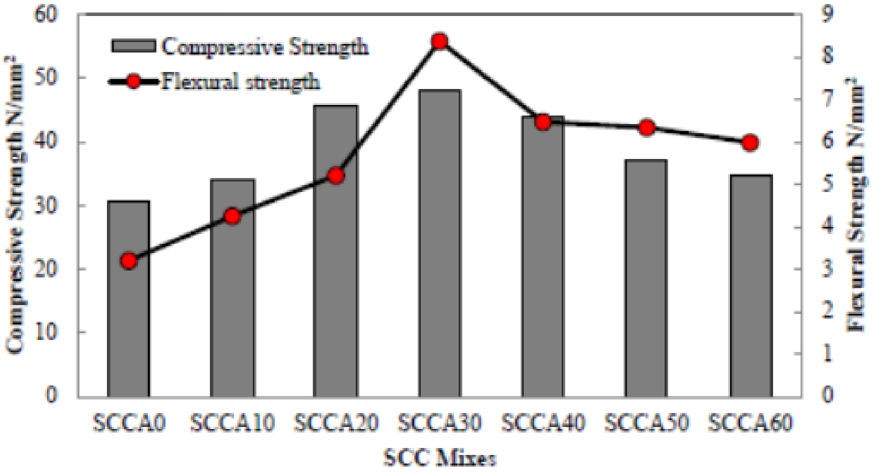


Fig. 12 Compressive and Flexural Strength of SCC Mixtures

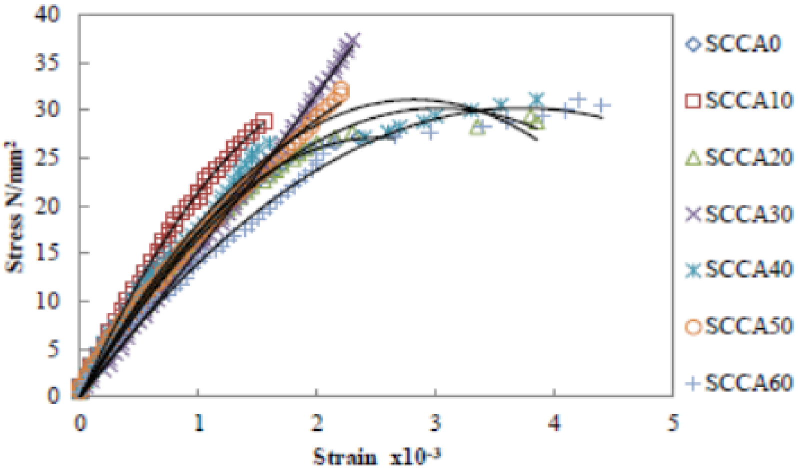


Fig. 13 Stress-Strain Curve of SCC Mixtures

5. Conclusion

This experimental work is carried out to determine the fresh and hardened properties of self-compacting concrete with varying percentages of ultrafine slag from 0% to 60%. From the results optimum mix is selected and examined the strength performance of SCCA0 and SCCA30. Based on the findings the following conclusions can be drawn:

- All the mixtures had satisfactory self-compacting properties in the fresh state. The addition of ultrafine slag had positive effect on the workability. When the properties of fresh SCC such as slump-flow, T_{50} time, L-box ratio and V-funnel test are considered as a criterion to determine the best fly ash admixtures among ultrafine slag, it can be said that 30% ultrafine slag is the most suitable for improving all of them. The results for hardened properties of the SCC mixtures containing fly ash and ultrafine slag were investigated; all the ultrafine slag mixtures have shown significant performance difference and the highest hardened properties has been obtained for the SCC mixtures.

- According to the findings, ultrafine slag with SCCA20 and SCCA30 produced the best results in the fresh state, while SCCA30 performed better in the hardened state. Overall, it can be stated that SCCA30 performed better in both phases and had higher ultrafine slag consumption.
- The slump values gradually increased from 0 to 30% due to the high lubrication behaviour between the finer particles with constant W/B ratio and SP dosage, and then decreased beyond that replacement due to an increase in the percentage of slag content because the finer particles would absorb more water content, resulting in sultry concrete.
- The inclusion of Ultrafine slag increased compressive strength compared to conventional SCC owing to the presence of CaO, SiO_2, Al_2O_3, and fineness, which might increase unit weight and packing density.
- The pozzolanic reaction of ultrafine slag improves the modulus of rupture, enhancing the binding strength between aggregate and binder material in ITZ.
- The volume of coarse aggregate and paste content determine the E for concrete value. Because SCC creates more paste content, the stiffness of the concrete is reduced and the volume of aggregate material is reduced. As a result, mixes with a higher concentration of Ultrafine slag (more than 30%) generated results lower than conventional SCC.

Acknowledgement

The authors acknowledge the Sri Venkateswara College of Engineering Technology, (Autonomous), R V S Nagar, Chittoor, Andhra Pradesh, providing laboratory testing facility. The authors are further thankful for the Ambuja Cement Ltd, Goa and BASF chemicals, Mumbai for providing required material.

References

[1] Kavyateja BV, Guru Jawahar J, Sashidhar C. Effectiveness of alccofine and fly ash on mechanical properties of ternary blended self-compacting concrete. Materials Today: Proceedings, 2020. https://doi.org/10.1016/j.matpr.2020.03.152

[2] Kavyateja BV, Guru Jawahar J, Sashidhar C. Effectiveness of alccofine and fly ash on mechanical properties of ternary blended self-compacting concrete. Materials Today: Proceedings, 2020. https://doi.org/10.1016/j.matpr.2020.03.152

[3] Reddy PN, Naqash JA. Durability and mechanical properties of concrete modified with ultra-fine slag, Int. J. Innov. Technol. Explor. Eng. 2019, 8 (5), 230-234. https://doi.org/10.33640/2405-609X.1141

[4] Reddy PN, Naqash JA. Strength prediction of high early strength concrete by artificial intelligence, Int. J. Eng. Adv. Technol. 2019, 8 (3), 330-334.

[5] Reddy PN, Naqash JA. Development of high early strength in concrete incorporating alccofine and non-chloride accelerator, SN Appl. Sci. 1 (2019) 755. https://doi.org/10.1007/s42452-019-0790-z

[6] Reddy PN, Naqash JA. Effect of alccofine on mechanical and durability index properities of green concrete. IJE Transcations C: Aspects, 2019, 32(6), 813-819. https://doi.org/10.5829/ije.2019.32.06c.03

[7] P Reddy PN, Naqash JA. Experimental study on TGA, XRD and SEM analysis of concrete with ultra-fine slag, IJE Trans. B Appl. 32 (5) (2019) 679-684. https://doi.org/10.5829/ije.2019.32.05b.09
[8] Reddy PN, Kavyateja BV, Jindal BB. Structural health monitoring methods, dispersion of fibers, micro and macro structural properties, sensing, and mechanical properties of self-sensing concrete-A review. Structural Concrete. 2021, 22(2):793-805. https://doi.org/10.1002/suco.202000337
[9] Kavyateja BV, Jawahar JG, Sashidhar C, Panga NR. Moment carrying capacity of RSCC beams incorporating alccofine and fly ash. Pollack Periodica. 2021, 16(1):19-24. https://doi.org/10.1556/606.2020.00231
[10] Kavyateja BV, Reddy PN. Effect of Industrial Waste on Strength Properties of Concrete, Annales de Chimie - Science des Matériaux, 2020, 44 (5), 353-358. https://doi.org/10.18280/acsm.440508
[11] Reddy AN, Reddy PN, Kavyateja BV, Reddy GG. Influence of nanomaterial on high-volume fly ash concrete: a statistical approach. Innovative Infrastructure Solutions. 2020 Dec;5(3):1-9. https://doi.org/10.1007/s41062-020-00340-9
[12] Reddy PN, Jindal BB, Kavyateja BV, Reddy AN. Strength enhancement of concrete incorporating alccofine and SNF based admixture. Advances in concrete construction. 2020;9(4):345-54.
[13] Reddy PN, Kavyateja BV. Durability performance of high strength concrete incorporating supplementary cementitious materials. Materials Today: Proceedings. 2020 Jan 1; 33:66-72. https://doi.org/10.1016/j.matpr.2020.03.149
[14] Reddy PN, Kavyateja BV. Experimental study on strength parameters of self-repairing concrete, Annales de Chimie-Science des Matériaux 2019 Oct (Vol. 43, No. 5, pp. 305-310). https://doi.org/10.18280/acsm.430505
[15] Reddy PN, Naqash JA. Effect of antifreeze admixtures on cold weather concrete. International Journal of Engineering. 2019 Mar 1;32(3):366-72. https://doi.org/10.5829/ije.2019.32.03c.03
[16] Bureau of Indian Standards, Method of test for strength of concrete (BIS:516-1959).
[17] Bureau of Indian Standards. (1970). Specifications for coarse and fine aggregate from natural sources for concrete (BIS:383).
[18] Bureau of Indian Standards. (1999). Concrete admixture-specifications (BIS:9103).
[19] Bureau of Indian Standards. (2013). Specification for 53 grade ordinary Portland cement (BIS:12269).