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Optimization of strength properties for Self-Compacting Concrete byTaguchi Method

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Abstract— Self-compacting concrete (SCC) was developed to address the problem of structural elements having highly congested reinforcement. This investigation was carried out to optimize experimentation process using design of experiments (DoE). Taguchi a standard L_9 (3^4) orthogonal array (OA) of four factors with three material parameters levels to rise a total of 9 trail mixes were employed. The factors considered in this study were water power ratiocementitious material content, steel fibre content and super-plasticizer content. The responses of material parameters were analyzed in order to maximize the compressive and tensile strength of concrete. The result indicated that the specific proportions (levels) of the different constituent material helped to give better compressive strength and split tensile strength. The role of super plasticizer dosage was observed to be relatively high marked on the fresh concrete properties of SCC. The steel fibres and fly ash content played a vital role to enhance the compressive and split tensile strength.

Index Terms— Self Compacting Concrete (SCC); Fly ash; High range water reducers; Compressive Strength; Split tensile Strength; Design Of Experiment (DoE), Steel Fibre.

1 INTRODUCTION

Professor Okaruma at university of Tokyo, Japan perceives the lack of talented work in Japan amid the year 1980's. So professor Okaruma devised a concrete which flows through congested reinforcement and consolidates under its own weight without segregation [1]. It also proves to be durable and high performance self-compacting concrete. Following quite a long while of his exploration work, a portion of the European nations were impacted by his examination work and consequently they shaped EFNARC organization which helps with the guidelines and specification of self-compacting concrete [2]. Modern application of self-compacting concrete is focused on high performance, better quality, dense and uniform surface texture and faster application. Particulary in India SCC has been used in metro project (Delhi metro project), bridges and building construction. Use of viscosity modifying agent along with high range water reducers are very important for flow ability and segregation control in SCC [3].

Conventional concrete possess compressive strength, stiffness, low thermal and electrical conductivity, low combusting and toxicity nature but two characteristic limited its use i.e. its brittleness and weakness in tension. The fibre reinforced has introduced in concrete, which could healed the two characteristic limitations of the conventional concrete. Fibre reinforcement also assists in prevention and propagation of cracks. The modulus of elasticity of fibre is greater than the modulus of elasticity of concrete. Thus it helps to carry the load which in turn helps to increase the tensile and flexure strength of the concrete. S.A. Bhalchandra et.al. [4]Adoptedsteel fibre content of 1.75% in SCC and noticed of increment in compressive strength 25.75% and flexural strength 19.47% over normal SCC. Balasaheb E. Giteet.al.[5]Adopted different types of steel fibres with different aspect ratios and noticed reduction in strength with decrease in aspect ratio of samefibre and also mentioned that straight fibre gives low strength compared to hooked end and crimped type fibres.

DeepaBalakrishnan et.al. [6] Replaced cement content by high volume of fly ash (12.5%, 18.75%, 25%, and 37.5%) and mentioned that the use of fly ash in SCC increases the workability, reduces the possibility of bleeding, segregation and increases the filling ability and passing ability of concrete. Heba A. Mohamed [7] noticed that the higher percentage of fly ash gives higher value of strength up to 30% of fly ash content.

In reviewing literature on the methods for mix design of SCC, various methods exist, most of

Which gives only general guidelines and ranges of quantities of materials to be used in SCC Proportioning. J. Guru Jawahar et.al. [8]Made a tool for mix design of SCC with or without of cement and coarse aggregate.

YoyokSetyo et.al. [9] used a Taguchi's approach with an L18 (2^1X3^7) orthogonal array and three-level Factor. Six control factors (coarse aggregate, sand, cement, silica fume, water and superplasticizer) were used for this study. Four responses (slump flow, flow time, V-funnel, L-box and segregation resistance) were evaluated and concluded that Taguchi method is a promising approach for optimizing mix proportion of SCC to meet several freshened properties of SCC.

2. RESEARCH SIGNIFICANCE

From literature it is easy to understand that Water powder ratio, Cementatious Material, Steel Fibre, High range water reducers are important parameters in mix Proportioning of SCC. These parameters has been researched in a distinguish way for different targets. The fundamental target of this study is to find out the optimum proportions of these parameters which gives high flow ability, passing ability and highest value of compressive strength and tensile strength and to analyse the influence of different parameters at different levels by using Taguchi method (DoE).

3. MATERIAL PROPERTIES

The Constituent materials for the generation of SCC are examined beneath [10].

3.1 Cementitious Material

Ordinary Portland cement (53 Grade) was used in all test specimen. Properties are tested by referring IS 12269-1987. The specific gravity of cement was 3.13. Standard consistency of cement is 34%. The fly ash was used as a replacement of cement by different proportions.

3.2 Fine Aggregates

The fine aggregate utilized was the normal sand free from pollutions and passing through 4.75 mm IS sieve. The specific gravity was found to be 2.65.

3.3 Coarse Aggregates

The locally available coarse aggregate passing through 20 mm IS sieve and retained on 10 mm IS sieve was used. The specific gravity of coarse aggregate was found to be 2.8.

3.4 Super Plasticizer

A commercially available (CERA HYPERPLAST XR-W40) high range water reducing admixture was used. This was poly carboxylate ether group and pale yellow color with specific gravity of 1.08.

3.5 Fibres

In this study commercially available and sorts of three distinct types of crimped steel fibre with aspect ratio (l/d) 50 were used. The physical specifications of the steel fibres are as shown in Table 1.

Table1 Fibre specification

Type	Length(mm)	Diameter(mm)	Aspect ratio
1	50	1	50
2	30	0.60	50
3	15	0.30	50

4. DESIGN OF EXPERIMENT

Design of Experiment (DoE) is a systematic approach to improve the quality of given material parameters. This experimental work was carried out to investigate the effect of steel fibres, different dosage of cementing material and plasticizer dosage. The design of experiments (DoE) was employed by Taguchi to optimize experimentation process and this simultaneously developed techniques are called “Taguchi method” Which reduces the number of experiments. In this study, a standard L_9 (3^4) orthogonal array (OA) of four factors with three material parameters levels to vary a total of 9 trail mixes. L_9 orthogonal array were utilized Table 3. By using the distinctive proportion materials shown in Table 2, nine mixes of self-compacting concrete are calculated and elaborated in Table 5.

5. MIX PROPORTION

Design of SCC is totally trial and error method. Design was prepared based on the mix design procedures and using “The European Guidelines for typical ranges of proportions and quantities” and considering EFNARC guidelines [2]. SCC mix was readied by changing the extent of water binder ratio, cementitious material, steel fibres and super plasticizers. Nine mixes were arranged and mix extents are recorded in Table 5.

5.1. Mixing of Concrete

The each mix proportion, the cement and sand are thoroughly mixed until the mixture is of uniform color. The coarse aggregate was added in dry to concrete mixture. Add 80% water and mix the whole mass for the least two minutes so that result in concrete is uniform in color. Further the right proportion of super plasticizer was diluted with the remaining 20% of water and added to the mix. After the appropriate proportion of steel fibre was distributed randomly within the mix and then the mixing was continued for other 5 minutes.

The cubes of 100mm and cylinders of 100mm diameter and 200mm height were cleaned and oiled. After conducting the fresh test, the concrete was poured in the respective moulds. After 24 hours of casting, the specimen were demoulded and submerged into the curing tank for curing.

Table 2 Mix parameters and their levels

Variable	Water Binder Ratio		Fly ash Content		Steel fibres		Superplasticizer	
	Code	Absolute	Code	Absolute	Code	Absolute	Code	Absolute
1	A1	0.42%	B1	0%	C1	50mm	D1	0.8%
2	A2	0.38%	B2	20%	C2	30mm	D2	1.2%
3	A3	0.34%	B3	40%	C3	15mm	D3	1.6%

Table 3 Design matrix of L9 (3^4) orthogonal array with parameters and their coding

Experiment No.	Variable 1 (Water binder ratio)		Variable 2 (Fly ash)		Variable 3 (Steel Fibres)		Variable 4 (Super plasticizer)	
	Code	Absolute	Code	Absolute	Code	Absolute	Code	Absolute
1	A1	0.42%	B1	0%	C1	50mm	D1	0.8%
2	A1	0.42%	B2	20%	C2	30mm	D2	1.2%
3	A1	0.42%	B3	40%	C3	15mm	D3	1.6%
4	A2	0.38%	B1	0%	C2	30mm	D3	1.6%
5	A2	0.38%	B2	20%	C3	15mm	D1	0.8%
6	A2	0.38%	B3	40%	C1	50mm	D2	1.2%
7	A3	0.34%	B1	0%	C3	15mm	D2	1.2%
8	A3	0.34%	B2	20%	C1	50mm	D3	1.6%
9	A3	0.34%	B3	40%	C2	30mm	D1	0.8%

6. Tests on fresh SCC

The workability is main characteristics of SCC and it was reported by fresh properties of test. A Concrete mix can be defined as a SCC if it fulfills three attributes –

(1) Filling ability
(2) Passing ability
(3) Segregation resistance

The workability of SCC is by and large higher than the level of workability said in IS 456-2000 as "very high". Acceptable values of fresh test as per the EFNARCguidelines [2]are as stated in the Table 4.

Table 4FreshConcrte critarea as per [2].

Sr. no .	Method	Unit	Typical Ranges	
			Minimum	Maximum
1	Slump flow test	mm	650	800
2	L-Box test	h_2/h_1	0.8	1

7. Hardened concrete test results for SCC

7.1. Concrete compressive strength:

The obtained value of compressive strength is the average of at least three test specimen tested. The compressive strength test was conducted at 7th and 28th days (Table 6).

7.2 Split tensile strength:

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In this test, indirect tensile test was conducted. The sample was loaded with compressive force along the length of the specimen and thus it produces tensile stress on the plane of the specimen. The split tensile strength for curing period of 7 days and 28 days were determined at least for three specimens respectively (Table 6).

Table 5 Detail of Mix Proportion

Experiment No.	Water (kg/m^3)	Cement (kg/m^3)	Fly ash (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	HRWR (kg/m^3)	Steel fibres (kg/m^3)
1	215	510	0	1008	781	4.08	4.4(50mm)
2	215	408	102	1008	781	6.12	4.4(30mm)
3	215	306	204	1008	781	8.16	4.4(15mm)
4	194	510	0	1008	781	8.16	4.4(30mm)
5	194	408	102	1008	781	4.08	4.4(15mm)
6	194	306	204	1008	781	6.12	4.4(50mm)
7	174	510	0	1008	781	6.12	4.4(15mm)
8	174	408	102	1008	781	8.16	4.4(50mm)
9	174	306	204	1008	781	4.08	4.4(30mm)

Table 6- Test results of SCC

Experiment no.	Fresh concrete test		Hardened concrete test			
	Slump flow(mm)	L-box (h2/h1)	Compressive strength (MPa)		Split tensile strength (MPa)	
			7th days	28th day	7th days	28th day
Mix no.1	692	0.89	28	38	2.05	2.57
Mix no.2	710	0.94	26	42	2.02	2.92
Mix no.3	730	0.96	25	40	2.00	2.85
Mix no.4	700	0.94	34	46	2.22	2.88
Mix no.5	692	0.89	28	44	2.16	3.02
Mix no.6	690	0.86	23	39	1.96	2.48
Mix no.7	668	0.84	32	42	2.32	2.98
Mix no.8	685	0.86	26	40	2.14	2.80
Mix no.9	680	0.86	26	39	2.12	2.82

Figure 1: Compressive Strength Result

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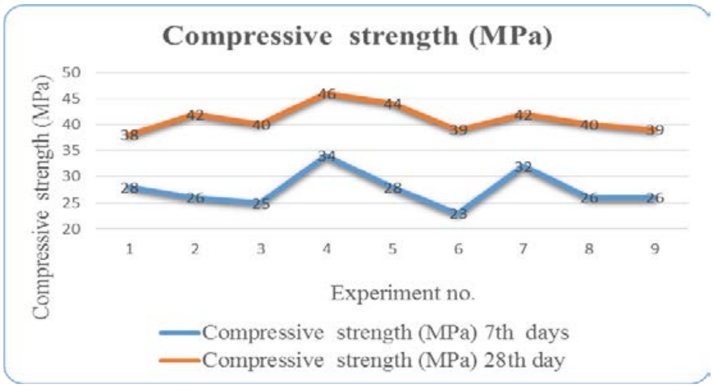
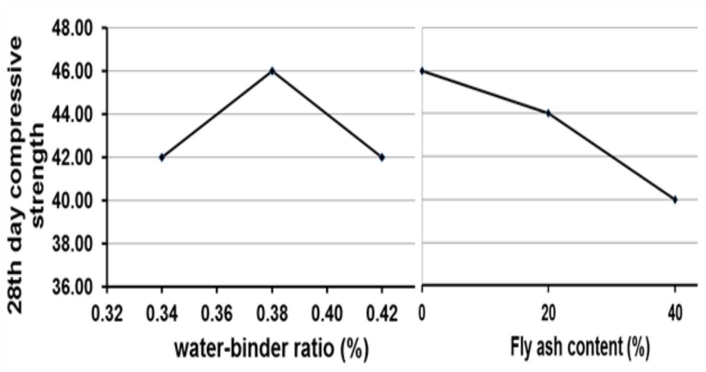




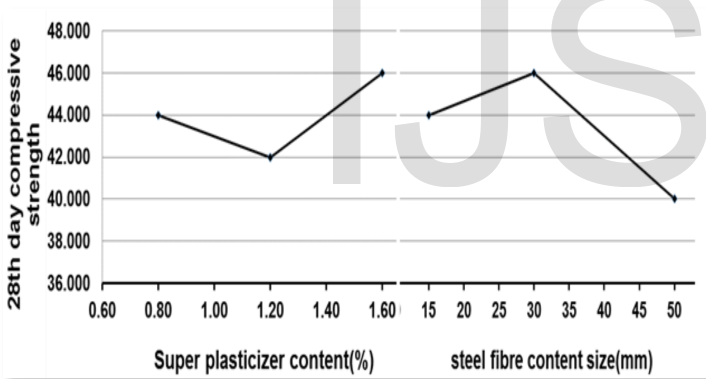
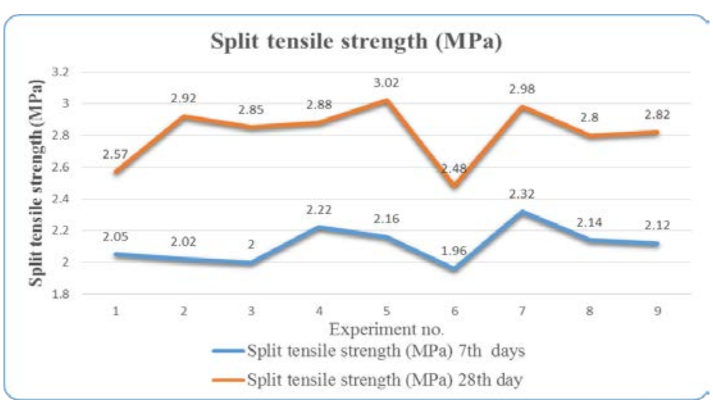
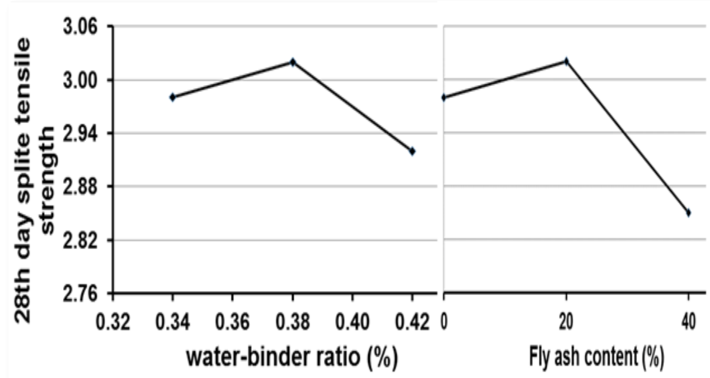
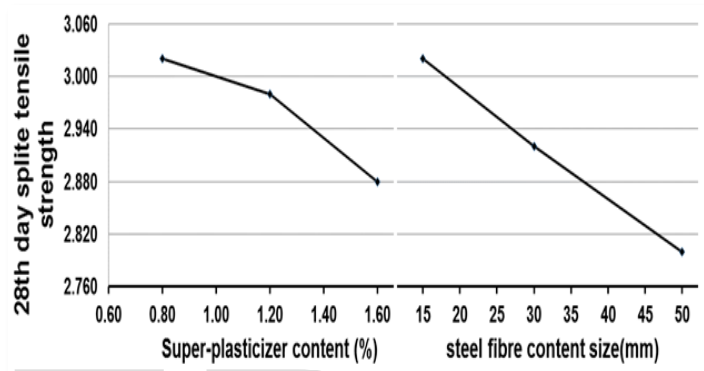


Figure 2: Split Tensile Strength Results







8. RESULTS AND DISCUSSIONS

From the above experimental works, the optimum proportion for slump flow and L-box result were obtained for water powder ratio at A1 (0.42%), fly ash content at B3 (40%), steel fibre type at C3 (15mm) and super plasticizer content at D3 (1.6%).

The optimum proportion for 7th day compressive strength were obtained for water powder ratio at A2 (0.38%), fly ash content at B1 (0%), steel fibre type at C2 (30mm) and super plasticizer content at D3 (1.6%).

The optimum condition at 28th day compressive strength were obtained for water powder ratio at A2 (0.38%), fly ash content at B1 (0%), steel fibre type at C2 (30mm) and super plasticizer content at D3 (1.6%).

The optimum condition was obtained for split tensile strength for water powder ratio at A3 (0.34%), fly ash content at B1 (0%), steel fibre type at C3 (15mm) and super plasticizer content at D2(1.2%) at the age of 7th Days.

The optimum proportion for 28th day split tensile strength were obtained for water powder ratio at A2 (0.38%), fly ash content at B2 (20%), steel fibre type at C3 (15mm) and super plasticizer content at D1 (0.8%).

When there is increase in percentage of fly ash the flow ability and passing ability increases. The optimum dosage of fly ash concluded from the fresh test result is 40% of cement material and for the hardened properties of concrete suitable content is 20% of cement material.

Super plasticizer doesn't take much role in a strengthening of concrete but it implement vital role in a fresh behavior of SCC. The optimum dosage of super plasticizer concluded from the test result is 1.6% by weight of cement which gives better self-compacting property to the concrete.

The slump flow value of nine trial mixes were in the range of 550mm to 800mm. From L-Box test, passing ability ratio for all trials was obtained satisfactory.

8. CONCLUSION

With these experimental results, all the mixes were able to develop a higher strength concrete without any vibration, with complies all the workability requirements of SCC as per EFNARC.

Workability characteristics i.e., passing ability, filling ability and segregation resistance of the SCC mixes are linearly decreasing with the decrease of water-cement ratio

It is observed that the w/c ratio increases, the compressive strength decreases and split tensile strength decreases.

This study shows that it is possible to prepare self-compacting concrete by incorporating steel fibres of length 50mm, 30mm, and 10mm. Among them 30 mm length fibres will give best results in terms of compressive strength and 15 mm length fibres in terms of tensile strength.

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