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SELF COMPACTING CONCRETE WITH SLAG AS COARSE AGGREGATE

Dr. G.C. BEHERA*[a], RANJAN KUMAR BEHERA[b],
[a]*prof. & Head, Civil Engineering Department, Gandhi Engineering College, Bbsr,752054, India*
[b]*asst. Prof. Civil Engineering Department, Bhadrak Institute Of Engineering And Technology, Bhadrak-756113, Odisha, India*

Abstract: Self compacting concrete requires no external or internal compaction as it is leveled and compacted under its own weight. Self compacting concrete is highly engineered concrete with much higher fluidity without segregation and bleeding. The three main requirement of self compacting concrete are filling ability, passing ability and resistance to segregation.

Plenty of availability natural resources in the past have become a dream for present day engineering society due to large scale consumptions. To overcome the problem of scarcity of natural aggregates and to save the environment from the pollution of dumping, civil engineers opined that there is significance potential for reuse of slag in value added application to maximize economic and environment benefit. Here an attempt has been made in this investigation to determine the strength characteristics of slag for application in self compacting concrete (SCC).

It is found that ACI-1985 predicts closely to the test values while the others overestimate in 7 days test. The predicated values by Yun Wang Choi (2004) and Hueste et al (2004) overestimate while ACI-1985, ACI-1992, and ACI-1995 underestimate the test results in 28 days. Flexural strength is found to be increasing with increasing in the percentage of slag. ACI-1992,overestimate the values, IS-456-2000 and ACI-1985 well predicts the test values while Foster F Z-1995 underestimates the values.

1.0 Introduction:

Development of new technology in the field of material science is progressing rapidly. In last three decades, a lot of research has been carried out throughout the globe to improve the performance of concrete in terms of strength and durability qualities. Consequently concrete has no longer remained a construction material consisting of cement, aggregate, and water only, but has becomes an engineered custom tailored material with several new constituents to meet the specific needs of construction industry. The growing use of concrete in special architectural configurations and closely spaced reinforcing bars have made it very important to produce concrete that ensures proper filling ability, good structural performance and adequate durability. In recent years, a lot of research was carried out throughout the world to improve the performance of concrete in terms of its most important properties, i.e. strength and durability. Concrete technology has under gone from macro to micro level study in the enhancement of strength and durability properties from 1980's onwards. Till 1980 the research was focused only to flow ability of concrete, so as to enhance the strength however durability did not draw lot of attention of the concrete technologists. This type of study has resulted in the development of self compacting concrete (SCC), a much needed revolution in concrete industry. Self compacting concrete is highly engineered concrete with much higher fluidity without segregation and is capable of filling every corner of form work under its self weight only (Okamura 1999) [1]. Thus SCC eliminates the needs of vibration either external or internal for the compaction of the concrete without compromising its engineering properties.

For several years, the problem of the durability of concrete structures has been a major problem posed to engineers. To make durable concrete structures, sufficient compaction is required. Compaction for conventional concrete is done by vibrating. Over vibration can easily cause segregation. In conventional concrete, it is difficult to ensure uniform material quality and good density in heavily reinforced locations. If steel is not properly surrounded by concrete it leads to durability problems. This is the problem mainly with heavily reinforced sections where a very high congestion of reinforcement is seen. In this case, it becomes extremely difficult to compact the concrete. Then what can be done to avoid honeycombing?

The answer to the problem may be a type of concrete which can get compacted into every corner of form work and gap between steel, purely by means of its own weight and without the need for compaction. This is the concept behind self compacting concrete(SCC). The SCC is an engineered material consisting of cement, aggregates, water and admixtures with several new constituents like colloidal silica, pozzolanic materials, and chemical admixtures to take care of specific requirements, such as, high-flow ability, compressive strength, high workability, enhanced resistances to chemical or mechanical stresses, lower permeability, durability, resistance against segregation, and possibility under dense reinforcement conditions. The properties, such as, fluidity and high resistance to segregation enables the placement of concrete without vibrations and with reduced labour, noise and much less wear and tear of equipment. Use of SCC overcomes the problem of concrete placement in heavily reinforced sections and it helps to shorten construction period. Self-compacting concrete is growing rapidly, especially in the precast market where its advantages are rapidly understood and utilized.

Slag is bi-product of Ferro alloys industries. It creates problems in dumping to environment and requires a vast area for deposition. As this material is densely packed, this material can be used as coarse aggregate.

1.1 Need for Self Compacting Concrete with Blast furnace slag

The ferroalloys industries generate substantial solid waste. The accumulated waste needs a huge space to be dumped and causes serious problems to the environment. This low carbon slag, which is considered as third class hazardous waste chemically composed of carcinogenic, such as hexavalent chromium. By exposure to the environment creates health hazard to the human beings like problems in respiration and nervous system disorder. When the slag is dumped it pollutes the ground water. The slag can be easily eroded by the water and wind to contaminate the air and surface water. As per the survey conducted by a single ferroalloys industry produces 220,000 tons of low carbon slag per year [1]. Ferroalloy production has been a problem for many years in the international market particularly in China [2]. The present day researchers are in the opinion that preservation of environment and conservation of rapidly diminishing natural resources should be the essence of sustainable development. To save the environment from the pollution caused due to the slag and to meet the scarcity of natural aggregate in the construction field, the possibility of use of the low carbon slag as coarse aggregate cannot be overlooked. Here an attempt is made to replace natural coarse aggregate with slag in production of concrete. The strength of the concrete depends on the properties of its constituent materials along with their volumetric fraction, water cement ratio, admixture added, curing methodology and degree of control. To find out the optimum volume fraction of slag as a coarse aggregate for making of concrete, the volume fraction of slag is varied in this research work keeping other parameters constant. This experimental work aims in preparation of self compacting concrete of grade M_{30} and to investigate the fresh workability properties at its fresh stage and mechanical properties at its hardened stage.

2.0 Literature Review

Keeping coarse and fine aggregate contents constant, self-compacting concrete can be made easily by varying water/cement ratio and super plasticizer dosage [3]. In self-compacting concrete, the amount of aggregates required are determined, and the paste of binders is then filled into the voids of aggregates to ensure that the concrete thus obtained has flow ability, self-compacting ability and other desired SCC properties [4]. According to [5] elastic modulus, creep and shrinkage of SCC do not differ significantly from the corresponding properties of normal vibrated concrete (NVC). Economical SCC mixes can be successfully developed by incorporating high volumes of Class F fly ash [6]. It is also reported that fly ash in self-compacting concrete helps in improving the strength beyond 28 days [7]. A mix design method for self compacting concrete is proposed based on paste and mortar studies for super plasticizer compatibility followed by trail mixes [8].A a procedure was presented for the design of self-compacting concrete mixes based on an experimental investigation [9]. Copper slag is used as fine aggregate in high strength concrete to improve its strength and durability characteristic [10]. According to [11] 50 to 100% coarse recycled aggregate decreases the tensile strength by 2.79 to 13.95. EAF (Electric Arc Furnace) slag aggregate was used replacing 30% of crushed lime stone aggregate and it is found that the compressive strength increased in all ages [12]. According to [13], slag as coarse aggregate in normal strength concrete increases workability, compressive, flexure and split tensile strength increased with increase in percentage of slag. SCC with 15% of silica fume gives higher value of compressive strength than those with 30% of fly ash [14]. Slag as replacement of normal crushed coarse aggregate and fine aggregate by [15] is found that the compressive strength increased by 4% to 7%. The workability of self compacting concrete with ground granulated blast furnace slag up to 30% replacement is very good [16]. A new mix design methodology for self compacting concrete with ground granulated blast furnace slag (GGBFS) as replacement material for cement is proposed [17]. According to this method they replaced GGBFS up to 80% for 30 MPa. Fly ash replacements of around 30% to 50% will be ideal for developing self compacting concrete [18]. An experimental study is taken up on cement content in the SCC mix for replacement with various percentage of limestone powder and the fresh and hardened properties are studied by [19].

3.0 OBJECTIVE AND SCOPE:

Even though extensive research is carried out on self compacting concrete, not much work is reported on the behavior of self compacting concrete with blast furnace slag as replacement of coarse aggregate. Keeping this in view, the present experimental program is taken up to study the behaviour of SCC with blast furnace slag aggregate (BFSA) and natural coarse aggregate (NCA) in different percentage. The main objective is to obtain specific experimental data, to understand fresh and hardened properties of the self compacting concrete with BFSA and NCA. For this design mix of M_{30} grade self compacting concrete is prepared with NCA and its strength is compared with substitution of BFSA in different percentage.

To achieve the above objectives, the total work was divided into two phases. A mix design was prepared for 30 MPa and it was cast and tested in the Phase-I. workability test(Slump flow, V Funnel, L Box ratio, T500 (sec), T5minute), Cubes, cylinders and prisms were casted to determine cube strength, split tensile strength and flexural strength respectively with natural coarse aggregate. The same were cast and tested with 10%, 20%, 40% and 60% replacement of NCA with BFSA in the Phase-II. The test results were analyzed and compared with theoretical values obtained from various codes.Fig.1 shows the flow chart of research work.

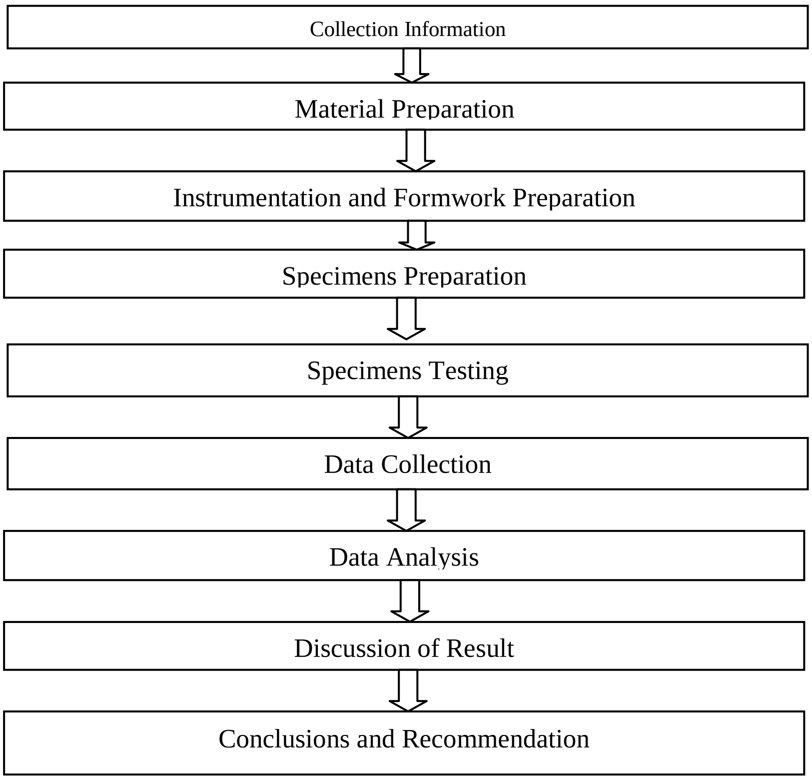
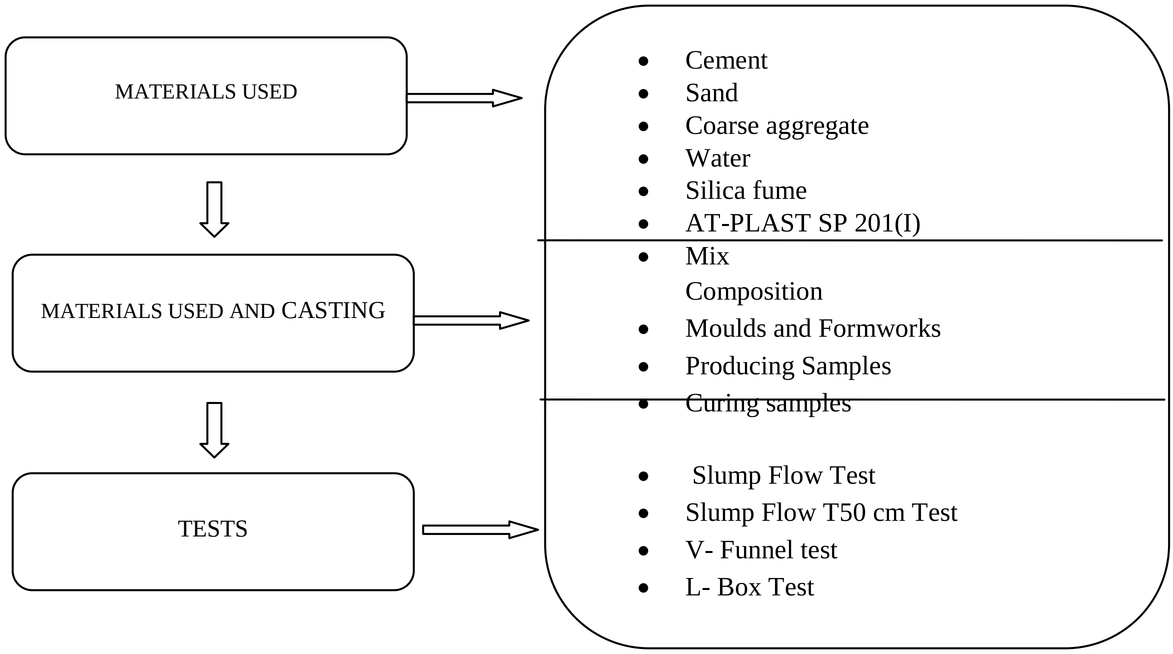


Fig.1 Flow Chart of Research work

4. 0 Material and their Properties

The arrangement of experimental program can be summarized in the flow chart as shown in Fig.2.



Cement, fine aggregate, coarse aggregate, mineral admixture and super plasticizer are taken to prepare SCC.

Fig.2 Flow chart of Experimental work

4.1 Cement

Ordinary Portland Cement of 53grade (zuari cement) conforming to [20] was used and properties are shown below in Table-1.

TABLE-.1: PHYSICAL PROPERTIES OF CEMENT

S.No	Properties of cement	Value obtained experimentally	Value as per IS 12269-1987
1	Normal consistency (%)	31	NA
2	Fineness	6	< 10
3	Initial setting time	120 minute	30(minimum)
4	Final setting time	250minute	600(maximum)
5	Specific gravity	3.13	3.15
6	Compressive strength of cement at 28 days	55.6 N/mm^2	53 N/mm^2

4.2 Fine Aggregate

Fine aggregate used in the present study is from the river bed of Baitarani, Panikoili (Sathipur) having specific gravity 2.68, bulk density 1600 kg/ m^3 and fineness modulus 2.81. The sieve analysis of fine aggregate has been carried out as per [21] and found that fine aggregate confirmed to grading zone-III.

4.3 Coarse Aggregate

In this investigation, two types of coarse aggregates such as NCA and BFCA were used for preparation of self compacting concrete.

Normal coarse aggregate of size below 20mm available in local market is used and tested as per [21] specifications and the properties are shown in Table-2.

TABLE-2: PROPERTIES OF COARSE AGGREGATE

S.no	Properties of coarse aggregate	Value obtained Experimentally for NCA IS 383-1978	Value obtained Experimentally for BFSA IS 383-1978
1	Maximum nominal size, mm	20	20
2	Bulk density Kg/m^3	1460	1940
3	Specific gravity	2.7	3.5
4	Impact value (%)	7.1	6.1
5	Crushing value (%)	54.8	35.5
6	Water absorption (%)	0.5	0.4

Blast furnace slag aggregate is a non-metallic product obtained from Facor Bhadrak. Blast furnace slag aggregate is the crystal material formed when molten chromites blast furnace slag is rapidly chilled by immersion in water. It is a crystal product with very limited granular formation.
The chemical properties of slag aggregate are shown in Table-3.

TABLE-3: PROPERTIES OF BLAST FURNACE SLAG COARSE AGGREGATE

S.no	Properties of slag aggregate	Value obtained as per Facor plant
1	Calcium oxide (%)	48
2	Silicon dioxide (%)	25
3	Manganese oxide (%)	11
4	Iron, sulfur, aluminum, chromium (%)	16

4.4 Silica Fume

Silica fume as very fine non crystalline silica produced in blast furnace as by product of the production of elemental silicon or alloys containing silicon. Silica fume is usually categorized as a supplementary cementitious material. It has excellent pozzolanic properties. The silica fume was used in this experiment conforms to [22].The silica fume is in white colour powder form. Silica fume has been procured from Singhania chemicals Ltd-Jharshuguda, Sambalpur and properties are shown in Table-4.

TABLE-4: PROPERTIES OF SILICA FUME

Sl.no	Properties of silica fume	Value obtained by manufacture IS 15388:2003
1	Particle size, mm	0.5µm-1µm
2	pack density Kg/m^3	0.76gm/cm^3
3	Specific gravity	2.63
4	Moisture content (%)	0.058

4.5 Super Plasticizer

AT-PLAST SP 201(I) super plasticizing admixture procured from ADO Additives Mfg. Pvt. Ltd Kolkata. It is brown in colour having density 1.2 kg/lt, air entrainment 1% and pH value of 8.

5.0 Mix design

In the present study normal vibrated concrete (NVC) of M_{30} grade was designed by using [23] and SCC of M_{30} grade was designed by EFNARC specifications. For this water cement ratio was taken 0.43. Different mixes prepared for the study is presented in Table-5.

Table- 5 Percentage of aggregate used in 6 batches of mixes.

Mix Designation	Mix 0	Mix 10	Mix 20	Mix 40	Mix 60
Natural Coarse Aggregate (%)	100	10	20	40	60
Slag (%)	0	90	80	60	40

The mix proportion for M_{30} grade concrete with 100% natural coarse aggregate was 1: 1.18: 2.64 with water cement ratio 0.43.

6.0 EXPERIMENTAL PROGRAM

The performance of slag aggregate self compacted concrete is influenced by the mixing. This means that a proper and good practice of mixing can lead a better performance and quality of slag aggregate concrete. Before concreting, batching is done properly.

6.1 Preparation of Concrete Mould.

Concrete moulds were oiled for stripping of specimen easily.

6.2 Preparation of Concrete

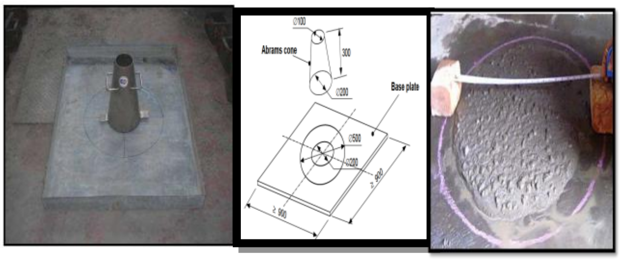
Concrete was prepared in the mixture, dumped in iron tray and manually mixed again properly before placing in the moulds.

6.3 Tests on Fresh Concrete

The three main properties of SCC are filling ability, passing ability and resistance to segregation.

6.3.1 Filling Ability:

Self compacting concrete must be able to flow into all the spaces within the formwork under its own weight. This is related to workability, as measured by slump flow test and slump flow T50cm test shown in Fig.3.



a Slump flow test Apparatus

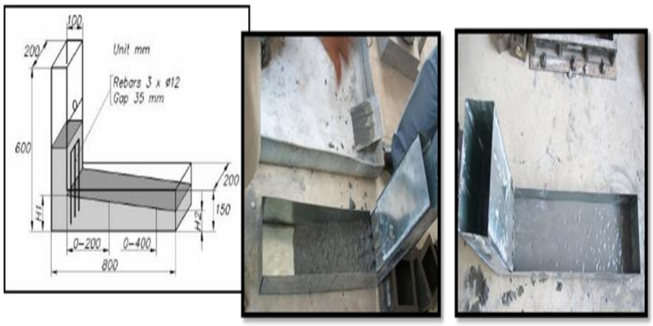
b. Dimensions of Base plate and Slump cone apparatus

c. Slump Flow Test

Fig.3.Measurement of Slump Flow Test

6.3.2 Passing Ability:

Self compacting concrete must flow through tight openings such as spaces between steel reinforcing bars under its own weight. The mix must not 'block' during placement. The L-Box test and U-Box test are the most common methods used to assess this property as shown in Fig.4.



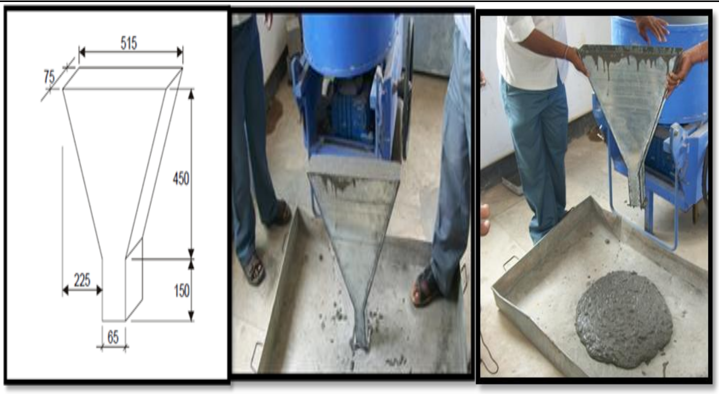
a .Dimensions of L-Box

b. Flow through rebar in L-Box

Fig.4 Passing Ability Test

6.3.3 Resistance of Segregation:

Stability or resistance to the segregation is the property that characterizes the ability of the SCC to avoid the segregation of its components, such as the coarse aggregates. The V- Funnel T5min test is the most common method used to assess this property as shown in Fig.5.



a. Dimensions of V- Funnel   b. V- Funnel test apparatus   c. V- Funnel flow

Fig.5 Segregation resistance Test by V- Funnel

6.3.4. Compaction factor Test

Compaction factor test was performed to determine the workability of fresh concrete. It was also known as drop test, which measure the weight of fully compacted concrete and compared it with the weight of partially compacted concrete.

6.4. Preparation of Samples

The placing process of the concrete mix is the most critical moment. For normal vibrated concrete, moulds were filled in three layers with each layer being compacted 25 times using steel bar. For SCC mixes which requires no compaction, moulds were filled with concrete in three layers and a time gap of one minute was maintained between two layers. The specimens were demoulded after 24 hours of casting and put in curing tank.

All concrete specimens were cured in water at room temperature further for 28 days. After 28 days curing concrete specimens were removed from the curing room to conduct tests on harden concrete.

6.5 LABORATRY TEST RESULT

6.5.1 Slump Flow Test and Slump Flow T50cm Test Results:

The results obtained from the slump flow test, slump T50 flow test are shown in Table 6.3. The acceptable range of SCC criteria for slump flow is 650mm to 800mm.The higher the slump value, the greater its ability to fill formwork under its own weight. The results of slump flow T50 for sample SCC-0, SCC-10, SCC-20, SCC-40 and SCC-60 are within the acceptable ranges of SCC criteria. The T50 time is a secondary indication of flow. A lower time indicates greater flow.

Table-6 Slump Flow test and slump flow T50 test results

Sample	Slump flow test(mm) Standard value (500-700)mm	Slump flow T50 test (sec) (2- 5 sec)	Concrete condition	remarks
SCC0	690	3.36	Flow	Satisfied
SCC10	685	3.4	Flow	Satisfied
SCC20	682	3.5	Flow	Satisfied
SCC40	675	3.9	Flow	Satisfied
SCC60	670	4.5	Flow	Satisfied

6.5.2 L-Box Test Results:

The L-Box test results of the sample S5 and S6 indicates high blocking ratio (H2/H1) which are within the acceptance criteria for SCC. Results of the tests are given in the Table-7. Higher value of blocking ratio indicates highly flow able concrete to self compact, excellent passing ability, without blockage, through closely spaced obstacles and the concrete flows freely as water until it will horizontal at rest.

Table-7 L-Box test results

Sample	H1(mm)	H2(mm)	H2/H1 (0.8-1.0)	T20 (1-2sec)	T40 (2-3 sec)	Remarks
SCC0	42	42	1.0	0.8	2.8	Satisfied
SCC10	41	39	0.95	0.9	2.8	Satisfied
SCC20	40	37	0.925	1.2	2.91	Satisfied
SCC40	40	34	0.85	1.87	2.93	Satisfied
SCC60	38	32	0.842	1.89	2.96	Satisfied

6.5.3 V- Funnel Test & V-Funnel T5 Minutes Test:

The V-Funnel test results of the sample presented in Table-8 indicates SCC-0 has greater flow ability than others. Shorter flow times indicate greater flow ability. The result of V- funnel test as shown in Table-7. To check segregation of concrete, V-funnel test at T5 minutes was carried out.

Table-8: V- Funnel test results

Samples	V- Funnel Test (sec) (6-12 sec)	V- Funnel T5 minutes test(≤6 sec)	Remarks
SCC0	7	3.4	Satisfied
SCC10	8	3.8	Satisfied
SCC20	9.2	4.2	Satisfied
SCC40	9.8	4.5	Satisfied
SCC60	10.4	5	Satisfied

6.6 Testing of harden properties

Compressive strength, split tensile strength and flexural strength of various tested mixes were presented in Table-9 .

Table-9: Experimental test results of different mixes

% of slag	cube strength after 7 days ($N.mm^2$)	cube strength after 28 days ($N.mm^2$)	Split tensile strength after 7 days ($N.mm^2$)	Split tensile strength after 28 days ($N.mm^2$)	Flexural strength after 28 days ($N.mm^2$)
NVC	28.95	41.19	2.59	3.42	4.40
SCC 0	29.48	41.26	2.69	3.59	4.46
SCC 10	31.04	41.56	2.74	3.66	4.62
SCC 20	34.15	42.10	2.83	3.73	4.67
SCC 40	37.56	44.67	2.85	3.80	4.74
SCC 60	40.00	46.96	2.95	3.82	4.82

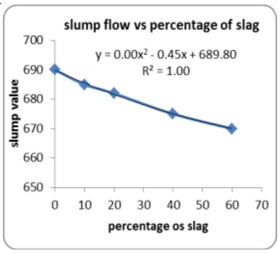
7.0 Interpretation of Test Results:

Fresh and hardened properties of SCC were investigated in this section, compared with codal values as well as values prescribed by earlier researchers.

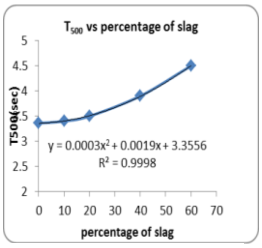
7.1 Workability

The fresh properties of different SCC mixes were presented in Table- . In terms of slump flow, all SCC mixtures exhibited satisfactory slump value in the range of 690–670 mm, which is an indication of good deformability.

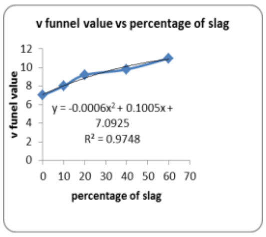
When cement is replaced by silica fume, perhaps a higher dosage of super plasticizer is required to maintain the same filling ability. As the test is conducted with same super plasticizer dosage, the slump value was found to be decreased with increase in percentage of slag. Fig-6 shows the slump value of different SCC mixes. T500 times mean the time required by concrete to reach 500 mm diameter of slump flow. Lower time indicates greater flowability. The T500 was influenced by the dosage of water and super plasticizer. V funnel test was performed to assess the flowabilty and stability of the SCC. Fig. 6 shows the relation between T500 test result and V-Funnel results of percentage of slag. The increase in slag percentage causes the increase in T_{500} time. This might be due to more absorption of water for slag. The increase in slag percentage causes the increase in V-Funnel time. The same has been reported by [24]. L-box ratio indicates the filling and passing ability of each mixture. L-box test is more sensitive to blocking. Fig.6 shows the comparison of L-Box test and Slump test. There is a risk of blocking of the mixture when the L-box blocking ratio is below 0.8.The obtained L-box values are presented in Table-7. If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1 = 1.



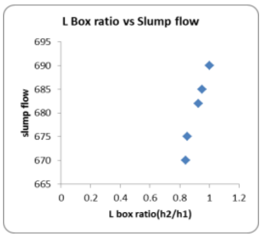
a. Slump Flow vs Percentage of Slag



b. T500 vs Percentage of Slag



c. V Funnel value vs Percentage of Slag

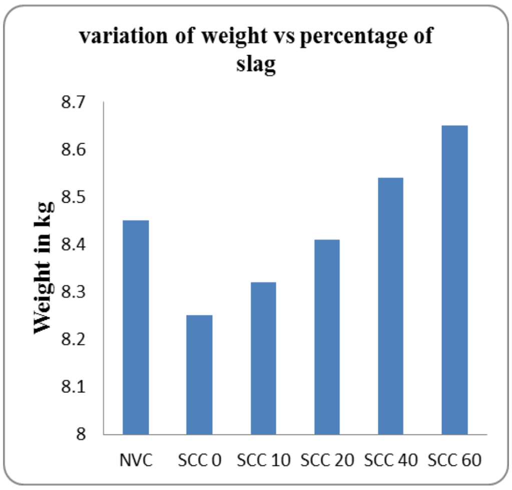


d. L Box ratio vs Slump Flow

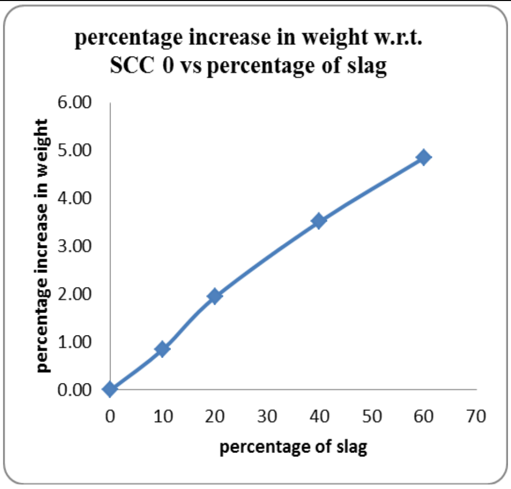
Fig. 6 Variation on Test results on fresh properties of with percentage of slag Funnel value vs Percentage of Slag

7.2 Weight

The weight of the specimen depends on specific gravity of its constituents materials. To verify the effects of weight of the specimen on strength parameters, individual weight of cubes were taken. The average weight of specimen prepared with NCC, SCC-0, SCC-10, SCC-20, SCC-40, and SCC-60 was found to be 8.45 Kg, 8.25 Kg, 8.32 Kg, 8.41 Kg, 8.54 Kg and 8.65 Kg respectively. The values are plotted in Fig.7.a. From the figure it is clear that the increase in weight is not marginal. So, when the natural aggregate is to be replaced with slag having higher specific gravity increases the self weight of the specimen. The increase in self weight is negligible which is reflected in Fig.7.b. The weight of the cube with natural coarse aggregate and proportion mentioned in the experimental program mathematically found to be 8.02 kg against the experimental value of 8.45 kg. When the natural aggregate is replaced by 10%, 20%, 40% and 60% with slag, the percentage increase is 0.85%, 1.94%, 3.52%, and 4.85% respectively. As the increase in self weight for 60% slag is only 4.85% of natural aggregate, it can be inferred that slag can be used as replacement of natural coarse aggregate in the construction field.



a. Average weight vs percentage of



b. Percentage increase in weight w.r.t. SCC 0 vs percentage of slag

Fig.7Variation of parameters with respect to percentage of slag

7.3 Compressive Strength:

Compressive strength is an important property of harden concrete which influences other mechanical properties of concrete. Compressive strength of concrete specimen prepared with NCA, SCC-0, SCC-10, SCC-20, SCC-40, and SCC-60was found to be 28.96 MPa, 29.48 MPa, 29.98 MPa, 30.65 MPa, 31.07MPa, and 32.24 MPa in 7 days and 41.19 MPa, 41.26 MPa, 42.00 MPa, 43.44 MPa, 44.67MPa, and 46.96 MPa in 28 days respectively. The same is plotted in Fig.8.a. It is found that compressive strength increases with increase in the percentage of slag content. A crushed specimen of SCC-60 is shown in Fig.8.b. It is clearly observed that the failure is due to the failure of mortar.

Percentage increase in compressive strengths of SCC-10, SCC-20, SCC-40, and SCC-60 over SCC-0 was found to be 1.70%, 3.96 %, 5.38%, and 9.37% in 7 days. The same was increasing by 1.80%, 5.28%, 8.26% and 13.82% in 28 days respectively. Percentage increase in compressive strength along with percentage of slag is plotted in the Fig.8.

The percentage increase in Strength was found to be 13.87% for 60% replacement of NCA with slag and the variation was found to be linear except for SCC-20. The same has been reported by earlier researchers when natural aggregate is replaced by recycled aggregates [13]. This may be possible due to low volume fraction of slag. The use of slag with high specific gravity might be the cause of enhancement of compressive strength. So, concrete with slag can be used for design of compression members.

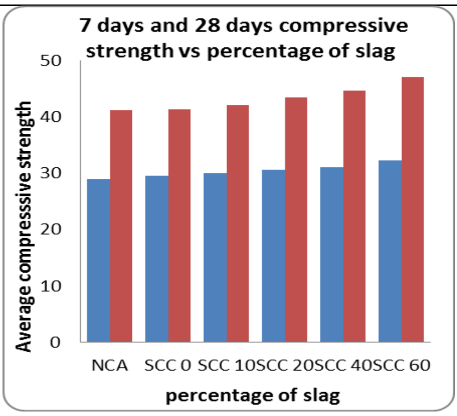


Fig..8.a Average compressive Strength vs Percentage of slag

Fig.8.b Crushed specimen of SCC 60

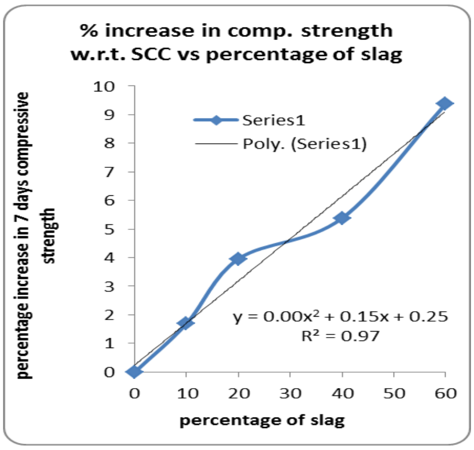


Fig.8.c Percentage increase in 7 days Compressive strength w.r.t. SCC 0 vs Percentage of Slag

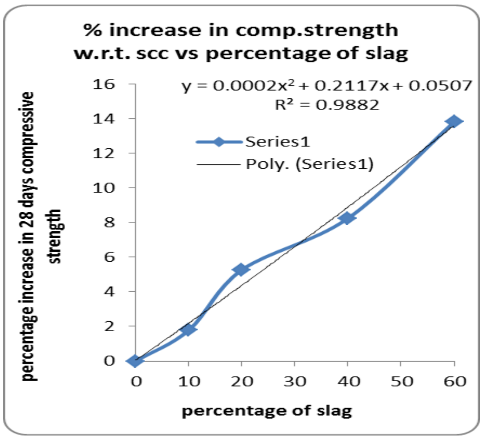


Fig.8.d Percentage increase in 28days Compressive strength w.r.t. SCC 0 vs Percentage of Slag

7.4 Split Tensile Strength:

The split tensile strength of concrete specimen with natural aggregate (SCC-0) and with slag (SCC-60) was found to be 2.69 MPa and 2.95MPa in 7 days and 3.58 MPa and 3.82 MPa in 28 days respectively. The increase in the spilt tensile strength is nominal. The split tensile strength of specimen prepared with SCC-10, SCC-20, SCC-40 and SCC-60 was found to be 2.69MPa, 2.74MPa, 2.83MPa, 2.85MPa and 2.95 MPa in 7days and3.66 MPa, 3.73 MPa, 3.8 MPa and 3.82 MPa in 28 days respectively. The theoretical values of split tensile strength were calculated according to ACI-1985, ACI-1992 , ACI-1995, Yun Choi et al – 2004 and Hueste et al (2004). The 7 days test value along with different theoretical values calculated by codes is plotted against the percentage of slag in Fig.9.a.

Here it is found that ACI-1985 predicts closely to the test values while the others overestimate. The percentage increase in spilt tensile strength with respect natural aggregate is calculated and compared with different codal values. Percentage increase in spilt tensile strength with percentage of slag is plotted in Fig.9.b.

The 28 days split tensile strength along with predicated values by different codes was plotted in Fig. 9.c and increase in percentage of split tensile strength with respect to SCC-0 as represented in Fig.9.d. The predicated values by Yun Wang Choi (2004) and Hueste et al (2004) overestimate while ACI-1985, ACI-1992, and ACI-1995 underestimate the test results. There is an increase of 2.23 %, 4.19%, 6.15% and 6.70 % of split tensile strength of Scc-10, SCC-20, SCC-40 and SCC-60 respectively over SCC-0.The increase is not prominent with substitution of slag percentage.

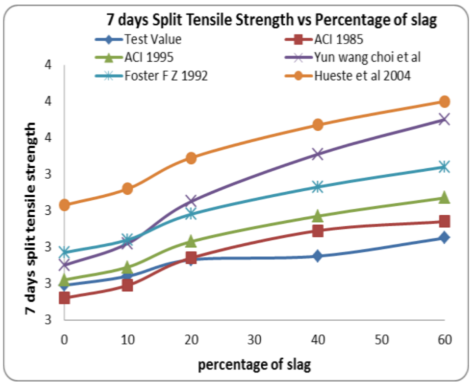


Fig.9.a Split Tensile strength vs. Percentage of slag

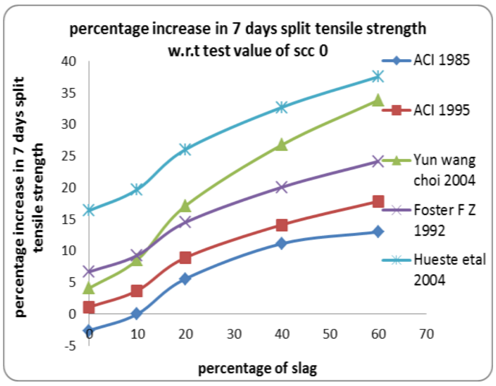


Fig.9.b Percentage increase in 7 days split tensile strength w.r.t test value of SCC 0 vs percentage of slag

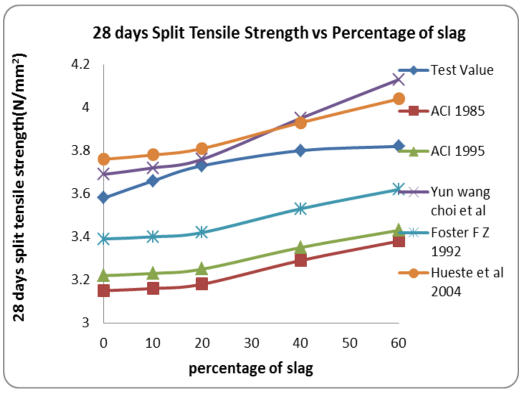


Fig.9.c 28 days split tensile strength vs Percentage of slag

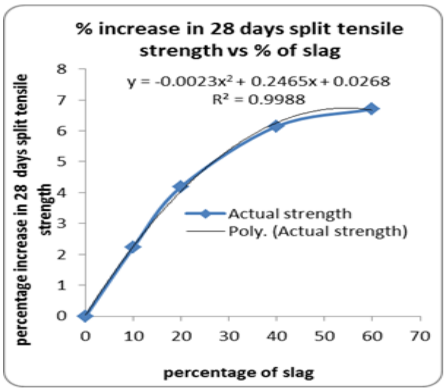


Fig.9.d Percentage increase in 28 days split tensile strength w.r.t test value vs Percentage of slag

7.5 Flexural Strength:

Flexural strength of concrete specimen prepared with SCC-0, SCC-10, SCC-20, SCC-40 and SCC-60 was found to be 4.46 MPa, 4.62 MPa, 4.67 MPa, 4.74 MPa and 4.82 MPa respectively. The theoretical values of flexural strength are also calculated from IS 456:2000 [25], ACI-1995, ACI-1992, ACI-1985, CRRI and plotted along with test results in Fig.10.a shows that ACI-1985 and IS-456 well predicts the values for self compacting concrete with slag. The percentage increase in flexural strength is plotted in Fig.10.b. The flexural strength is found to be increasing with increasing in the percentage of slag. ACI-1992, overestimates the values, IS-456-2000 and ACI-1985 well predicts the test values, while Foster-1995 underestimates the values. This is due to the fact that the above mentioned codal values are for normal vibrated concrete. The same cannot be applied for prediction of self compacted concrete with slag. The percentage increase in flexural strength of SCC-10, SCC-20, SCC-40 and SCC- 60 over SCC-0 was found to be 3.68%, 4.63%, 4.82%, and 8.07% respectively.

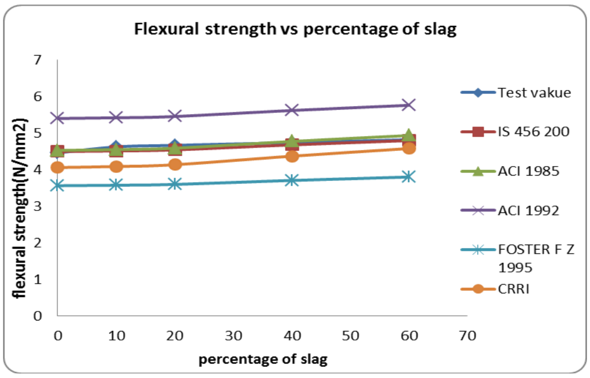


Fig. 10.a 7.14 Flexural Strength vs Percentage of Slag

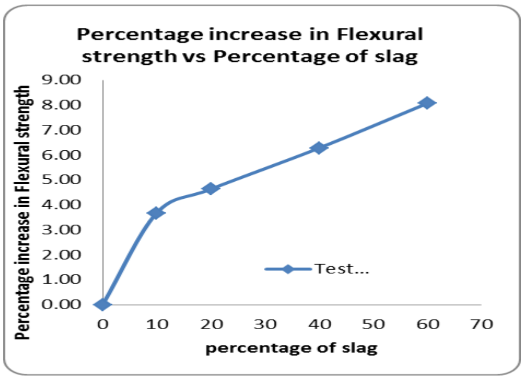


Fig. 10.b 7.16 Percentage increase in flexural test

8. CONCLUSION

The tests were performed to determine the fresh and mechanical properties of Self-Compacting Concrete mixtures and the results of the tests are as follows.

1. All the self-compacting concrete with replacement of slag as coarse aggregate up to 60% mixes had a satisfactory performance in the fresh state.
2. The T50 time value increases with increase in percentage of slag.
3. The slump value decreases from 690 mm to 670 mm with increase in percentage of slag from SCC-0 to SCC-60.
4. The compressive strength increases with increasing percentage of slag contain.
5. There is an increase of 13.82% in compressive strength for SCC-60 over SCC-0.
6. The split tensile strength increases with increase in percentage of slag and the increase is not prominent as compressive strength.
7. The increase in split tensile strength is up to 6.70% over self compacting concrete with natural aggregate for 60% replacement.
8. The flexural strength also increases with increase in percentage of slag.
9. The increase in split tensile strength is up to 8.07% over self compacting concrete with natural aggregate for 60% replacement.
10. The changes in properties are found to be almost same up to 20% replacement of NCA with slag.

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