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A Study on Self Compacting Concrete by Replacement of Coarse Aggregate with Ferrous Manganese Slag

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Abstract: Self Compacting Concrete (SCC) is an innovative concrete and it is having desirable properties to consolidate itself due to its own weight. Conventional concrete requires more compaction to obtain a more durable structure. Hence it requires a compaction process during casting such that vibrators could be used. Sometimes it is difficult to use where structure having more reinforcement.

Therefore to overcome such situation a High Performance Concrete having flow ability property without segregation may used. Later HPC with little compaction get modified into SCC which exhibits flow ability, segregation resistance characteristics without honey combing.

This experimental studies focus on application of the industrial by-product or wastes obtained at the steel plant i.e., Ferrous-Manganese Slag aggregate. Preparation of SCC using Ferrous-Manganese Slag aggregate by percentage replacement of coarse aggregate by Nan-Su mix design procedure. Cement and coarse aggregate get replaced by Ground granulated blast furnace slag(GGBS) reference to [2] and Ferrous-Manganese Slag aggregate respectively as per the mix design procedure. Ferrous-Manganese Slag is replaced with 10, 20, 30 upto 100% of coarse aggregate and GGBS about 63% of cement.

SCC having 70 percent of FMSA which are replaced for coarse aggregate shows a good result compare to other mix proportions. To achieve the objectives there are two sections to be followed namely, casting of specimen with desired grade and test result are compared with other mix proportions.

Workability of the SCC could not be affected by replacing the FMSA but hardened property of concrete get varies due to voids formation between the rounded granular structures of the FMSA.

Keywords: Self Compacting Concrete (SCC), Ferrous Manganese Slag Aggregate(FMSA), High Performance Concrete(HPC)

I. INTRODUCTION

In 1970s Europe uses a little compacted concrete. Later 1980s Japan Society of Civil Engineers (JSCE) uses a concept of Self Compacting Concrete with reference of utilization to High Performance Concrete by Europe at transportation civil works in 1990s. SCC is a next decade innovation in which it compacted due to its own weight.

Due to its flowing ability, Elimination of vibrator improves the minimal concrete voids, superior level of finish and faster use of the structure. Concrete is hard and strong which is substantially used for building construction. Concrete consists larger constituent of coarse aggregate.

Hence finding an alternative for this is very much necessary. Therefore the alternative material reduces the heat of hydration, thus it helps reduction of fatigue in rigid pavement. SCC mainly depends upon mineral composition and its characteristics so that it has to reduce the men and material labor resource and increases rapid fixing with fit and finish work. In the sense of sustainable development, usage of industrial by-products or alternatives to the construction materials evokes the systematic planning and designing of environment for the future days.

Therefore, to check the depletion rate of rock bed, usage of alternatives such as tile bats, coconut shell, slag aggregate materials etc., for aggregate and sugarcane bagasse ash, fly ash, silica fume, GGBS for cement leads to the sustainable development and hazardous free surroundings.

In SCC, substitute material reduces heat of hydration so that surface cracking is avoidable. Alternative material provides a platform to research and study on different homogeneous property. The construction cost may reduce due to utilization of material in and around the site by reduction in lead and lift charges. It provides eco-friendly environment by avoiding the free disposal of wastes.

A. *Self-Compacting Concrete with Ferrous Manganese slag*

In India nearly 100 mega tons of steel manufactured per year. To make 1 ton of steel requires of about 1.3 ton of raw material. So much of raw material consumed and remaining matrices will be treated as waste or by-product i.e., Blast Furnace Slag. There are different variety of slag available in India categorized based on the industry location and type of ore utilized for manufacturing. Generally, steel slag contains more carbon compare to other chemical constituent of slag. Though it is a by- product, the disposal of such industrial waste is difficult now a days and it is harmful to human beings. To handle such situation lot of research and studies are takes place to recycle a material. Slag aggregate has ferrous content so it can be used instead of normal aggregates in proper proportions. Slag aggregate can also be used in sub-base, base course layer of pavement structure. In this experimental work self compacting concrete aims to be prepared with M40 grade. The workability and durability properties of the concrete can be tested on fresh and hardened phase.

B. *Objectives*

Present experimental work is taken up to examine the strength property of Ferrous Manganese Slag Aggregate(SCA) based self compacting concrete by Nan-Su mix design method and to compare the cost, weight, density of M40 grade conventional SCC which is prepared by natural coarse aggregate(NCA) with M40 grade SCC using Ferrous Manganese slag coarse aggregate. The optimum ferrous manganese slag aggregate percentage can be determined. To achieve an above objective, the workability test on fresh concrete (Slump Flow, T500, V-Funnel, L-Box ratio, T5 minute, U-Box, J-Ring test) and cube, cylinder, beam were casted to test the hardened property of the concrete. The same test were conducted for the SCC having slag aggregates with the 10,20,30 upto 100 percent variation in the place of coarse aggregate. The obtained results were analyzed, tabulated and it is compared with standard values from various reference code.

II. LITERATURE REVIEWS

A. *"A study on properties of Self Compacting Concrete with Slag as coarse aggregate"by G.C Behrera, R.K. Behera, IJRET, ISSN: 2395-0072, Volume 03, January 2016.*

The natural coarse aggregate is replace with the blast furnace slag aggregate for M30 grade of SCC. Here upto 60% mix shows a satisfactory result for workability and SCC having 60 percent slag shows a good hardened property and the Slump value decreases from 690 mm to 670 mm with increase in slag percentage.

B. *"Design of SCC with Ground Granulated blast furnace Slag", P. Dinakar et al,Materials and design 43:2013 page no 161-169.*

This paper evaluate about cementitious effectiveness when other pozzolanic material gets added in SCC with different proportions. Here they found out the efficiency factor (K). The K generally defines in terms of the strength relative to control concrete. Here K gives the amount of pozzolanic material such as Fly-Ash, GGBS that can be considered for replacing cement. This experimental investigation on GGBS embedded SCC done for strength from 30 Mpa to 100 Mpa by adopting replacement of GGBS from 30 to 80%.

C. *"Self Compacting Concrete", Hajime Okamura and Masahiro Ouchi, Journal of advanced concrete technology, volume 1, April 2003.*

This paper explains most development of SCC, Self compactability of fresh concrete, mechanism for activity, self compactability, factors affecting compactability such as coarse aggregate, mortar as fluid and as solid. Influence of shape, content and grading of coarse aggregate. Also discuss about rational mix design water-powder ratio and dosage of super plasticizer.

D. *"A simple mix design method for self compacting concrete", Nan-Su, Kung-Chung Hsu, His-wen chai, cement and Concrete research 31(2001), page no.1799-1807.*

Author explained that the aggregate content, flowability, self-compacting ability are determined by Packing Factor (PF). And also SCC designed and produced with the proposed mix design contains more sand and less coarse aggregate. The volume of sand to mortar is in range of 54 - 60%. He also suggested that proposed mix design mix design requires less quantity of binder and coarse aggregate compare to other design mix.

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III. MATERIALS

A. Experimental Program

Basic test are conducted on the concrete constituents and physical properties of the material are tabulated.

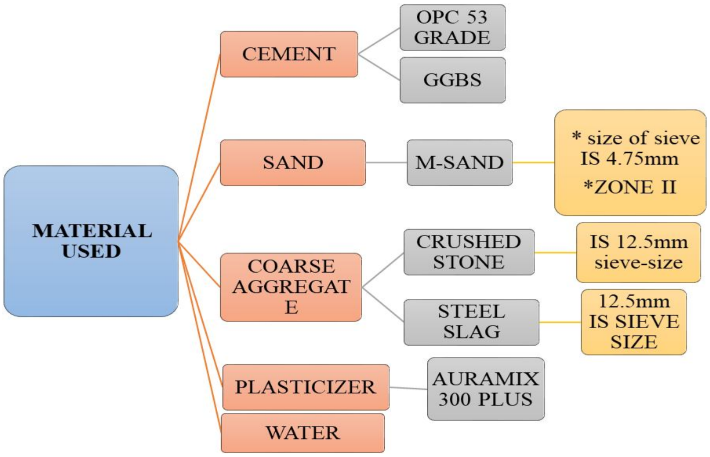

Fig 1: Experimental Programme chart

B. Cement

Birla Super OPC 53 grade conforming to IS: 12269-1987 used in this work and property of material are mentioned in table1.

C. Fine Aggregate

In this work, crushed stone sand i.e., M-sand belongs to zone II. Obtained laboratory test result are mentioned in table 2 as per clause 4.3 of IS: 383-1970.

Table 1. Cement Physical Property

Sl.No	Property of cement	Experimental Value obtained	Value as per 12269 -1987 IS code
01	Initial Setting Time(min)	40	min 30
02	Final Setting Time(min)	480	max 600
03	Normal Consistency (%)	29	NA
04	Specific Gravity	3.11	3.15
05	Fineness	7.00	<10
06	Cement compressive-strength at 28th day.	53.6	53 (N/ mm^2)

Table 2. M-Sand Physical Property

Sl.No	Properties of M-sand	Experimental value obtained	Value as per IS: 2386-1963
01	Specific Gravity	2.61	2.40-2.65
02	Bulk Density	1717	1850 kg/m^3
03	Fineness modulus	3.14	2.6 – 4.7
04	Water Absorption	1.6	<2 %

D. Super Plasticizer

Chemical namely Aura mix 300 Plus was used. Its having the property to provide flow-ability and especially designed it for SCC. Procured from FOSROC Pvt. Ltd.

E. Coarse Aggregate

Here there are two type of aggregate are used.

1) *Natural Coarse Aggregate:* In which they are angular in shape and 12.5 mm IS sieve down size.
2) *Ferrous Manganese Slag Coarse Aggregate:* These aggregates are rounded aggregates which are having size of IS 12.5mm sieve. Notation for this aggregate given as Slag Coarse Aggregate (SCA).

Table 3. NCA Physical Property

Sl.No	Property of M-sand	Experimental value obtained	IS: 2386-1963 Value
01	Specific Gravity	2.78	2.5-3.0
02	Impact value	16.18 %	Less than 45%
03	Los Angeles abrasion value	23.54 %	Less than 30%
04	Combined Index	29.74%	Less than 35%
05	Water absorption	0.6 %	Less than 1%
06	Fineness Modulus	7.66	6 - 8.5

Table 4. SCA Physical Property

Sl.No	Property of M-sand	Experimental value obtained	IS: 2386-1963 Value
01	Specific Gravity	2.85	2.5-3.0
02	Impact value	23 %	Less than45%
03	Los Angeles abrasion value	26.18 %	Less than 30%
04	Combined Index	21.67 %	Less than 35%
05	Water absorption	0.9	Less than 1%
06	FM	8.86	6.0 – 8.5

F. Water

Water must be free from all chemical and physical impurities as such that it deemed to be a drinking water. To avoid such deterioration of concrete structure it aims to maintain a pure water as per IS: 456-2000 codal provision and also it should have permissible limit as per IS: 3025-2005. The pH value of water used in this work is 6.5.

G. Ground Granulated Blast Furnace Slag

GGBSs one of the industrial by-product in the steel plant. It's like a powder form having the ferrous, magnesium and other content.

IV. EXPERIMENTAL METHODOLOGY

A. Desired Mix Proportion

1) Obtained Proportions of Desired Mix

Cement Quantity =394.28 kgs /m^3
Ground-Granulated-Blast-Furnace Slag =66.78 kgs /m^3.
Fine-aggregate =1135.280 kgs /m^3
Normal Coarse-aggregates =644.94 kgs /m^3
Water content =180.680 Liters/m^3
Chemical admixture =3.92 kgs /m^3
Mix Proportion of the desired mix =1:0.16:2.87:1.63
{Cement: GGBS: FA: CA by weight}

2) *Trail Mix:* Based on the number of trail mixes are conducted to determine the SCC property such as flow-ability, passing-ability etc., so that final proportion is 1: 0.42: 4.07: 2.19 as Cement: GGBS: FA: CA by weight with W/C as 0.4.

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V. RESULTS AND DISCUSSION

There are 3 main properties of SCC are tested to determine the workability of SCC as per EFNARC guidelines.

A. Workability Test Result

1) *Filling Ability:* Filling ability is the property of the SCC to filling of voids by its self weight. Filling ability properties can be determined by the Slump-Flow test. Slump flow value increases in increases in percentage of slag, T500 mm test value in time decreases with increase in percentage of slag and in U – Box test height decreases in increases in percentage of slag. The below shows the apparatus used to find the Filling ability property.

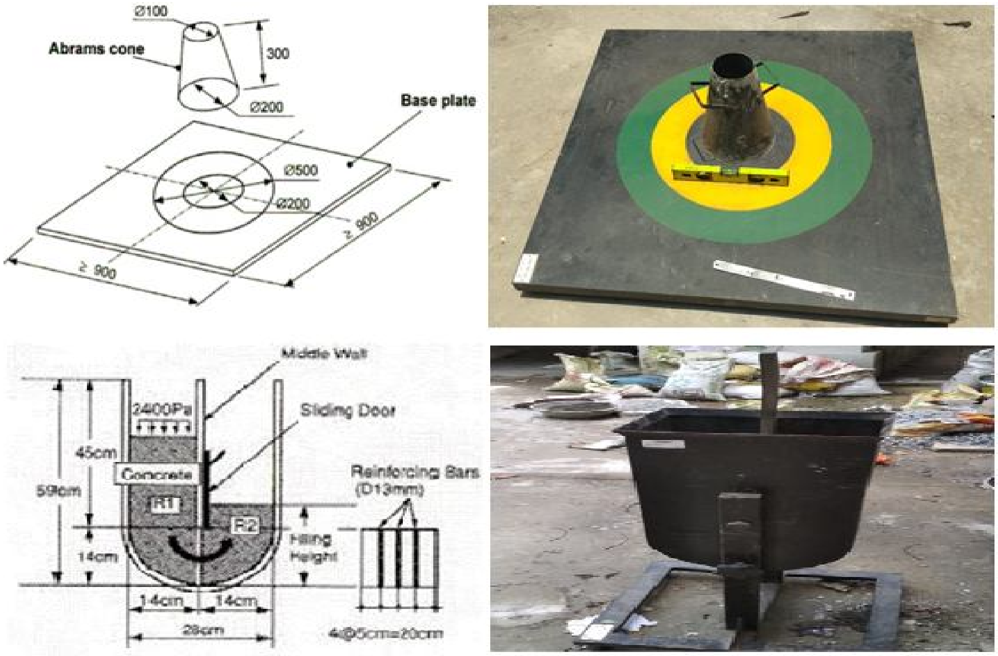

Fig 2: Apparatus for Slump flow and U – Box test

Table 5. Slump-Flow, T500 Test and U-Box test result.

Samples	Slump-Flow Test in mm {500.0-850.0}	Slump-Flow T500 in sec {2.0-5.0 Sec}	U-Box Test Difference in height{H=H1-H2} (mm)	Remarks Satisfactory-Y Unsatisfactory-N No Visible blocking - NB
SCC 0	655	4.36	38.0	Y, NB
SCC 10	662	4.33	36.6	Y, NB
SCC 20	671	4.15	35.6	Y, NB
SCC 30	679	4.05	35.0	Y, NB
SCC 40	687	3.97	32.0	Y, NB
SCC 50	694	3.93	30.8	Y, NB
SCC 60	712	3.84	30.0	Y, NB
SCC 70	724	3.76	24.0	Y, NB
SCC 80	735	3.71	23.0	Y, NB
SCC 90	741	3.63	8.0	Y, NB
SCC 100	752	3.55	3.0	Y, NB

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a. Slump-Flow value versus percentage varies of Slag

b. T-500 value versus percentage varies in Slag

c. U-Box value versus percentage varies in Slag

Fig 3: Graphical representation of Filling ability property

2) *Viscosity and Resistance to Segregation:* Viscosity is property to resistance to flow. Whenever the SCC shows low viscosity that means its having less resistance to flow and shows high flow rate. This property is determined by the V-Funnel test, the time in seconds decreases in increase in percentage of slag. Resistance to segregation is the property which characterized the ability to resist the segregation. It has been found out by V-Funnel apparatus by T5 minute test, here also the value of time decreases in increase in percentage of slag.

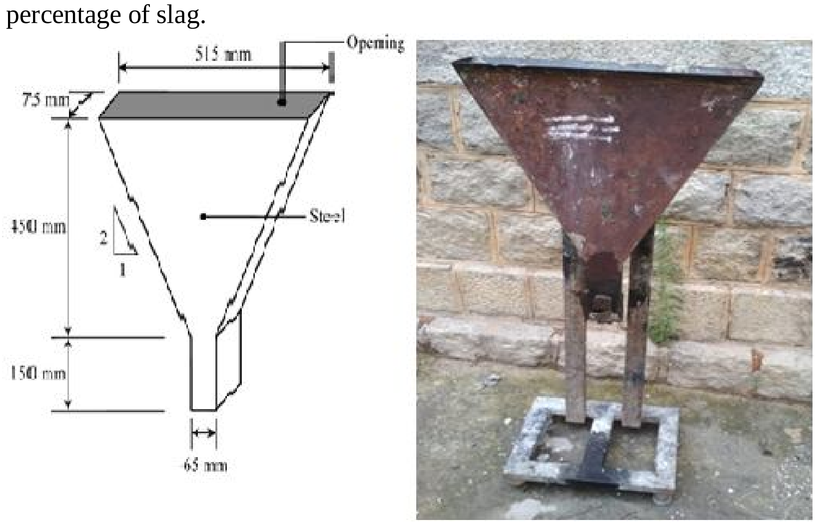

Fig 4: Apparatus for V-funnel test

Table 6. V-Funnel and T5 min test result.

Samples	V-Funnel test {6.0-12.0 sec}	V-Funnel T-5 min tests { ≤ 6.0sec}
SCC 0	11.48	5.59
SCC 10	11.16	5.47
SCC 20	11.04	5.16
SCC 30	10.79	5.07
SCC 40	10.39	5.02
SCC 50	10.17	4.86
SCC 60	09.02	4.22
SCC 70	08.84	4.13
SCC 80	08.02	4.09
SCC 90	07.29	3.86
SCC 100	07.17	3.67

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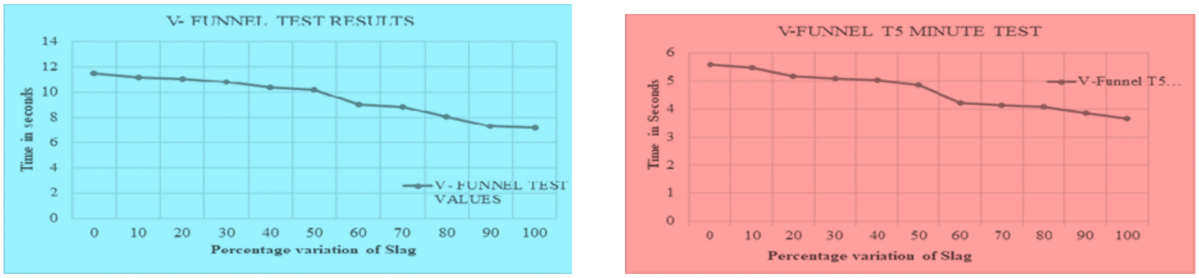


a. V-funnel value versus percentage variation in slag b. T5 value versus percentage variation in slag

Fig 5: Graphical representation of Viscosity and segregation resistance property

3) *Passing Ability*: Passing ability is the property of the SCC to flow easy through the spaces of reinforcement within the formwork by its self weight. Filling ability properties can be determined by L-Box test and the value increases in increase in percentage of slag. If blocking ratio is one represents the property of water, J-Ring test, here the value increases in increases in slag percentage.

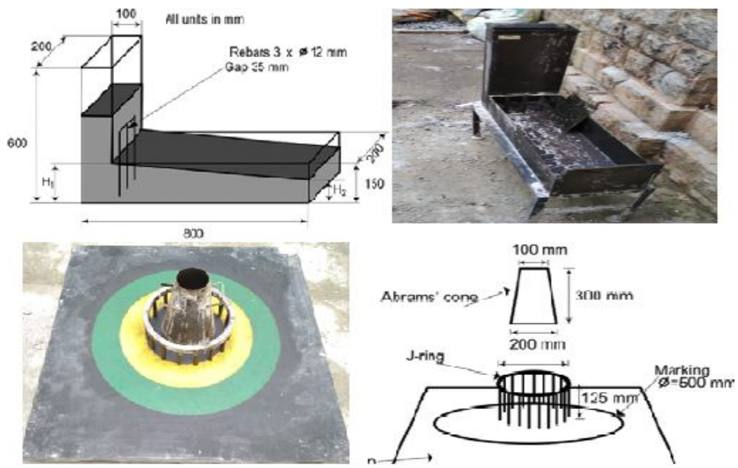
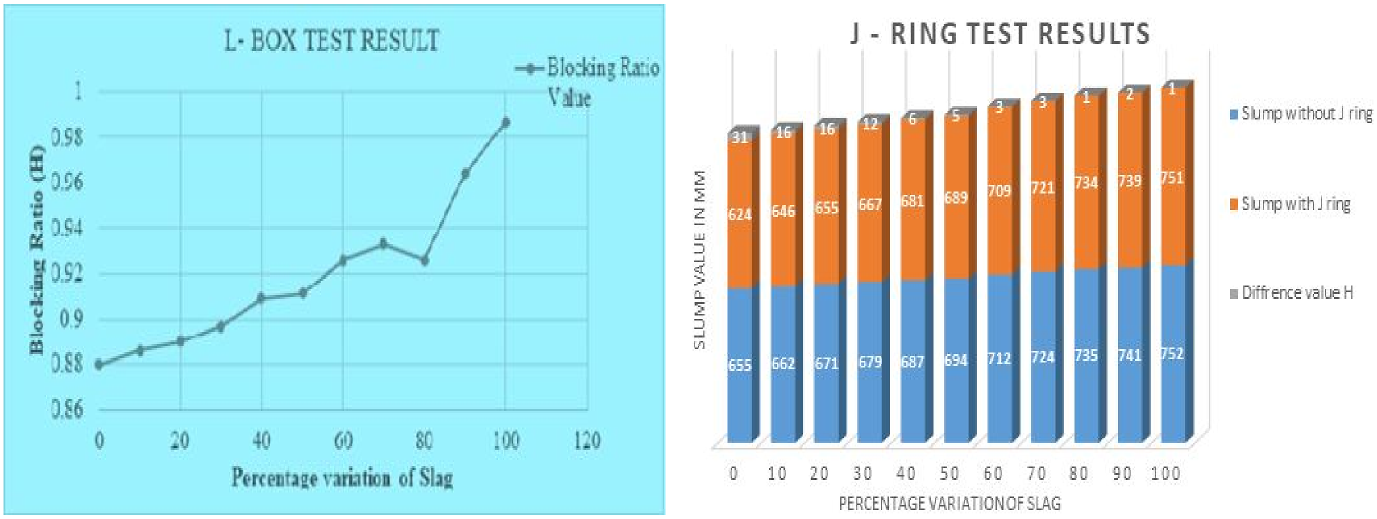


Fig 6: Apparatus for L-Box and J-Ring test

Table 7. L-Box and J-Ring test result.

Samples	Blocking Ratio (H=H-2 / H-1) {1.0-0.8}	Slump Value Without J- Ring D1 mm	Slump Value with J-Ring D2 mm	Difference value (D1-D2) {0-25 mm} If@{25-50}
SCC 0	0.880	655	624	31
SCC 10	0.886	662	646	16
SCC 20	0.890	671	655	16
SCC 30	0.897	679	667	12
SCC 40	0.909	687	681	06
SCC 50	0.911	694	689	05
SCC 60	0.926	712	709	03
SCC 70	0.933	724	721	03
SCC 80	0.926	735	734	01
SCC 90	0.964	741	739	02
SCC100	0.987	752	751	01

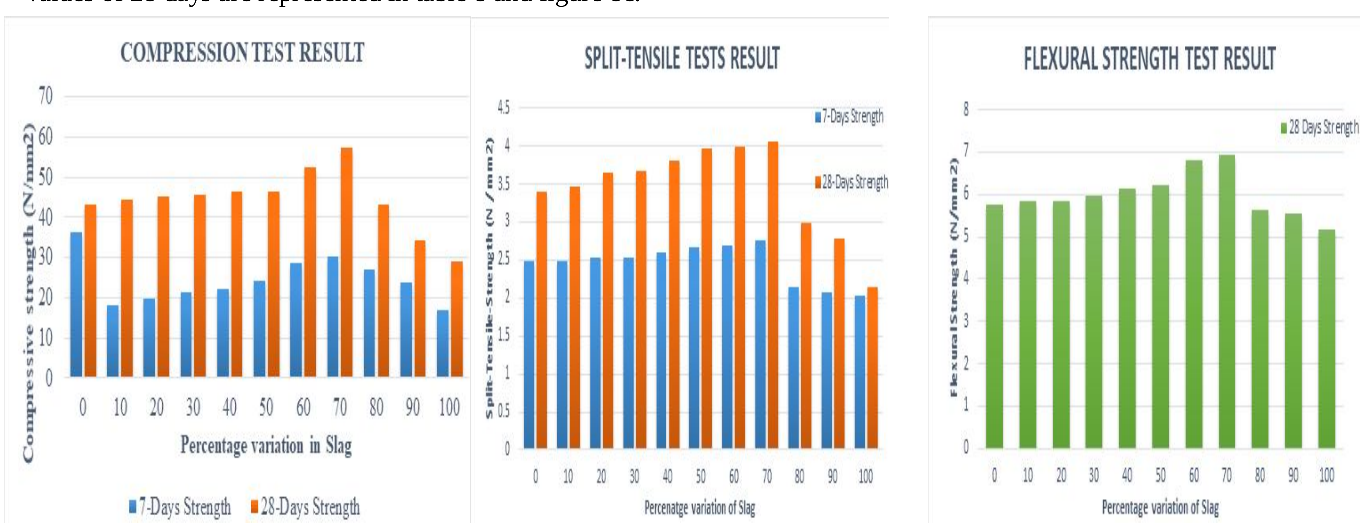


a. L-Box results versus percentage variation in slag b. J-Ring test result versus percentage variation in slag

Fig 7: Graphical representation of Passing Ability property

B. Test on Hardened Concrete

1) *Compression Test*: Compressive strength can be determined by the compression test. Here the cube of 150 mm^3 dimension is casted for testing, the mean average strength value for the three cube specimens are considered. The compressive strength results are mentioned in the table 8 and figure 8a.
2) *Split tensile test:* Usually concrete may not allowed for direct tension due to their brittle nature and least tensile strength. The maximum load at where members of concrete may get cracks, it is the point which required for knowing about tensile strength for the concrete. Here specimen of 300 mm length and 150 mm diameter were casted. Table 8 and figure 8b represents the Split-Tensile value.
3) *Flexural Strength:* The specimen of 500mm in length, 100mm in width and 100 mm in depth is casted and placed at machines in which loads are acted to top most layer for beam specimen, along 2 sides spaced 20cm or 13.3cm spacing. Specimen axis is aligned with loaded device axis. The applying load should be in increasing order upto specimen get fails. Flexural strength values of 28 days are represented in table 8 and figure 8c.



a. Average Compressive strength value with % varies in slag for 7 & 28 days **b.** Average Split-Tensile strength value with % varies in slag for 7 & 28 days **c.** Average 28 days flexural strength value versus percentage varies in slag

Fig 8: Graphical representation of Hardened concrete property

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Table 8. Concrete hardened property test result.

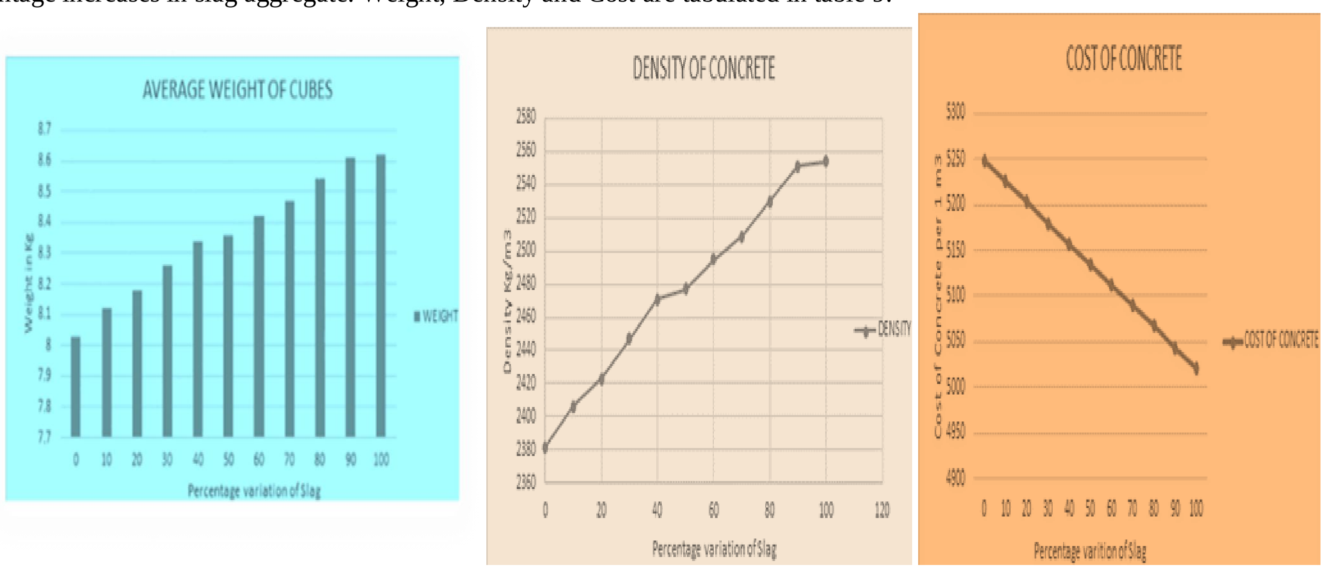
Sample	Compression Test (N/ mm^2)	Compression Test (N/ mm^2)	Split-Tensile Test (N/ mm^2)	Split-Tensile Test (N/ mm^2)	Flexural Test (N/ mm^2)
	7-Days	28-Days	7-Days	28-Days	28-Days
SCC 0	36.30	43.10	2.48	3.40	5.75
SCC 10	18.20	44.30	2.49	3.46	5.82
SCC 20	19.80	45.10	2.52	3.64	5.84
SCC 30	21.50	45.70	2.53	3.67	5.96
SCC 40	22.30	46.30	2.61	3.82	6.12
SCC 50	24.20	46.50	2.67	3.97	6.23
SCC 60	28.80	52.60	2.69	3.98	6.80
SCC70	30.40	57.30	2.77	4.06	6.92
SCC 80	27.00	43.00	2.14	2.98	5.63
SCC 90	23.80	34.40	2.08	2.78	5.54
SCC 100	17.00	29.20	2.02	2.14	5.17

Table 9. Tabulation of weight, density of cube and cost of concrete per cum.

Slag aggregates in %	weight of cube (Kg)	Density of Concrete Kg/ cum	Cost of concrete per 1 cum in Rs
0	8.03	2382	5248
10	8.12	2406	5226
20	8.18	2423	5203
30	8.26	2447	5180
40	8.34	2471	5157
50	8.36	2477	5135
60	8.42	2495	5113
70	8.47	2509	5089
80	8.54	2530	5067
90	8.61	2551	5043
100	8.62	2554	5021

C. *Weight, Density and Cost analysis*

Weight of the each cube is tabulated. The weight of the cube is increases from SCC0 to SCC10 due to slag aggregates having more specific gravity. Cost analysis per cum of concrete is calculated as per SR 2014-15 PWD, Karnataka. Here the cost decreases when percentage increases in slag aggregate. Weight, Density and Cost are tabulated in table 9.



a. Average weight of the cube versus slag percentage

b. Density of the concrete per cum versus variation in slag percentage

c. Cost analysis of concrete per cum VS percentage variation in slag

Fig 9: Graphical representation of weight, density and cost analysis

VI. CONCLUSION

This work entitles with the replacement of Normal Coarse aggregate with the Ferrous Manganese Steel Slag aggregate by percentage. As the SCC is made according to the NAN-Su designs and EFNARC guidelines.

A. The numbers of trial mix were made and finalized the proportion of **1: 0.42: 4.07: 2.19** as Cement of 345 kg, GGBS of 145 kg, Fine-aggregate of 1403 Kgs and Coarse-aggregate of 756 Kgs per cum with W/C ratio as 0.40.

B. Slump-flow value for SCC0 and SCC100 gives a result of 655 mm and 752 mm respectively. The flow value increase with increase in the slag aggregate. Compare to 0% replacement of coarse-aggregate, 100% replacement of coarse-aggregate shows the 15 percent increase in slump flow value.

C. T500 test value shows a decrease from SCC0 to SCC100. The results being 4.36 seconds for SCC0and 3.55 seconds for SCC100.

D. The result of U-Box test shows the trend of decrease from SCC0 to SCC100. The result of SCC0 being 38.0 and SCC100 is 3.0 mm.

E. Viscosity by V-Funnel tests gives 11.48 seconds to 7.17 seconds for SCC100. This shows there is decrease in viscosity with increase in percentage of slag.

F. The results T5 test for SCC0 and SCC100 are 5.59 seconds and 3.67 seconds respectively. This shows there is a decrease in segregation.

G. The blocking ratios of the L-Box test results gets reduces as the percentage replacement of the coarse aggregate increases. The passing ability thus increase by 12.15 % from SCC0 to SCC100.

H. The value of compressive strength for the design mix SCC0 without having ferrous manganese slag as coarse aggregate is 43.10 MPa at 28-days. Similarly for mix SCC10, SCC20, SCC30, SCC40, SCC50, SCC60, **SCC70**, SCC80, SCC90 and SCC100 gives 44.30, 45.10, 45.70, 46.30, 46.50, 52.60, **57.30**,43, 34.40, 29.20 MPa respectively at 28 days.

I. The percent increment in compressive strengths is found as 32.94 percent for SCC 70 with-respect-to SCC 0. The compressive strengths increase with increases in the percent replacement for ferrous manganese slag aggregates i.e., SCC0 upto SCC70. Thereafter for SCC80, SCC90, SCC100 mix strength decreases with increases in the percentage of slag.

J. Similarly the Split-Tensile Strength, upto 70 percent replacement of natural coarse aggregate gives a good result.

K. Percentage increases in the Split-Tensile Strength of SCC70 over the SCC0 will be 19.41 percent increment.

L. The Flexural-Strength is increased with increases in percent replacement of ferrous manganese slag aggregate upto 70 percent in the SCC mix.

M. Compressive, Split-Tensile strength and Flexural strength decrease after SCC70 mix proportion due to increase in voids present between the rounded granular slag aggregates.

N. There is an increase in weight of 7.34 percent from SCC0 to SCC100 and increase in density with 7.22 percent from SCC0 to SCC100 .

O. Rate analysis shows that the cost of concrete preparation per 1 cum will be decreases when increase in the Ferrous Manganese slag from 0 to 100 percent. And the percentage decrease in the range of 4.3 percent between SCC0 and SCC100.

P. The design mix sample of SCC 70 which is having 70 percent of Ferrous Manganese slag concluded that it has the decent self compacting concrete's fresh and mechanical properties and also it having decent compressive, split tensile and flexural strength.

VII. ACKNOWLEDGMENT

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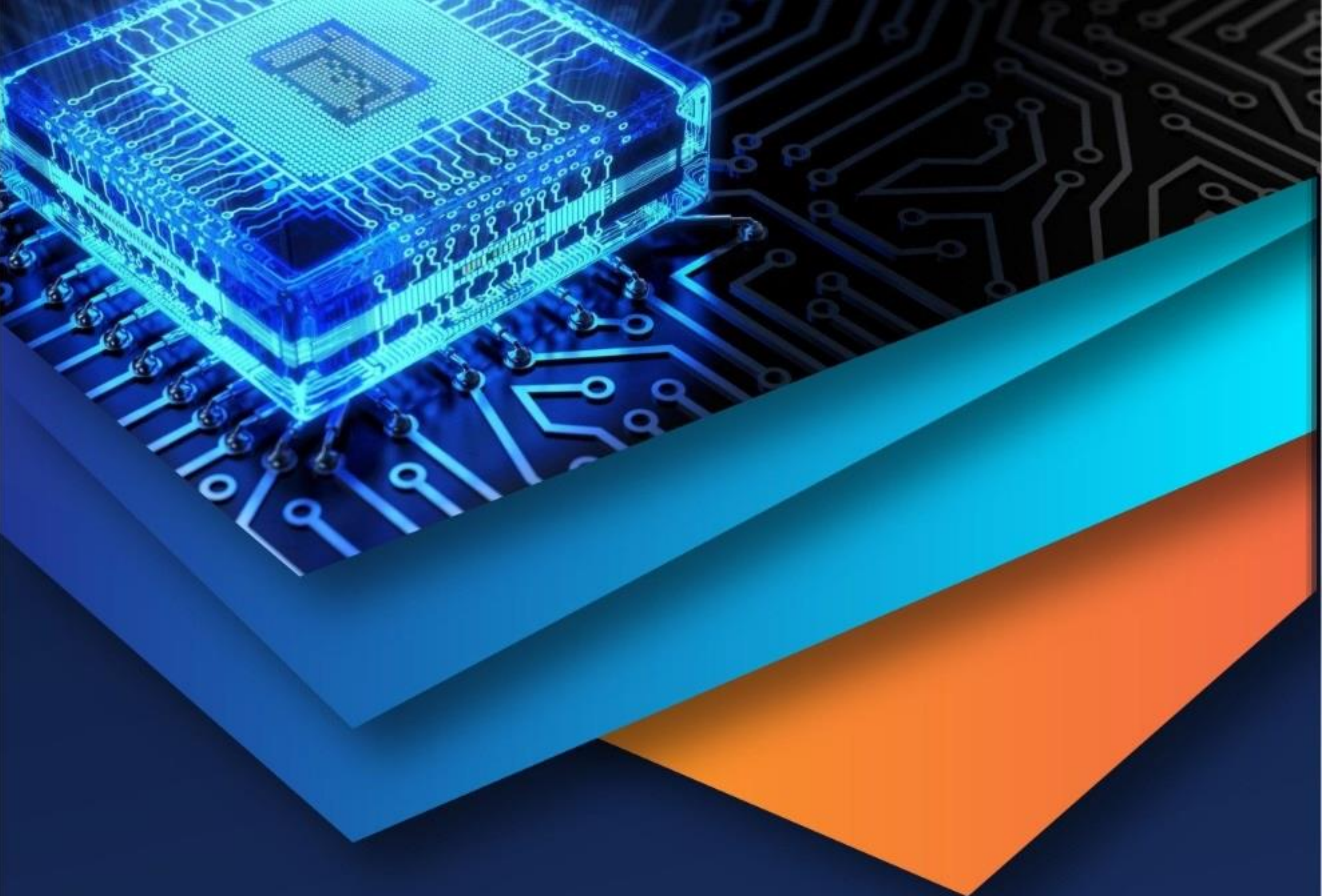

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