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Experimental study of optimal self compacting concrete with spent foundry sand as partial replacement for M-sand using Taguchi approach

D.B. Nirmala, S. Raviraj
Dept of Construction Technology and Management, SJCE, Mysuru, India
e-mail: nirmala_db@yahoo.com, ravirajshivaiah@gmail.com

Abstract

This paper presents the application of Taguchi approach to obtain optimal mix proportion for Self Compacting Concrete (SCC) containing spent foundry sand and M-sand. Spent foundry sand is used as a partial replacement for M- sand. The SCC mix has seven control factors namely, Coarse aggregate, M-sand with Spent Foundry sand, Cement, Fly ash, Water, Super plasticizer and Viscosity modifying agent. Modified Nan Su method is used to proportion the initial SCC mix. L18 ($2^1\times^{37)}$ Orthogonal Arrays (OA) with the seven control factors having 3 levels is used in Taguchi approach which resulted in 18 SCC mix proportions. All mixtures are extensively tested both in fresh and hardened states to verify whether they meet the practical and technical requirements of SCC. The quality characteristics considering "Nominal the better" situation is applied to the test results to arrive at the optimal SCC mix proportion. Test results indicate that the optimal mix satisfies the requirements of fresh and hardened properties of SCC. The study reveals the feasibility of using spent foundry sand as a partial replacement of M-sand in SCC and also that Taguchi method is a reliable tool to arrive at optimal mix proportion of SCC.

Key words: Fly ash, M-sand, Spent foundry sand, Self compacting concrete, Modified Nan Su method, Taguchi approach, Signal to noise ratio, Optimal mix proportion

1 Introduction

In 1983, the major topic of interest in Japan regarding concrete structures was the durability. It was observed that sufficient compaction by skilled workers was needed to achieve durable concrete structures. The quality of construction work declined in Japan's construction industry because of reduction in the number of skilled workers. This resulted in the development of Self-Compacting Concrete (SCC). Concrete has the ability to flow into every corner even in the region of congested reinforcement by means of its own weight, thus eliminating the need for vibrating compaction. SCC was initially conceptualized by Okamura in 1986 which was later investigated by several other researchers.

Due to its high fluidity, self compacting ability and segregation resistance, SCC enormously reduces honeycombs in concrete; and greatly improves the reliability and durability of the reinforced concrete structures. Also, with the presence of high content of fine particles in

SCC, the flow properties are different than conventional concrete. Filling ability, passing ability and resistance to segregation are three essential properties to be satisfied in SCC.
In SCC low water –cement ratio (W/C) and a high-range water reducing admixture combined with stabilizing agents, such as Viscosity Modifying Admixture (VMA) are used. Use of high amount of mineral admixtures such as Flyash, Ground Granulated Blast Furnace Slag (GGBFS) and Limestone powder increases the fine contents in SCC mixture. This reduces the cost and improves the rheological properties of SCC mixtures.

Arriving at the optimum mixture for SCC involves large number of experiments which consumes lot of time. In the present study Taguchi Orthogonal Array (OA) is used to arrive at the optimal mixture for SCC with less number of experiments. This method has a systematic approach to optimize the seven control parameters in SCC. Researchers have earlier applied Taguchi method to normal concrete in a limited way by changing one or two parameters. Fauzan et al. (2003) determined the most influencing factor of concrete containing air entraining agent and high range water reducer agent by using Taguchi design of experiments. Ribeiro et al. (2003) carried out experiments to optimize the influence of composition and curing conditions in bending strength of polyster and epoxy concrete using Taguchi method. Turkmen et al. (2003) studied the optimum conditions for mechanical properties of high strength concrete with silica fume and blast furnace slag admixtures by using Taguchi method. Nirmala and Raviraj (2015) in their studies investigated the applicability of Taguchi orthogonal array approach of design of experiments techniques to SCC containing flyash and spent foundry sand as a partial replacement for natural sand to obtain optimal SCC mix proportion. The study confirmed the feasibility of using spent foundry sand as a partial replacement for natural sand and Taguchi method as reliable tool to arrive at optimal mix proportion of SCC. The above studies suggest that Taguchi method of experimentation can be used as an effective tool to minimise the number of experiments to decide the influencing parameters in concrete.

In foundries, high quality silica sand is used as molding material to cast ferrous and non-ferrous metals. When sand is reused for several times it becomes a waste material and is referred as Used or Spent Foundry Sand (USF or SFS). Most of the SFS are classified as nonhazardous waste. Khatib and Ellis (2001) studied the effect of replacing SFS with ‘up to” 100% river sand and concluded that concrete undergoes shrinkage and loss in strength with an increase in the amount of SFS. A study on concrete blocks, bricks and paving stones containing SFS as a partial replacement of sand in the range of 25% to 35% was attempted by Naik et al. (2003). Reduction in compressive strength and decrease in freezing and thawing resistance were reported in mixtures containing SFS. However these reduced values still satisfied the specification of concrete blocks, bricks and paving stones.

From many years river sand is used as fine aggregate in concrete. Of late due to restrictions on use of river sand, Manufactured sand (M-sand) obtained from crushing rock deposits is used as fine aggregate. M-sand is generally well graded, more angular and has a rougher surface texture than naturally weathered sand particles. High amount of fines are present in M- sand in which the fines are rock dust rather than silt and clay as in the case of natural sand. The maximum permissible limit on fines (75 µm passing) in M-sand as per ASTM C 33 is 7% and the limit proposed for fines (150 µm passing) in M-sand as per the Indian standards (IS 383:1970) is 20%. High powder content (cement, cementitious materials and inert fillers) is essential in SCC to achieve the desired fresh concrete properties. Since M-sand contains excess of fines it contributes to the filler content of the SCC. While a number of studies have been conducted on the use M-sand in conventional concrete, the studies of its application in SCC and also replacement for M-sand with spent foundry sand are limited.

Based on an investigation on SCC with M-sand Prakash and Manu (2010) reported that relatively higher paste volume is essential to achieve the required flow for SCC using M-sand, as compared to river sand. Low and medium strength (25–60 MPa) SCCs were achieved by using M-sand based on the approach adopted in their study. Results showed that it is possible to successfully utilize M-sand in producing SCC.

Ganeshwaran and Suji (2013) carried out experiments on SCC using flyash and M-sand for fresh and durability properties. The test results showed an increase in percentage of water absorption at initial ages. However, there was no significant rise in water absorption at 28 days and 56 days. With reference to sulphate resistance of SCC, the percentage of weight loss decreased with an increase of age of test specimens.

2 Material and methods

2.1 Taguchi orthogonal array approach for design of experiments

In the present study, Taguchi approach is considered for designing and improving quality of the experiments on SCC. The approach is very efficient for design and analysis of experiments which involves number of parameters. ‘Orthogonal Arrays (OA)’ and ‘Signal-to-noise (SN) ratios’ are two prime features in this approach. Orthogonal arrays are used to reduce the number of experiments and overall cost. SN ratios are used to determine the relative importance of factors in the study by considering their average value and standard deviation. There are three categories of quality characteristics for evaluating the performance of parameters namely “Larger the better”, “Smaller the better” and “Nominal the better”.

Smaller the better: Applies when the goal is to minimize the response and the S/N ratio is calculated using eq. (1).

$$S/_N = -10 * log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right) \quad (1)$$

Larger the better: Applies when the goal is to maximize the response and the S/N ratio is calculated using eq. (2).

$$S/_N = -10 * log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{Y_i^2}\right) \quad (2)$$

Nominal the better: Applies when the goal is to target the response and is required to base the S/N ratio on standard deviation only. The S/N ratio is calculated using eq. (3).

$$S/_N = -10 * log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\left(Y_i - Y_0\right)^2\right) \quad (3)$$

In eqs. (1) to (3), y_i is the performance value of the i^{th} experiment, y_o is the nominal value desired and n is the number of repetitions for an experimental combination.

2.2 Present study

The main objective of the study is to demonstrate the applicability of Taguchi approach to arrive at the optimum mix proportions of SCC with minimum number of experiments. The seven constituents of SCC, namely Coarse aggregate (CA), Fine aggregate (M-sand+SFS), Cement (C), Flyash (FLA), Water (W), Superplasticizer (SP) and Viscosity Modifying Admixture (VMA) are considered as the control factors. SFS is used as partial replacement for M- sand.

2.3 Materials

Ordinary Portland cement of grade 43 confirming to Indian standard specifications IS 8112:1989 is used in all SCC mixtures. The specific gravity and Blaine’s fineness of cement are 3.15 and 329 m^2/kg respectively. Flyash collected from Raichur thermal power station, India, with a specific gravity of 2.00 and Blaine’s fineness of 303 m^2/kg is used. The chemical composition of the cementitious materials is given in Table 1.

The properties of Superplasticizer Glenium B233 and Viscosity Modifying Admixture Glenium stream 2 used in all concrete mixtures are shown in Table 2. The coarse aggregate used is gravel having a nominal maximum size of 12.5mm, bulk density of 1395.9 kg/m3, fineness modulus of 6.53 and specific gravity of 2.68. The M-sand used is crushed rock deposits with fineness modulus of 3.04, bulk density of 1400 kg/m^3 and specific gravity of 2.58. The particle size gradation obtained through sieve analysis, and physical properties of the M-sand and coarse aggregates conformed to Indian standard specifications IS 383:1970 (R2011). The spent foundry sand obtained from Global Foundry Company, India, having dark grey in color with water absorption of 6.16 % and specific gravity of 2.51 is used. The chemical composition of the spent foundry sand is also presented in Table 1.

Table 1: Chemical composition of Cement, Fly ash and Spent foundry sand (in %)

Chemical compounds	Cement	Fly ash	Spent foundry sand
CaO	62.40	2.94	1.67
SiO_2	22.50	61.20	88.09
Al_2O_3	4.20	28.22	0.48
Fe_2O_3	3.20	3.91	2.16
MgO	2.10	0.93	0.76
SO_3	2.14	0.74	-
Na_2O	0.21	0.01	0.98
K_2O	0.27	1.34	0.60
TiO_2	-	-	0.10
Loss on iginition	2.98	0.74	4.68
Total	100.00	100.00	100.00

Table 2: Properties of Superplasticizer and VMA

Properties	Superplasticizer	VMA
Color tone	Light Brown liquid	Colourless
State	Free flowing liquid	Free flowing liquid
Relative density (kg/l)	1.09 ± 0.01	1.01 ± 0.01
Chloride content (%)	< 0.2	-
pH	> 6	8 ± 1
Chemical description	Modified polycarboxylic ether	Water-soluble polymer
Recommended dosage	500ml to 1500ml per 100 kg of cementitious material	-

3 Results

3.1 Orthogonal array SCC mixes using Taguchi method

The proportion of the initial SCC mix is obtained from modified Nan Su method (Vilas and Shrishail, 2009). Selection of control factors and their levels are made on the basis of preliminary trial experiments conducted in the laboratory. The choice of three levels is made to include the non linear effect of control factors, if any, on the performance characteristics. Table 3 shows the three levels considered for each of the seven factors taken in the experimentation. In the OA technique, the minimum required experiments for seven factors at three levels are 18. The standard L18 OA for seven parameters is represented in Table 4. The three levels control parameter values given in Table 3 are used in Table 4 to obtain the 18 SCC mixes for experimentation which are given in Table 5.

Table 3: Control factors with three variation levels

Levels	CA (kg/m^3)	MS+SFS (kg/m^3)	C (kg/m^3)	FLA (kg/m^3)	W (kg/m^3)	SP (kg/m^3)	VMA (kg/m^3)
1	706.00	811.80+90.2	353.50	105.44	229.93	2.75	0.46
2	720.12	707.17+176.79	335.83	115.98	234.53	2.81	0.47
3	734.24	606.14+259.78	318.15	126.53	239.13	2.86	0.48

Table 4: Standard L18 orthogonal array

Expt no	Parameters							
	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Table 5: SCC mix proportions for experimentation

Expt no	CA (kg/m^3)	MS +SFS (kg/m^3)	C (kg/m^3)	FLA (kg/m^3)	W (kg/m^3)	SP (kg/m^3)	VMA (kg/m^3)
1	706.00	811.80+90.2	353.50	105.44	229.93	2.75	0.46
2	706.00	707.17+176.79	335.83	115.98	234.53	2.81	0.47
3	706.00	606.14+259.78	318.15	126.53	239.13	2.86	0.48
4	720.12	811.80+90.2	353.50	115.98	234.53	2.86	0.48
5	720.12	707.17+176.79	335.83	126.53	239.13	2.75	0.46
6	720.12	606.14+259.78	318.15	105.44	229.93	2.81	0.47
7	734.24	811.80+90.2	335.83	105.44	239.13	2.81	0.48
8	734.24	707.17+176.79	318.15	115.98	229.93	2.86	0.46
9	734.24	606.14+259.78	353.50	126.53	234.53	2.75	0.47
10	706.00	811.80+90.2	318.15	126.53	234.53	2.81	0.46
11	706.00	707.17+176.79	353.50	105.44	239.13	2.86	0.47
12	706.00	606.14+259.78	335.83	115.98	229.93	2.75	0.48
13	720.12	811.80+90.2	335.83	126.53	229.93	2.86	0.47

14	720.12	707.17+176.79	318.15	105.44	234.53	2.75	0.48
15	720.12	606.14+259.78	353.50	115.98	239.13	2.81	0.46
16	734.24	811.80+90.2	318.15	115.98	239.13	2.75	0.47
17	734.24	707.17+176.79	353.50	126.53	229.93	2.81	0.48
18	734.24	606.14+259.78	335.83	105.44	234.53	2.86	0.46

3.2 SCC fresh properties

Experiments are carried out to evaluate the fresh properties of SCC mixes with respect to filling ability, passing ability and segregation resistance. The materials are loaded into pan mixer in a specified order to achieve effective mixing. Tests on fresh concrete are conducted immediately to determine the slump flow diameter (mm), T_{50} cm (sec), V funnel flow time (sec), V-funnel at T_5 min (sec) and, filling height in U-box (mm) and filling and passing height in L-box (mm). The flowability test results of the 18 SCC concrete mixes are given in Table 6. The slump flow diameter for all mixtures is in the range of 650-800 mm. The time measured for T50 cm is within the range of 2-5 sec, the time measured via the V-funnel flow is within the range of 6-12 sec and for the V-funnel at T5min is within the range of 0-+3 sec. The values from U-box and L-box tests are within the range of 0 - 30 mm and 0.8-1.0 respectively.

Table 6: Flowability test results of SCC mixes

Expt no	Slump flow (mm)	T_{50} cm (Sec)	V-funnel (Sec)	V-funnel at T_5min (sec)	U-box h2-h1 (mm)	L-box h2/h1
1	710	3.00	6.30	9.00	0	0.94
2	680	4.05	6.58	9.10	10	0.88
3	670	4.00	6.60	9.13	10	0.93
4	695	4.20	6.41	7.22	0	0.93
5	685	4.25	8.00	10.26	7.5	0.94
6	720	3.00	7.20	9.88	5	0.94
7	705	2.98	8.20	10.35	10	0.95
8	660	4.10	7.90	9.90	0	0.95
9	660	4.00	8.20	9.80	6	0.98
10	690	3.98	8.00	9.00	6	0.93
11	710	3.20	8.10	9.40	15	0.88
12	670	3.95	6.90	9.65	10	0.94
13	700	3.40	7.20	8.90	0	0.91
14	710	3.35	7.40	8.73	22	0.93
15	690	3.96	8.40	9.60	0	0.94
16	680	3.76	7.40	8.91	13	0.88
17	720	4.10	7.60	8.62	3	0.94
18	690	3.85	7.40	8.91	0	0.94

3.3 Optimum SCC mix proportion

For all 18 SCC mixes, the compressive strength is determined using 150 mm cubes at 3, 7 and 28 days. The average strength of the three test results for each age are given in Table 7. The control factors and the levels given in Table 3 are used for calculating the SN ratios. The quality characteristic with "Nominal the better" situation is used in analyzing results of the 18 SCC mixes. Maximization of the compressive strength is considered while arriving at the best possible combination of mix proportion which is achieved through the use of Minitab 14 software. The main effects plot graphs shown in Figure 1 gives values of control factors for the best possible testing conditions of the SCC. The maximum value of the control factors in Figure 1 indicate their optimum values which results in the optimal mix proportion of SCC and is tabulated in Table 8. For the control factors considered, use of 20% replacement of M-sand with spent foundry sand resulted in the best optimal SCC mix. This optimal mix proportion is further tested for flowability and mechanical properties. Fifteen samples each of 150 mm cubes, 150 mm diameter and 300 mm length cylinders, and 100 mm × 100 mm × 500 mm prisms are prepared and tested for compressive strength, split tensile strength and flexural strength respectively at 3, 7, 28, 90 and 180 days. The results of fresh and hardened properties of the optimal SCC mix proportion are shown in Tables 9 and 10. The results satisfy the expected flowability and mechanical properties of SCC.

Table 7: Compressive strength results of SCC mixes

Expt No	Compressive strength (MPa)		
	3 days	7 days	28 days
1	38.54	41.56	48.79
2	20.93	27.82	39.88
3	20.71	25.57	39.00
4	22.29	27.83	33.27
5	21.09	26.95	35.93
6	24.26	35.51	46.96
7	21.69	30.79	40.10
8	21.78	29.19	41.58
9	23.64	36.43	42.84
10	26.67	31.11	44.36
11	25.54	32.03	44.03
12	30.13	34.13	44.62
13	20.24	29.85	40.74
14	22.19	30.62	41.93
15	21.78	27.16	42.28
16	21.54	27.88	40.88
17	22.78	31.26	44.71
18	23.29	34.09	44.65

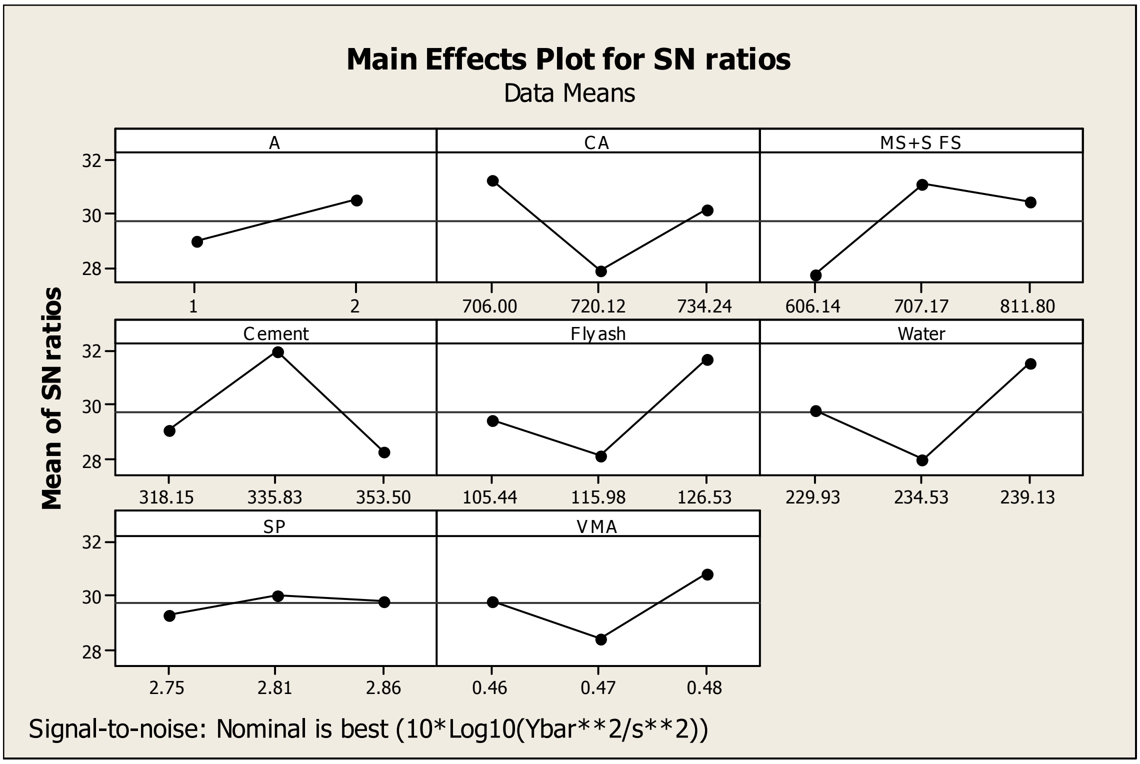

Figure 1: Main effects plot for compressive strength

Table 8: Optimal mix proportion of SCC

Control factors	CA kg/m^3	MS+SFS kg/m^3	C kg/m^3	FLA kg/m^3	W kg/m^3	SP kg/m^3	VMA kg/m^3
Optimal mix proportions	706.00	707.17+ 176.79	335.83	126.53	239.13	2.81	0.48

Table 9: Flowability test results of optimal SCC mix

Concrete property	Test results
Slump flow (mm)	700
T_{50} (sec)	3.4
V-funnel (sec)	8.2
V-funnel at T_5min (sec)	9.8
U-box (mm)	5
L-box	0.88

Table 10: Test results of hardened properties of optimal SCC mix

Age	3d	7d	28d	90d	180d
Compressive strength MPa	28.22	40.29	53.33	67.25	71.11
Split tensile strength MPa	2.12	3.66	4.97	5.52	6.08
Flexural strength MPa	4.63	5.87	7.83	9.14	10.02

4 Concluding remarks

Identifying the critical values of the various components in SCC mixture under a set of constraints is a very complex task. Use of Taguchi approach reduces the number of trial batches and simplifies the procedure required to arrive at optimal mix proportion of SCC. The study confirms the applicability of Taguchi approach with L18 (3^7) OA and 3 levels factor to identify critical values of the control factors of SCC. The test results of fresh and hardened properties of all 18 OA samples also satisfied the expected properties of SCC. The optimal SCC mix proportion satisfied the required fresh and hardened properties of SCC mixes. For the seven control factors considered, use of 20% replacement of M- sand with spent foundry sand resulted in the most optimal SCC mix which resulted in a compressive strength of 53.33 MPa at 28 days. The study confirms the possibility of using spent foundry sand as partial replacement of M- sand in SCC.

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