Compressive Strength of Different Grades of SCC Mix Using Portland Slag Cement (75%), GGBS (25%) and Replacing 20% Fine Aggregate with Copper Slag

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Abstract - *The use of Self Compacting Concrete (SCC) is increasing day by day in India and many infrastructure projects are going in for SCC, the example being 'The Signature Bridge' on river Yamuna near New Delhi and the Bandra-Worli sea link project, Mumbai.*

The Nan-Su mix design is used for OPC concrete, but its application for Portland Slag Cement (PSC) concrete is not investigated as per the literature review. The present work proposes modification to Nan-Su mix design for application to PSC concrete. The workability properties Slump Flow, J-Ring, V- Funnel and L Box values satisfy EFNARC Guidelines. Also establishes the use of Cooper Slag as mineral admixture to concrete.

Key Words: SCC, Copper Slag, Portland Slag Cement, Nan-Su Mix Design, EFNARC Guidelines, Slump Flow Test, J-Ring Test, V-Funnel Test and L-Box Test.

1. INTRODUCTION

The use of Self Compacting Concrete (SCC) is increasing day by day in India and many infrastructure projects are going in for SCC, the example being 'The Signature Bridge' on river Yamuna near New Delhi and the Bandra-Worli sea link project, Mumbai.

The workability properties of SCC can be characterized by the three properties (EFNARC, 2002): filling ability, passing ability and segregation resistance. Additional properties, such as robustness and consistence retention, are also important in applications of SCC. Robustness refers to the ability of SCC to retain its fresh property when the quantity and quality of constituent materials and the environmental conditions change. Consistence retention refers to the period of duration of fresh properties.

The Nan-Su mix design application for Portland Slag Cement (PSC) concrete is not investigated as per the literature review. In the present investigation modification is proposed for application in design of SCC with PSC. Also, the use of industrial by product copper slag as mineral admixture is studied.

2. EXPERIMENTAL INVESTIGATION

2.1 Nan-Su Mix Design

The steps used in Nan-Su Mix Design are given below.

Step 1: Calculation of Coarse and Fine aggregate contents:

$$W_{fa} = PF \times \Upsilon_{fa}\left(\frac{s}{a}\right) \quad (1)$$

$$W_{ca} = PF \times \Upsilon_{ca}\left(1-\frac{s}{a}\right) \quad (2)$$

Where,
W_{fa} : content of fine aggregates in SCC (kg/m^3),
W_{ca} : content of coarse aggregates in SCC (kg/m^3),
Υ_{fa} : unit volume weight of loosely piled saturated surface-dry fine aggregates in air (kg/m^3),
Υ_{ca} : unit volume weight of loosely piled saturated surface-dry coarse aggregates in air (kg/m^3),
PF : packing factor, the ratio of mass of aggregates of tightly packed state in SCC to that of loosely packed state in air,
$\frac{s}{a}$: volume ratio of fine aggregates (sand) to total aggregates, which ranges from 50% to 57%.

Step 2: Calculation of Cement Content:

$$C = \frac{f_c^{'}}{20}(\,for\ OPC\ Concrete) \quad (3)$$

$$C = \frac{1.5\,f_c^{'}}{20}(\,for\ PSC\ Concrete)\quad \text{Proposed} \quad (4)$$

Where,
C= Cement content (kg/m^3);
f'_c = designed compressive strength (psi).

Step 3: Calculation of mixing water content required by cement:

$$W_{wc} = \frac{W}{C} \times C \quad (5)$$

Where,
W_{wc} = content of mixing water content required by cement (kg/m^3),
$\frac{W}{C}$= the water/cement ratio by weight.

Step 4: Calculation of SP dosage

Dosage of SP used $W_{sp} = n\% \times W_C$ (6)
Where,
n% = Dosage of SP as 1%
W_c = Cement content in kg/m^3
Amount of water in SP $W_{wsp} = (1\text{-}m\%)\, W_{sp}$ (7)
Where,
m% = Amount of binders and its solid content of SP taken as 50%.

Step 5: Calculation FA and GGBS contents:

$$V_{PF} + V_{PG} = \left[1 - \left(\frac{W_{ca}}{\Upsilon_W G_{ca}} + \frac{W_{fa}}{\Upsilon_W G_{fa}} + \frac{W_c}{\Upsilon_W G_c} + \frac{W_w}{\Upsilon_W G_w} + V_a\right)\right] \quad (8)$$

Where, Υ_w = density of water,
G_{ca} = specific gravity of coarse aggregates,
G_{fa} = specific gravity of fine aggregates,
G_c = specific gravity of Cement,
G_w = specific gravity of water,
V_a = air content in SCC (%).
As per Nansu Mix Design the formula for calculating W_{PM} is

$$V_{PF} + V_{PG} = \left[1 + \left(\frac{W}{F}\right)\right] \times A\% \times \frac{W_{PM}}{\Upsilon_W G_F} + \left[1 + \left(\frac{W}{G}\right)\right] \times B\% \times \frac{W_{PM}}{\Upsilon_W G_G} \quad (9)$$

Where A% = percentage of Fly Ash (Weight basis)

B% = percentage of GGBS (Weight basis)

In this design A% = 100%, B% = 0%

But as per following derivation the modified formula (Eq. 9a) for calculating W_{PM} is used in the present investigation.

$$V_{PF} + V_{PG} = V_F + V_{WF} + V_G + V_{WG}$$
$$= \frac{W_F}{\Upsilon_W G_F} + \frac{W_{WF}}{\Upsilon_W} + \frac{W_G}{\Upsilon_W G_G} + \frac{W_{WG}}{\Upsilon_W}$$
$$= \left(\frac{W_F}{\Upsilon_W G_F} + \frac{W_{WF}}{W_F}.\frac{W_F}{\Upsilon_W}\right) + \left(\frac{W_G}{\Upsilon_W G_G} + \frac{W_{WG}}{W_G}.\frac{W_G}{\Upsilon_W}\right)$$
$$= \frac{W_F}{\Upsilon_W}\left(\frac{1}{G_F} + \frac{W}{F}\right) + \frac{W_G}{\Upsilon_W}\left(\frac{1}{G_G} + \frac{W}{G}\right)$$
$$V_{PF} + V_{PG} = \left[1 + \left(\frac{W}{F}\right)G_F\right] \times A\% \times \frac{W_{PM}}{\Upsilon_W G_F} + \left[1 + \left(\frac{W}{G}\right)G_G\right] \times B\% \times \frac{W_{PM}}{\Upsilon_W G_G} \quad (9a)$$

Where, G_G, G_{FA}, $\frac{W}{F}$ and $\frac{W}{G}$ can be obtained from tests, A% and B% are given and $V_{PF} + V_{PG}$ can be obtained from Eq.(8)

$W_F = A\% \times W_{PM}$ (10)

$W_G = B\% \times W_{PM}$ (11)

Mixing water content required for fly ash paste is obtained from Eq(12)

$W_{WF} = \frac{W}{F} \times W_F$ (12)

Mixing water content required for GGBS paste is obtained from Eq(13)

$W_{WG} = \frac{W}{G} \times W_G$ (13)

Step 6: Calculation of mixing water content needed in SCC:

The mixing water content required by SCC is the total amount of water needed for cement, FA and GGBS in the mix. Therefore, it can be calculated from Eq. (14)
$W_w = W_{wc} + W_{WG} + W_{WF} - W_{wsp}$ (14)

2.2 Materials Used

The materials used in the SCC are

i. Portland Slag Cement
ii. GGBS
iii. Fly Ash
iv. Fine Aggregate
v. Copper Slag
vi. Coarse Aggregate (12.5 mm and 20 mm)
vii. Master Glenium Sky 8233 (Super Plasticizer)

2.21 Material Properties

The properties of materials are determined and are shown in Table 1, 2 & 3. Table 4 shows the super plasticizer properties as given by the manufacturer.

Table 1: Cementitious Materials Properties

Properties	Portland Slag Cement (PSC)	GGBS	Fly Ash	PSC (75%) & GGBS (25%)
Specific Gravity of Cement	2.94	2.83	2.24	2.97
Standard Consistency of Cement	36%	36%	67%	34%
Initial Setting Time	105 minutes	More than 600 minutes	More than 600 minutes	75 minutes
Final Setting time	380 minutes	---	---	320 minutes
Fineness of Cement	2%	0%	28%	1%
Soundness of cement	1 mm	---	---	1 mm

Table 2: Fine Aggregate and Copper Slag Materials Properties

Properties	Fine Aggregate	Copper Slag
Specific Gravity	2.60	3.67
Bulk Density (Loosely Packed)	1518 Kg/m^3	1860 Kg/m^3
Bulk Density (Tightly Packed)	1655 Kg/m^3	2097 Kg/m^3
Fineness Modulus	2.89 (Zone-2)	2.90 (Zone-2)

Table 3: Coarse Aggregate Materials Properties

Properties		Results obtained		Standard range
		20 mm	12.5 mm	
Specific Gravity		2.805	2.715	2.6-2.8
Bulk Density (Loosely Packed)		1428.95 Kg/m^3	1315.18 Kg/m^3	1450-2082 Kg/m^3
Bulk Density (Tightly packed)		1617.30 Kg/m^3	1488.83Kg/m^3	1450-2082Kg/m^3
Shape Tests	a)Flakiness Test	13.87 %	33.67 %	Less than 40%
	b)Elongation Test	24.98 %	38.71 %	Less than 40%
Impact Test		---	13.19 %	Less than 35%
Abrasion Test		14.30 %		Less than 40%
Crushing Test		---	16.89 %	Less than 45%

Table 4: Master Glenium Sky 8233(Super Plasticizer)

Properties	Test Results of Manufacturer Catalogue
Appearance	Reddish Brown Liquid
pH Value	≥ 6
Solubility	Readily Soluble In Water
Relative Density	1.08 ± 0.02 at 25°C
Chloride Content	0%
Solid	50 ± 1%

2.3. Mix Design

Concrete grades M20, M25, M30, M35, M40 are considered for investigation. M20 to M40 mixes are designed as per the above Nan-Su mix design with proposed changes. Target mean strength as per IS 10262:2019 is used for M20 to M40 mixes in Eq. 4 in place of f'_c. The cement content calculated from Eq. 4 is replaced with 25% of GGBS. The fine aggregate content calculated from Eq. 1 is replaced with 20% of copper slag. Based on trial mixes W/C ratio and SP dosage is fixed satisfying EFNARC guidelines. The mix proportions for the above SCC grades are shown in Table 5.

Table -5 Mix Proportions M1-M5

Mix Trails	Grades	Compressive Strength (N/mm²)	W/C Ratio (as per NANSU)	W/C Ratio	W/P Ratio	SP Dosage(%)	SP Content (Kg/m³)	Water (lit/m³)	Cement (Kg/m³)	Cement (Kg/m³)		Fine Aggregate (Kg/m³)	Fine Aggregate (Kg/m³)		Coarse Aggregate (Kg/m³)	Coarse Aggregate (Kg/m³)		Packing Factor
										Cement (75%)	GGBS (25%)		Fine Aggregate (80%)	Copper Slag (20%)		12.5 mm(70%)	20 mm (30%)	
M1	M20	20	0.47	0.727	0.467	1	2.894	210.61	289.35	217.01	72.33							
M2	M25	25	0.455	0.611	0.451	0.91	3.128	210.21	343.74	257.80	85.93							
M3	M30	30	0.44	0.506	0.436	082	3.412	210.56	416.08	312.60	104.02	884.083	707.267	176.817	725.760	508.032	217.728	1.12
M4	M35	35	0.425	0.446	0.421	0.73	3.434	209.76	470.07	352.85	117.61							
M5	M40	40	0.41	0.397	0.397	0.65	3.412	208.73	524.86	393.64	131.21							

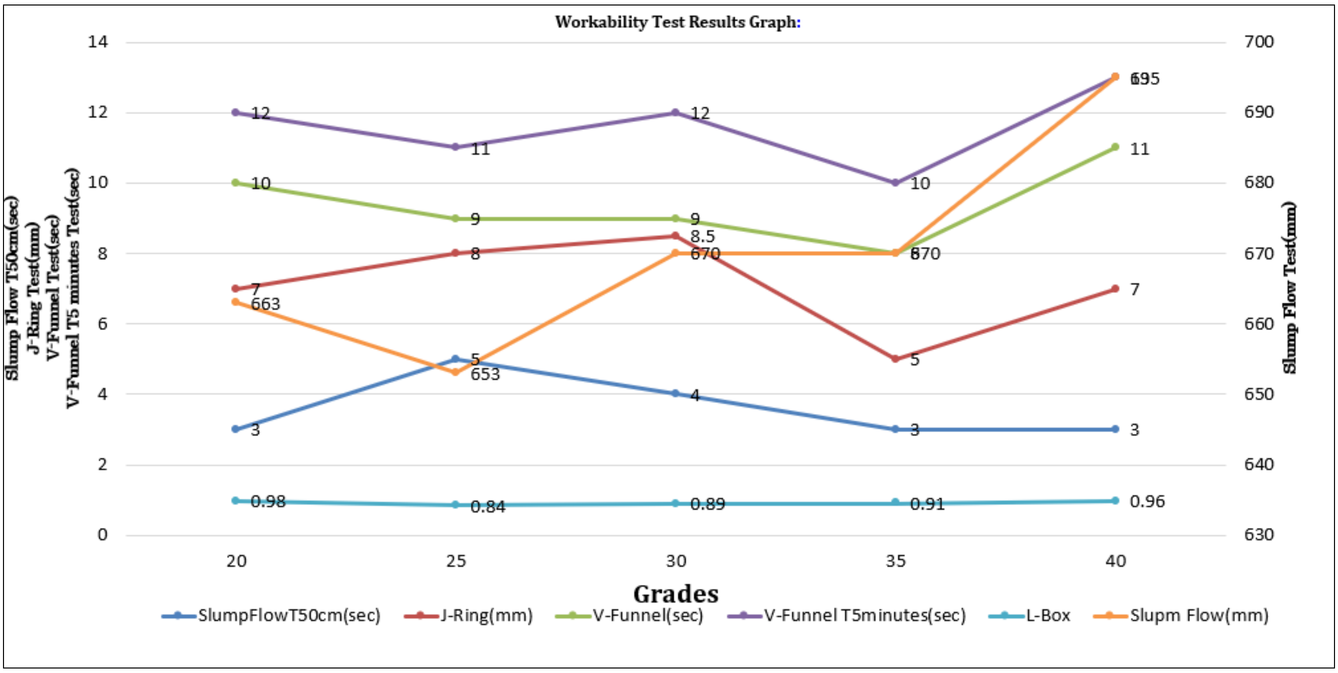

Fig 1. Fresh Properties of SCC

2.4. Workability Tests

Tests are conducted to find fresh properties of SCC. The results are shown in Table 6 and also in Fig. 1. All the test results are conforming to EFNARC guidelines for SCC.

Table-6 Fresh Properties of SCC

Grades	Slump Flow (mm)	Slump Flow T-50 cm (sec)	J-Ring (mm)	V-Funnel Test(sec)	V-Funnel $T_{5minutes}$ sec)	L-Box
M20	663	3	7	10	12	0.98
M25	653	5	8	9	11	0.84
M30	670	4	8.5	9	12	0.89
M35	670	3	5	8	10	0.91
M40	695	3	7	11	13	0.96
Ranges	**650-680**	**2-5**	**0-10**	**6-12**	**+3**	**0.8-1**

3.0 RESULTS & DISCUSSION

3.1 Compressive Strength of Mixes

Cubes are casted for each mix to determine the 3, 7 and 28 days compressive strength. The compressive strength of cubes for the mixes M20 to M40 grades are shown in Table 7 and the variation of compressive strength of above grades of concrete are shown in Fig 2.

Table 7 Compressive Strength Results

Mix Trails	Grades	Compressive Strength (N/mm²)		
		3 Days	7 Days	28 Days
M1	M20	8.38	14.99	22.86
M2	M25	11.23	20.37	32.74
M3	M30	13.17	25.62	37.39
M4	M35	20.6	30.13	36.44
M5	M40	22.33	34.58	44.98

The compressive strength obtained for all the grades is more than f_{ck} (f_{ck} =Characteristic compressive strength of concrete, for M20; f_{ck} =20 N/mm²). The compressive strength obtained for grades M25 & M30 is more than target mean strength.

The above results establish the use of proposed Eq. 4 for SCC with PSC. Copper slag can be used as mineral admixture for partially replacing fine aggregate.

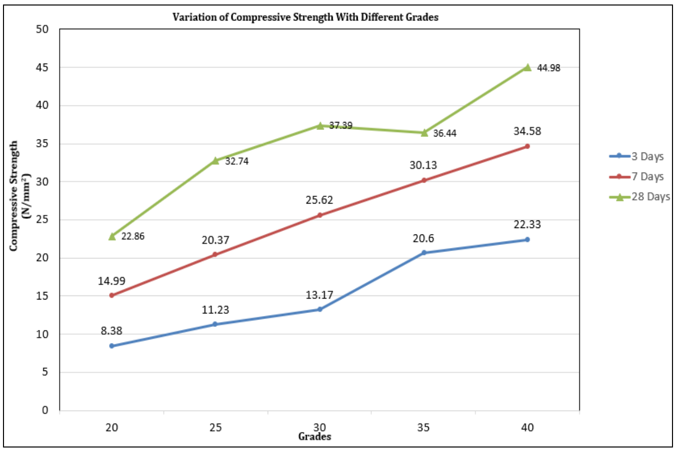

Fig 2. Variation of Compressive Strength with Different Grades

3.2 Non Destructive Tests

The results of Ultrasonic Pulse Velocity Test conducted on cubes at the age of 28 days is shown in Table 8 and in Fig 3. The quality of concrete is good based on the above test results.

Table 8 Ultrasonic Pulse Velocity Test Results

Mix	Grades	Ultrasonic Pulse Velocity(m/sec)	Quality of Concrete
M1	M20	3680	Good
M2	M25	4011	Good
M3	M30	4060	Good
M4	M35	4290	Good
M5	M40	4200	Good

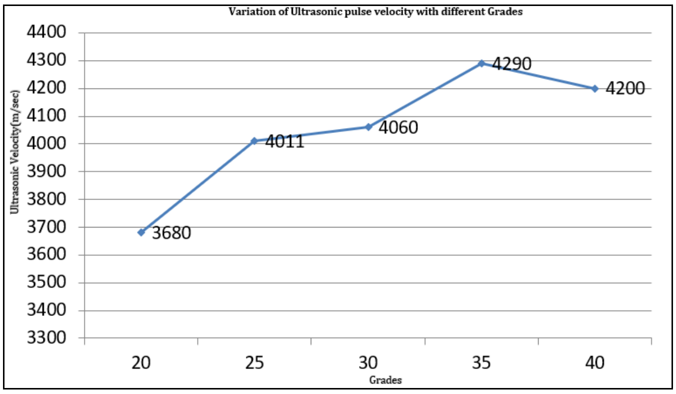

Fig 3. Variation of Ultrasonic Pulse Velocity with Different Grades

4. CONCLUSIONS

1. For all the grades the compressive strength obtained is more than characteristic compressive strength.
2. For M25 & M30 grades Compressive strength obtained is more than the target mean strength.
3. The quality of all the grades of concrete it good based on Ultrasonic Pulse Velocity test.
4. As per the results the modification proposed for Nan-Su mix design equation for the estimation of cement for PSC is acceptable.
5. Copper slag can be used as mineral admixture for partial replacing fine aggregate.

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