An investigation on the characteristic properties of high performance SCC with mineral admixtures

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In this experimental work, a mix design for Self-Compacting Concrete (SCC) has been carried out using Nan-Su method. Flow properties such as passing ability, filling ability, and segregation resistance were evaluated by varying the dosage of super plasticiser (HRWRA) and viscosity modifying admixture (VMA). The mix design incorporated fly ash, silica fume and metakaolin as mineral admixtures. Mix proportions for self compacting concrete of strengths M20, M30, M40 and M50 were developed. Nan-Su method method is suitable for SCC concrete grades which are more than M50 but for the normal grades such as M20 to M50, some modifications were needed in the mix design procedure. Tests revealed that the quantity of cement was insufficient to get the targeted strengths. Accordingly, trials were carried out to increase the cement content by reducing the mineral admixtures. Comparative evaluations of compressive strength, tensile strength, flexural strength, young's modulus, Poisson's ratio and density of concrete on 7 and 28 days cured specimens are reported Also, SCC's mechanical properties are compared with those of the conventional concrete.

Keywords: *Self-compacting concrete, flow ability, filling ability, segregation, high range water reducer, viscosity modifying admixture.*

Self-compacting concrete

With the construction industry becoming more discerning for performance of concrete, the demands are not only for the performance of hardened concrete, but also for fresh concrete properties, lower life cycle cost and higher durability of structures.

SCC with its ability to consolidate under its own weight is suitable for placing in difficult sections with congested reinforcement. Its use can help eliminate damages induced by vibration meant for compacting conventional concretes. Another advantage of using SCC is reduction in time needed to place the concrete in large sections. Also, SCC minimises voids in concrete, enhances strength and improves the durability of concretes.

The following are typical requirements of SCC

1. Filling ability: The ability of SCC to flow in to and fill completely all spaces within the formwork, under its own weight.

2. Passing ability: The ability of SCC to flow through tight opening such as spaces between steel reinforcing bars without segregation and blocking.

3. Segregation resistance: The ability of SCC to remain homogeneous in composition during transport and placing.

Experimental work

In the experimental work, the mix design was carried out using Nan-Su method for M20, M30, M40 and M50 grades of concrete. Cube specimens of 150 mm, cylindrical specimens of 150 mm diameter and 300 mm height and beam specimens of 150 mm x 150 mm x

Table 1. Normal cement concrete

Designed strength / materials	M20	M30	M40	M50
Cement, kg/m^3	361.84	456.23	550.00	653.125
FA, kg/m^3	675.50	605.53	444.00	401.90
CA, kg/m^3	1030.30	1022.77	1113.00	1068.90
Water, *l*	209.87	209.87	209.00	209.00
HRWRA, %	0.5	0.5	0.5	0.5

Table 2a. Materials required for M20 grade with fly ash, metakaolin and silica fume

Designed strength / materials	M20 / F	M20 / S	M20 / M	M20 / F / 60	M20 / S / 60	M20 / M / 60
Cement, kg/m^3	143.00	143.00	143.00	331.55	333.30	354.53
Mineral admixture, kg/m^3	314.25	318.18	352.56	125.70	127.27	141.02
Fine aggregate, kg/m^3	887.20	887.20	887.20	887.20	887.20	887.20
Coarse aggregate, kg/m^3	710.00	710.00	710.00	710.00	710.00	710.00
Water powder ratio	0.38	0.50	0.48	0.38	0.50	0.48
HRWRA, %	0.68	1.32	0.75	0.68	1.68	0.89
VMA, %	0.10	0.15	0.10	0.10	0.23	0.12

Table 2b. Materials required for M30 grade with fly ash, metakaolin and silica fume

Designed strength / Materials	M30 / F	M30 / S	M30 / M	M30 / F / 60	M30 / S / 60	M30 / M / 60
Cement, kg/m^3	215.00	215.00	215.00	369.86	369.77	389.61
Mineral admixture, kg/m^3	258.11	257.95	291.02	103.244	103.18	116.41
Fine aggregate, kg/m^3	887.20	887.20	887.20	887.20	887.20	887.20
Coarse aggregate, kg/m^3	710.00	710.00	710.00	710.00	710.00	710.00
Water powder ratio	0.38	0.50	0.48	0.38	0.50	0.48
HRWRA, %	0.68	1.40	0.75	0.81	1.71	0.90
VMA, %	0.16	0.19	0.15	0.16	0.28	0.17

Table 2c. Materials required for M40 grade with fly ash, metakaolin and silica fume

Designed strength / Materials	M40 / F	M40 / S	M40 / M	M40 / F / 60	M40 / S / 60	M40 / M / 60
Cement, kg/m^3	237.275	286.00	286.00	409.48	408.73	424.46
Mineral admixture, kg/m^3	219.975	204.54	205.80	82.32	81.82	92.308
Fine aggregate, kg/m^3	887.20	887.20	887.20	887.20	887.20	887.20
Coarse aggregate, kg/m^3	710.00	710.00	710.00	710.00	710.00	710.00
Water powder ratio	0.38	0.45	0.48	0.38	0.45	0.48
HRWRA, %	0.68	1.48	0.75	0.80	1.85	0.86
VMA, %	0.12	0.21	0.10	0.12	0.31	0.13

Table 2d. Materials required for M50 grade with fly ash, metakaolin and silica fume

Designed strength / materials	M50 /F	M50/S	M50/M	M50/ F/60	M50/ S/60	M50/ M/60
Cement, kg/m^3	354.142	357.14	357.14	442.342	445.1	456.37
Mineral admixture, Kg/m^3	147.00	146.6	165.38	58.80	58.64	66.15
Fine aggregate, kg/m^3	887.20	887.20	887.20	887.20	887.20	887.20
Coarse aggregate, kg/m^3	710.00	710.00	710.00	679.74	679.80	679.74
Water powder ratio	0.38	0.45	0.48	0.38	0.45	0.48
HRWRA, %	0.74	1.50	0.75	0.82	1.85	0.86
VMA, %	0.20	0.21	0.10	0.20	0.31	0.14

700 mm were cast to test mechanical properties of SCC. It was observed that the cement quantity was insufficient to meet the strength and durability properties of the concretes. The SCCs had fly ash, silica fume and metakaolin as mineral admixtures. Hence an attempt was made to find the correct quantity of cement in relation to the proportion of mineral admixture in the total powder content. To attain the mix proportion for the required strength, a number of trials were taken and a comparative study of properties of the SCC was carried out with those of the conventional concrete (CVC).

Table 3. Mix proportion of CVC and SCC

Grade of concrete	Normal concrete	SCC with fly ash	SCC with silica fume	SCC with metakaolin
M20	1:1.86:2.84:0.50	1:1.94:1.55:0.38	1:1.92:1.53:0.48	1:1.79:1.43:0.48
M30	1:1.32:2.24:0.40	1:1.86:1.50:0.38	1:1.88:1.50:0.48	1:1.75:1.40:0.48
M40	1:0.85:2.02:0.35	1:1.80:1.44:0.38	1:1.80:1.44:0.45	1:1.71:1.37:0.45
M50	1:0.65:1.64:0.35	1:1.77:1.42:0.38	1:1.76:1.40:0.45	1:1.70:1.36:0.45

Experiment

The basic properties of all the ingredients used for the mix design are given below.

- Cement: (IS 12269 : 1987)

- OPC 53 grade
- Specific gravity (G_c) - 3.18

- Fly ash

- Thermal power plant from Raichur
- Specific gravity (G_f) - 2.01

- Silica fume

- Specific gravity (G_s) - 2.00

- Metakaolin

- Specific gravity (G_m) - 2.50

- Fine aggregate

- Specific gravity (G_{fa}) - 2.64
- Unit mass (W_{fal}) - 1415 kg/m^3
- F.M - 2.52

- Coarse aggregate:

- Specific gravity (G_{ca}) - 2.65
- Unit mass (W_{cal})- 1383 kg/m^3
- F.M - 6.49

- Water

Ordinary potable tap water was used for mixing and curing the concrete specimen

- Superplasticiser

A superplasticiser was used which had an excellent dispersion properties.

- Viscosity modifying admixture (VMA)

The VMA which was ready to use as a liquid admixture.

Table 4. Workability Test Results with recommended values (one sample in each mix)

No	Method	Test Results				Recommend values	
		M20	M30	M40	M50	Min	Max
1	Slump flow, mm	725	710	700	670	650	800
2	T50 slump flow, s	3	3	4	5	2	5
3	V Funnel, s	8	9	9	10	6	12
4	L Box, H2/H1	0.90	0.90	0.84	0.84	0.8	1.0
5	U Box, H2-H1	10	15	18	20	0	30
6	J Ring, mm	4	4	5	6	3	10
7	Orimit, s	4	4	5	5	0	5

Other parameters considered in the mix design of SCC were:

- s/a-ratio: It is the ratio of fine aggregates to total mass of aggregates. This usually ranges from 50% to 57%; In this experimental work s/a was taken as 55%.
- Packing factor: It is defined as of mass aggregates of tightly packed state to that of loosely packed state.

Mix design method adopted

Conventional concrete (CVC)

Mix design was carried out following IS 10262 : 1999 Code and the calculated quantities of all the ingredients for the conventional concrete are shown in the Table 1.

Self-compacting concrete

Nan-Su Method: This method is suitable for SCC concrete grades which are more than M50 but for the normal grades such as M20 to M50, some modifications were needed in the mix design procedure.

The mix proportions of SCCs arrived at using Nan-Su method for grades M20 to M50 are shown in Table 2. Table 3 compares the mix proportions of SCC and CVC. The flow properties were evaluated by varying the dosage of HRWRA and VMA till they satisfied the basic criteria of both SCC. Table 4 shows some of the flow properties. The standard cubes, cylinders and beam

specimens were cast to test mechanical properties of both SCC and CVC after 7 and 28 days curing. Table 5 summarises the results.

Conclusions

The following conclusions have been drawn:

- Optimum dosage of superplasticiser enhanced the flow property of the concrete. Bleeding and segregation were controlled by the addition of VMA in SCC containing fly ash, silica fume and metakaolin
- To fulfil the requirement of SCC in fresh state and evaluate flow characteristics using Slump cone, L-Box, U-Box, V-Funnel, J-Ring and Orimet and to fix dosage of superplastciser (HRWRA) and VMA a number of trials as per EFNARC guidelines were needed.
- During the trial mix, it was observed that, flow properties were better with metakaolin than with fly ash or silica fume in all the four grades tested.
- The addition of VMA increased the viscosity of the concrete as due to reduced internal friction between the fine and coarse aggregates. As a result overall improvements in the flow and filling ability of the SCC were observed.
- By reducing the quantity of fly ash, silica fume and metakaolin in the mix, flow ability reduced by about 5% to 10%. This may be due to the friction between coarse aggregate and fine aggregate as these mineral admixtures act as filler.

Table 5a. M20 grade with 60% replacement of fly ash, silica fume, metakaolin

Name of the test /age in days	CVCM20		SCCM20/F		SCCM20/S		SCCM20/M	
	7	28	7	28	7	28	7	28
Compressive strength, MPa	18.33	28.45	19.99	28.55	25.22	37.77	22.11	30.11
Tensile strength, MPa	1.783	2.548	1.83	3.10	2.65	3.93	2.92	4.12
Flexural strength, MPa	3.95	4.86	3.75	4.75	4.25	5.15	4.15	5.7
Young's modulus, GPa	-	34.2	-	33.5	-	33.00	-	32.55
Poisson's ratio	-	0.21	-	0.21	-	0.21	-	0.20
Density, KN/m^3	-	24.29	-	23.41	-	22.51	-	22.52

CVCM20, CVCM30, CVCM40 and CVCM50 – Conventional concrete of M20, M30, M40 and M50 grades.

SCCM20/F, SCCM20/M and SCCM20/S – M20 Grade of SCC with fly ash, metakaolin and silica fume at 60% replacement.

SCCM30/F, SCCM30/M and SCCM30/S – M30 Grade of SCC with fly ash, metakaolin and silica fume at 60% replacement

SCCM40/F, SCCM40/M and SCCM40/S – M40 Grade of SCC with fly ash, metakaolin and silica fume at 60% replacement.

SCCM50/F, SCCM50/M and SCCM50/S – M50 Grade of SCC with fly ash, metakaolin and silica fume at 60% replacement.

Table 5b. M30 grade with 60% replacement of fly ash, silica fume and matekiolin

Name of the test /Age in days	CVCM30		SCCM30/F		SCCM30/S		SCCM30/M	
	7	28	7	28	7	28	7	28
Compressive strength, MPa	26.82	39.77	28.77	38.50	28.77	39.00	27.10	40.33
Tensile strength, MPa	2.85	3.96	2.63	3.65	2.50	3.95	3.00	4.25
Flexural strength, MPa	4.25	5.95	4.38	5.85	4.50	5.75	4.10	5.42
Yong's modulus, GPa	-	35.2	-	35.0	-	33.50	-	33.68
Poisson's ratio	-	0.20	-	0.193	-	0.195	-	0.21
Density, KN/m^3	-	24.50	-	23.70	-	22.95	-	22.52

Table 5c. M40 grade with 60% replacement of fly ash, silica fume and matekiolin

Name of the test /age in days	CVCM40		SCCM40/F		SCCM40/S		SCCM40/M	
	7	28	7	28	7	28	7	28
Compressive strength, MPa	36.22	50.22	37.45	52.55	37.11	55.22	36.70	52.44
Tensile strength, MPa	3.60	5.52	3.75	4.95	3.54	5.22	3.65	4.95
Flexural strength, MPa	4.65	6.72	4.63	6.55	4.85	6.75	4.62	6.32
Young's modulus, GPa	-	35.6	-	34.00	-	33.25	-	34.25
Poisson's ratio	-	0.18	-	0.18	-	0.190	-	0.19
Density, KN/m^3	-	24.70	-	24.00	-	23.60	-	23.11

Table 5d. M50 grade with 60% replacement of fly ash, silica fume and metakaolin

Name of the test /Age in days	CVCM50		SCCM50/F		SCCM50/S		SCCM50/M	
	7	28	7	28	7	28	7	28
Compressive strength, MPa	43.50	62.55	43.28	62.11	42.00	64.00	42.23	63.44
Tensile strength, MPa	4.41	5.81	4.56	5.42	4.25	6.45	4.23	6.10
Flexural strength, MPa	5.65	7.25	5.78	7.35	5.85	7.35	5.25	7.25
Yong's modulus, GPa	-	35.8	-	35.20	-	33.40	-	35.35
Poisson's ratio	-	0.17	-	0.175	-	0.18	-	0.18
Density, KN/m^3	-	24.59	-	24.65	-	24.25	-	24.25

- It was found that mechanical properties in SCC's were low compared to those of the CVC; hence cement was used to replace fly ash, silica fume and metakaolin in all the mixes. At 60% replacement, required strengths were achieved. This improvement was attributed to enhancement in binding property and strength of the mortar.
- It was observed, that the mechanical properties were better with silica fume than with fly ash and metakaolin .
- With silica fume, appreciable improvement of strength in M20 and slight improvement of strength in M30, M40 and M50 grades of concrete was noted.
- It was observed that the deformation (longitudinal and lateral) was more in M20 concrete and it gradually reduced as the specimens strength increased to M30, M40 and M50. This trend was reflected in Young's modulus which was less in M20 and gradually increased in M30, M40 and M50 grades. These were true for both SCC and CVC.
- The Poisson's ratios of all the mixes were almost same in all the mixes of SCC.
- The density of concrete depended on the amount of mineral admixture in each mix for all the grades. This was because of difference in specific gravity of cement, fly ash and metakaolin.

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