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Experimental Study on The Properties of Self Compacting Concrete with Ground Granulated Blast Furnace Slag and Micro Silica

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Abstract: Compacting of concrete is one of the major concepts in civil construction in day-to-day life. The main factors effecting due to improper compacting concrete causes leakages, corrosion which finally leads disintegration of the structure to encounter this conflict we prefer good compacting as also compaction plays prominent role in any civil constructions.

based on availability resources and type of construction different methods in compaction is preferred. So based on some critical areas and places where human and machine involvement is restricted in those areas we can go prefer for Self-compacting concrete. This is what my thesis completely talks about the process and requirements that necessary to make the study successful.

I. Introduction

In the years of 19th century, the civil structures have major issue with durability in Japan to avoid this and to provide good durable concrete structures adequate compaction Is necessary by very skilled labor but by then as there is fall in skilled labor in Japan is the reason why compaction of human and machine made is challenged with the concept of self-compacting concrete. Self-compacting concrete is done under the own weight of concrete.

It has lot terminologies to figure out like self-levelled concrete, high workable and flowable concrete, self-consolidated concrete. This concrete undergo compaction without cavities and entrainment of air.

Ingredients of this type of concrete are as same as conventional type concrete but to develop self-compacting behavior to the concrete the usage of admixtures is expected.

II. Literature Review

a) Okuamura in 2003 was the first to explore SCC he developed on methods testing, mix designs to be preferred also the type of admixtures. The project outcomes are as follows.
   i) Coarse aggregate influences the flowability of fresh concrete highly depends on size of obstacle.
   ii) SCC can be tested in V-flow & Slump flow.

b) Jagdish Vengala have checked the process to develop the SCC firstly ACI mix design was preferred to get high slump 100mm with no superplasticizer moving on coarse aggregate replaced by fly ash and Poly carboxylic ether based super plasticizer, but there is no fixed grade preferred in this thesis.
   i) The conclusion was Flowability can be improved by adding fly ash.

c) Chattopadyay & Subraminan did various studies on mix proportions of SCC by taking reference case studies of Okuamura thesis and observed that could be suitable for rounded gravel aggregates. Welan gum in optimal dosage is considered the bleeding tendency also enough dosage of micro silica used to reduce setting time from 16hrs to 10hrs and increased the compressive strength.
   i) The water share is of 170-176kg/m^3 for medium compressive strength.

III. Theoretical Framework

3.1 Materials of self-compacting concrete

1. Cement
2. Fine Aggregate
3. Coarse Aggregate
4. Water
5. Mineral admixtures
6. Chemical Admixtures

Now will discuss about Mineral and Chemical admixtures as we are already familiar with Cement, Fine and Coarse Aggregate

Mineral Admixtures:
1. Fly Ash: The fine material used to better workability, but the main disadvantage cannot upgrade the pozzolanic conditioning. The setting time of SCC with respective high volume fly ash made to delay for 3 to 4 hours.
2. Ground Granulated Blast furnace slag: Reportedly use of slag helps to strengthen of concrete compared with fly ash.
3. Silica Fume: Used to attain high strength concrete. The application of 8 silica by replacing cement helped to reduce washout loss and improves segregation resistance when compared to normal conventional concrete. Also, have the properties to enrich the durability and reduce bleeding using micro silica.
4. Stone powder: Crushed material of Limestone, dolomite & granite etc., are used. Limestone powder is preferred for fineness. Whereas Dolomite might exhibit durability risk due to alkali- carbonate reaction.

Chemical Admixtures: Often used Chemical Admixtures within SCC as follows
1. High range water reducers: It's a super plasticizer, Deformability including flowability is maintained in concrete using super plasticizer, also used to decrease the water volume required for concrete as fluid mix and plays prominent role in reducing W/CM ratio. Preferred examples to be (HRWR) are Melamine, Naphthalene based Sulphonates & Poly carboxylic ether.
2. Viscosity Modifying Agent: These polymers are water soluble in order to increase solubility. VMA's also termed to be Anti bleeding & Anti washout admixtures. Some of them are Guar gum, Hydro Propyl Methyl Cellulose & Welan gum etc.,

3.2 Self Compacting Concrete Mechanism

SCC to designed that it could be self-levelled and have ability to deform by its own weight resulting in restricted air entrainment. The Major fact is to restrict compaction mechanically and manually. High challenge in this includes concrete to be fully flowable with no bleeding and segregation therefore cement and mortar of SCC needs possessing greater viscosity to enrich flowability and maintains non sedimentation of large aggregates.
There are Three major types of SCC Powdered, Viscosity Agent SCC & Combination type SCC.

3.3 Methods for Testing Self-Compatibility

Main aim of the SCC tests is to evaluate the concrete is self-compacting or not secondly to evaluate deformability /Viscosity to estimate proper mix proportionality. Filling ability, Passing ability & Resistance to segregation.

3.3.1 Slump flow test

Base plate and slump cone were moisture & 6 kgs desired concrete mix was taken and filled in slump cone using trowel, The surplus amount of concrete removed around the cone. Now the cone lifted vertically allowing concrete flow freely. Now note the time taken for concrete to reach 500mm spread circle calculated using stopwatch.

This test is used to assess the filling ability of concrete. From studies of Nagataki it's declared that slump flow 500-700 mm is necessary for SSC.

- Slump flow more than 700mm segregation of concrete occurs.
- Slump flow less than 500mm resulted in insufficient flow through highly congested reinforcement.
- So, the suggested slump flow for SCC 600-750mm.

3.3.2 V-Funnel Test

12 liters of concrete mix is needed to conduct this experiment V-Funnel placed on firm ground and moistened using oil. The trapped door was closed and filled with concrete mix without compacting and funnel was levelled with trowel. Now the trap door is to be opened within 10 seconds and concrete is allowed to flow out by gravity now using stopwatch measure the time for the complete concrete mix to flow out. The whole test to be completed in 5 minutes.
Now without cleaning the same funnel concrete is refilled without compacting. Now the trap door opened after 5 minutes, and concrete is allowed to flow under gravity after the second fill of the funnel. Now measure the time taken to flow out the concrete.

- This experiment used for flow of concrete
- Flow time less than 6 sec proposed to prefer for SCC

3.3.2 L-Box test

This is a widely used test, suitable for laboratory and site use. It assesses filling ability and passing ability of SCC, and segregation was also detected visually.

14 Liters concrete mix necessary to perform the experiment mean while apparatus moistened, and vertical section is filled with concrete and leave it stand for 1 minute. Now the sliding gate is opened to allow the concrete to flow into horizontal section using stopwatch measure the concrete reach 200mm and 400mm distances were recorded.

- The distance H1 & H2 are measured after the flow has been stopped
- The blocking ratio H2/H1 is calculated
- The whole test must be performed within 5 minutes

IV. Experimental Programe:

4.1 Materials used for the experiment

The materials used in the production of SCC were cement, ground granulated blast furnace slag, silica fume, fine aggregate, Coarse aggregate a High ange water reducer and a viscosity-modifying agent. The properties of the ingredients are given below.

4.1.1Ground granulated blast furnace slag

Used as filler in SCC. It has been reported that the use of slag results in better early strength of concrete when compared to fly ash (fang et al., 1999). Physical properties of GGBS:

Glass content	93
Colour	Grey
Texture	Fine
Specific gravity	2.85
Plasticity index	Non-plastic
Optimum moisture content %	25.60
Maximum dry density gm/cc	1.64
Cohesion Kpa	4.00
Angle of internal friction degrees	31

4.1.2 Silica Fume

Silica Fume is a mineral admixture used to produce hight strength of concrete. Usage of 8% silica fume as cement replacement is reported to reduce washout loss and improves segregation resistance.

4.1.3 Viscosity Modifying Agents

These are water soluble also known as anti-washout or anti-bleeding admixtures. The basic purpose of VMA is stabilizing the concrete mixture and restricts dosage of superplasticizer.

Hydroxy Propyl methyl cellulose was used as VMA

Glass content	93
Colour	Grey
Texture	Fine
Specific gravity	2.85
Plasticity index	Non-plastic
Optimum moisture content %	25.60
Maximum dry density gm/cc	1.64
Cohesion Kpa	4.00
Angle of internal friction degrees	31

V. Mix Design

Initially, the mix was designed by Indian standard method of concrete mix design (IS: (10262 — 1982). Then it was optimized based on the specifications given by some of the researchers. To proceed towards achieving SCC, coarse aggregate content is then replaced with fine aggregate, and fine powder. Super plasticizer and viscosity modifying agents were incorporated in the mix to get a flowable and stable mix. The Initial Mix Design details adopted in this study are as follows:

The concrete was designed for M40 grade

Design stipulations:

Maximum size of aggregates (restricted to 10 mm only) : 10 mm
Degree of workability : 0.8 C.F
Type of exposure : mild

Test data for materials:

Specific gravity of cement : 3.14
Compressive strength of cement at 28 days :57 MPa
Specific gravity of course aggregate :2.85
Specific gravity of fine aggregate :2.65
Sand conforming to zone 2
The target average compressive strength at 28 days, Fck = fck + t*S
FCK = Characteristic compressive strength at 28 days
S = Standard deviation
t = A static, depending upon the accepted proportion of low results and number of tests
The value of t is taken as 1.65 from table2 (IS: 10262-1982) and s=5 from table 8 (IS 456:2000)
Therefore fck = 40 + (1.65*5) = 48.25 MPa

Selection of water-cement ratio:

From (IS: 10262 - 1982) the water-cement ratio required for the target mean strength of 48.25 MPa is 0.39. Hence water cement ratio of 0.39 was adopted.

Selection of water and sand content:

From Table 5 (IS: 10262-1982) for 10mm maximum size aggregate, water content per cubic meter of concrete = 200 kg and sand content as percentage of total aggregate by absolute volume = 28 percent.

Correction for sand:

For each 0.05 increase in free water-cement ratio correction for sand is +1 percent.

0.35-0.39/0.05 (+1) = -0.8

Therefore, sand content =28-0.8 = 27.2%

Coarse aggregate = 100-27.2 = 72.8 %

Determination of cementitious content:

Water to cement ratio = 0.39

Water = 200 Lt/m^3

Cement = 200/0.39 = 512.82 kg/m^3

In this, cement was replaced with 40% GGBS

Cement (60%) = (60*512.82)/100 = 307.69 kg/m^3

Slag (40%) = (40*512.82)/100 = 205.13 kg/m^3

Determination of fine aggregate content:

[1-0.0275] = 1/1000 [200 + 30769/3.14 + 20513/2.85 + 1/0.272 * fa/2.65]

Fa = 434.32 kg/m^3

Determination of coarse aggregate content:

[1-0.0275] = 1/1000 [200+307.69/3.14 + 205.13/2.85 + 1/0.272 * ca/2.85]

Ca = 1250.32 kg/m^3

Solid volume = weight(cement + slag + F.A + C.A) / corresponding specific gravities

(307.69/3.14) + (205.13/2.85) + (434.32/2.65) + (1250.32/2.85) = 772.57

50% of solid volume = (50*772.57/100) = 386.29

Weight of coarse aggregate= 386.29*specific gravity of CA => 386.29*2.85=1100.91kg/m^3

[1-1.0275] = 1/1000[200+307.69/3.14+205.13/2.85 + 1/x*1100.91/2.85]

x=0.6411

therefore, coarse aggregate content = 64.11%, Sand content = 35.89%, Fa = 573.06 kg/m3

Final mix:

Water **:** [cement + sand] **:** F.A **:** C.A

200 **:** [(307.69+205.13)/512.82] **:** 573.06 **:** 1100.91

0.39 **:** 1 **:** 1.12 **:** 2.15

Components	
Water (lit)	200.00
Cement(kg)	307.69
Slag(kg)	205.13
w/cm by mass	0.39
w/p ratio by mass	1.18
Fine aggregate (kg)	573.06
Coarse aggregate(kg)	1100.91
Ratio of sand to mortar volume	0.37
Ratio of C.A to the total aggregate volume	0.641

VI. Test Results: Trail Mixes

W/cm =water to cementitious materials ratio

SP = Superplasticizer dosage by weight of cementitious material

Mix designation	Cementitious cement	Cementitious slag	Fine aggregate	Coarse aggregate	slag	w/cm*	Sp** lit/100kg	Slump(mm)	Method of compaction cubes
G1	307.69	205.13	573.06	1100.91	-	0.39	-	28	Vibration
G2	300.00	190.48	582.08	1088.70	-	0.42	-	30	Vibration
G3	316.92	211.28	548.72	1088.34	-	0.39	-	30	Vibration
G4	316.92	211.28	548.72	1088.34	-	0.39	0.8	170	Hand compaction
G5	316.92	211.28	603.14	1033.92	-	0.39	0.9	210	Hand compaction
G6	264.10	264.10	544.63	1088.36	-	0.39	1.0	250	Hand compaction
G7	316.92	211.28	654.83	982.22	-	0.39	1.0	235	Hand compaction
G8	316.92	211.28	654.83	933.11	49.11	0.39	1.0	245	Hand compaction
G9	316.92	211.28	654.83	886.45	95.77	0.39	1.05	Failed	Vibration

Mix designation	Cementitious cement	Cementitious slag	Fine aggregate	Coarse aggregate	slag	w/c m*	Sp** lit/100kg	Slump(mm)	Method of compaction cubes
G10	300.00	112.00	735.95	1001.69	-	0.50	-	85	Vibration
G11	300.00	112.00	735.95	1001.61	-	0.50	0.80	125	Hand compaction
G12	300.00	112.00	786.03	951.52	-	0.50	0.85	205	Hand compaction
G13	300.00	112.00	878.81	858.75	-	0.50	0.85	205	Pouring
G14	300.0	112.00	878.81	815.81	42.94	0.50	0.85	243	Pouring

Mix designation	Cement	Cementitious slag	SF	Fine aggregate	Coarse aggregate	slag	SF	w/c m	SP *	VMA**	Slump(mm)	Spread(mm)	Methods of compaction of cubes
G15	300	91.40	20.60	830.46	901.49	-	-	0.50	0.85	-	210	-	pouring
G16	300	91.40	20.60	780.37	904.00	47.58	-	0.50	0.85	-	235	467.50	Pouring
G17	300	91.40	20.60	730.29	858.80	92.78	-	0.50	0.85	0.02	262	455.00	Pouring
G18	300	91.40	20.60	730.29	814.73	172.82	-	0.50	0.90	0.02	275	587.50	Pouring
G19	300	91.40	20.60	730.29	814.73	172.82	-	0.50	1.00	0.0225	281	540.00	Pouring
G20	300	91.40	20.60	730.29	814.73	152.82	20.00	0.50	0.95	0.0185	260	526.50	Pouring
G21	300	91.40	20.60	730.29	814.73	152.82	20.00	0.50	0.95	0.0180	270	515.00	Pouring

Mix designation	Cement	Cementitious slag	SF	Fine aggregate	Coarse aggregate	slag	SF	w/c m	SP *	VMA**	Slump(mm)	Spread(mm)	Methods of compaction of cubes
JI	300.02	77.86	45.32	741.85	734.04	137.71	5.80	0.5	1	0.0195	285	729.50	pouring
J2	330.02	77.86	45.32	741.85	734.04	32.71	5.80	0.5	0.97	0.0200	283	712.50	Pouring
J3	320.41	75.59	44.00	732.86	723.32	183.34	7.15	0.5	1.04	0.0200	287	745.50	Pouring

Mix -J3

This is the final mix proportion through which SCC is achieved satisfactorily. The mix design procedure for this trail is as follows:

The concrete was designed for M40 grade.

Design stipulation

Characteristic compressive strength of concrete at 28 days : 40Mpa
Maximum size of aggregate : 10 mm
(Size of aggregate restricted to 10mm only for achieving flowability)
Type of exposure : mild

Test data of materials

Specific gravity of cement : 3.14
Compressive strength of cement at 28 days : 57 Mpa
Specific gravity of coarse aggregate : 2.81
Specific gravity of fine aggregate : 2.65
Sand conforming to Zone 2

The target average compressive strength at 28 days, F^ck = fck + t*s
Fck = characteristic compressive strength at 28 days.
S = standard deviation
T = a static, depending upon the accepted proportion of low results and the number of tests.
The value of t is taken as 1.65 from table 2(IS:10262-1982) and s=5 from table 8 (IS:456-2000).
Therefore, f^ck = 40+(1.65*5) = 48.25Mpa

Selection of water cement ratio:

w/cm = 0.5

water content per cubic meter of concrete =220 kg and sand content as percentage of total aggregate by absolute volume =28%

Correction for sand:

For each 0.05 increases in free water to cement ratio, correction for sand is +1%

= {(0.35-0.50)/(0.05)}(+1)

= -3

Therefore, sand content = 28-3 =25%

Coarse aggregate content =100-25=75%

Determination of cementitious content:

w/cm = 0.5

water = 220 litre/m^3

cement = 220/0.5 =440 kg/m^3

In this, cement was replaced with 17.18% GGBS

Cement (72.82%) = 320.41kg/m^3

Slag (17.18%) = 75.59 kg/m^3

SF (10%) = 44 kg/m^3

Determination of fine and coarse aggregate contents:

The amount of entrapped air int the concrete is taken as 3%

V=[w+c/sc+1/p*fa/Sfa]*1/1000

V=[w+c/Sc+1/1-p*Ca/Sca]*1/1000

V=absolute volume of fresh concrete, which is equal to gross volume (m^3) minus the volume of entrapped air,

W=mass of water (kg)per m^3 of concrete

C= mass of cement(kg) perm^3 of concrete

Sc=specific gravity of cement

P=ratio of fine aggregate to total aggregate by absolute volume

Fa,ca=total masses of fine aggregate and coarse aggregate (kg)per m^3 of concrete respectively

SfaSca=specific gravities of saturated surfaces dry fine aggregate and coarse aggregate respectively

[1-0.03] = 1/10^3 [220+ {(320.41/3.14) + (75.59/2.85) + (44/2.2) + (1/0.25) * (fa/2.65)}]

Fa=398.45 kg/m3

[1-0.03] = 1/10^3 [220+ {(320.41/3.14) + (75.59/2.85) + (44/2.2) + (1/0.75) * (Ca/2.81)}]

Ca=1267.53 kg/m^3

Following are the mix proportions by weight

Water	:	[cement + slag + SF]	:	F.A	:	C.A
200	:	(320.41+75.59+44)/440	:	398.45	:	1267.53
0.5	:	1.0	:	0.91	:	2.88

Now by applying the conditions given by EFNARC standards (2002), the mix proportion have been modified further by fixing the fine aggregate content to 50% of mortar volume.

Mortar volume = weight [cement, slag, SF, F.A, Water] divided by corresponding specific gravities respectively.

= {(320.41/3.14) + (75.59/2.85) + (44/2.2) + (398.45/2.65)}]+220

= 518.92

30% of mortar volume=259.46

Weight of fine aggregate=687.57 kg/m^3

Now the percentage of fine aggregate 1.e, x was found by substituting the weight of fine aggregate in the equation no 1

[1-0.03] = 1/10^3 [220+ {(320.41/3.14) + (75.59/2.85) + (44/2.2) + (1/X) * (687.57/2.65)}]

X = 0.4314

Therefore, fine aggregate content = 43.14%

Hence coarse aggregate = 56.86%

By using this% of coarse aggregate, the weight of coarse aggregate content was calculated content was calculated as follows:

By substituting the values in the equation no 2

[1-0.03] = 1/10^3 [220+ {(320.41/3.14) + (75.59/2.85) + (44/2.2) + (1/0.5686) * (Ca/2.81)}]

Ca = 960.98 kg/m^3

Hence the final mix proportions by weight are

Water	:	[cement + slag + SF]	:	F.A	:	C.A
220	:	(320.41+75.59+44)/440	:	687.57	:	960.98
0.5	:	1.0	:	1.56	:	2.18

C.A reduced by 5% by volume by F.A

(960.98*5)/(2.81*100) = 17.09

C.A = 960.68 - 17.09 * 2.81 = 912.96 kg/m^3

F.A = 687.57 + 17.09 * 2.65 = 732.86 kg/m^3

Mix proportions by weight

Water	:	[cement + slag + SF]	:	F.A	:	C.A
220	:	(320.41+75.59+44)/440	:	732.86	:	1267.53
0.5	:	1.0	:	1.67	:	2.08

C.A reduced by 1% by volume by SF

(912.96*1)/(2.81*100) = 3.25

C.A = 912.96 – 3.25 * 2.81 = 903.83 kg/m^3

SF = 3.25 * 2.2 = 7.15 kg/m^3

Mix proportions by weight

Water	:	[cement + slag + SF]	:	F.A	:	C.A	:	SF
220	:	(320.41+75.59+44)/440	:	732.86	:	903.83	:	7.15
0.5	:	1.0	:	1.67	:	2.05	:	0.016

C.A reduced by 20% by volume by slag

(903.83*20)/(2.81*100) = 64.3295

C.A = 903.83 – 64.3295 – 2.81 = 723.32 kg/m^3

Slag = 64.3295 * 2.85 = 183.34 kg/m^3

Mix proportions by weight

Water	:	[cement + slag + SF]	:	F.A	:	C.A	: SF	: Slag
220	:	(320.41+75.59+44)/440	:	732.86	:	732.32	: 7.15	: 183.34
0.5	:	1.0	:	1.67	:	1.64	: 0.016	: 0.42

Volumetric relationships of mixes:

Mix designation	Water(lt)	W/P ratio by volume	Ration of sand to mortar volume	Ratio of CA to total aggregate volume	Volume of fraction of paste (Vp)	Total powder content by volume
G1	200	1.177	0.369	0.641	0.380	169.97
G2	206	1.269	0.374	0.635	0.379	162.38
G3	206	1.177	0.352	0.648	0.393	175.06
G4	206	1.177	0.352	0.648	0.393	175.06
G5	206	1.177	0.374	0.615	0.392	175.06
G6	206	1.165	0.349	0.650	0.395	176.79
G7	206	1.177	0.393	0.582	0.392	175.06
G8	206	1.070	0.383	0.569	0.410	192.29
G9	206	0.990	0.373	0.557	0.426	208.66
G10	206	1.530	0.449	0.559	0.351	134.83
G11	206	1.530	0.449	0.559	0.351	134.83
G12	206	1.530	0.446	0.529	0.351	134.83
G13	206	1.530	0.493	0.476	0.350	134.83
G14	206	1.374	0.482	0.463	0.365	149.90
G15	206	1.504	0.477	0.502	0.392	136.97
G16	206	1.341	0.450	0.519	0.370	153.66
G17	206	1.215	0.439	0.506	0.387	169.52
G18	206	1.040	0.406	0.513	0.417	197.61
G19	206	1.040	0.406	0.513	0.417	197.61
G20	206	1.030	0.405	0.513	0.418	197.61
G21	206	1.030	0.405	0.513	0.418	199.68
J1	226.6	0.395	0.395	0.483	0.442	202.22
J2	226.6	0.395	0.395	0.483	0.442	202.22
J3	220	0.388	0.388	0.482	0.449	216.14

Strength Results:

Mix designation	Compressive strength at 28 days, Mpa
G1	37.62
G2	40.15
G3	45.92
G4	29.18
G5	25.33
G6	28.59
G7	27.26
G8	33.34
G9	40.00
G10	39.41
G11	32.44
G12	26.85
G13	27.41
G14	33.63
G15	36.59
G16	35.78
G17	37.34
G18	44.44
G19	42.07
G20	42.22
G21	48.67
J1	52.29
J2	52.89
J3	53.48

VII. Further Scope of Work

The possibility of producing SCC with different other mineral admixtures has to be tried in the laboratory. Various trails for producing SCC corresponding to target strengths must be made. The effect of other viscosity modifying agents available elsewhere must be investigated. Other workability tests also are to be conducted. The correlations between various workability tests need to be addressed.

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