Optimum Mix Proportioning of High Strength Self Compacting Concrete

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Abstract*-Self-compacting concrete (SCC) has become more popular in building industry in recent years, due to its superior performance over conventional concrete mix. The main drawback in adopting self-compacting concrete is that there is no proper design mix standard throughout world. The aim of this study is to find out an optimum mix proportioning of high strength self-compacted concrete for different grades (30MPa – 80MPa). Numerous trial mixes have to be adopted including mineral admixtures like Fly Ash. The strength can be increased by reducing the water-Cement ration and adding sufficient quantity of mineral admixture. Also chemical admixtures are used to improve the workability and to minimize segregation. Tests such as Slump flow test, L-box test V-funnel test, etc., will be conducted in fresh state to estimate the quality of mix. After casting the specimens are tested for three basic strengths such as Compressive strength, Split tensile strength and Flexural strength at 1, 7, 14, 28, 56 and 90th days respectively. With the assumed mix proportion and the tested results, empirical relationship shall be obtained using SYSTAT. Hence for any assumed mix proportion, it is not necessary to cast an SCC specimen, not necessary to wait until the curing period to determine the strength parameter of the specimen by using the established relationships, the strength parameter can be determined. The accuracy of the relationships may be in the order of about 90% to 95%

Keywords*- self-compacting concrete, Fly ash, Super plasticizer, Viscosity Modifying Agent, development of self-compatibility of fresh concrete, mix design, tests methods for self-compacting concrete, Slump flow test, L-Box test, V-Funnel test, U-Box test, SYSTAT.

1. INTRODUCTION

1.1 Definition:

Self-compacting concrete, also referred to as self-consolidating concrete can flow and consolidate under its own self weight and de-aerated almost completely while flowing in the formwork. It is cohesive enough to fill the spaces of almost any size and shape without segregation or bleeding. This makes self-compacting concrete particularly useful wherever placing such as in heavily reinforced concrete members or in complicated noise and lead to innovative construction methods, it has been used in Japan for the construction of bridge girders, towers and piers, LNG tanks, culverts and building structures. Precast concrete plants are using self-compacting concrete in manufacturing, where it eliminates the need for vibrating machines and their associated noise.

1.2 History of SCC:

SCC was first introduced in the late 1980's by Japanese researchers and it is highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding. Such concrete should have a relatively low yield value to ensure high flow ability, a moderate viscosity to resist segregation and bleeding and must maintain its homogeneity during transportation, placing and curing to ensure adequate structural performance and long term durability. The successful development of SCC must ensure a good balance between deformability and stability. Researchers have set some guidelines for mixture proportioning of SCC which include, reducing the volume ratio of aggregate to cementitious material. Increasing the paste volume and water-cement ratio. Carefully controlling the maximum coarse aggregate particle size and total volume and using viscosity enhancing admixtures.

For SCC, it is generally necessary to use super plasticizers in order to obtain workability and Viscosity Modifying Agent for stability. Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. The mineral admixture that can be added are fly ash, silica fume, lime stone powder, glass filler and quartzite filler to obtain high performance. Since self-compatibility is largely affected by the characteristics of materials and the mix proportions, it becomes necessary to evolve a procedure for mix design of SCC. In this system, the coarse aggregate and fine aggregate contents are fixed and self-compatibility is to be achieved by adjusting the water / powder ratio and super plasticizer dosage. The coarse aggregate content in concrete is generally fixed at 40% of the total solid volume, the fine aggregate content is fixed at 60% of the mortar volume and the water / powder ratio is assumed to be 0.9-1.0 by volume depending on the properties of the powder and the super plasticizer dosage. The required water / powder ratio is determined by conducting a number of trials. One of the limitations of SCC is that there is no established mix design procedure yet.

1.3 Workability requirement for fresh SCC

SCC should satisfy the following

Table 1.1 Tests to determine the workability

Property	Test Method
Filling Ability	Slump Flow, T50 cm slump flow, V-Funnel
Passing Ability	L-Box, U-Box
Segregation Resistance	V-Funnel at T5 min

1.4 Properties of SCC:

A concrete mix is called Self Compacting Concrete if it fulfills the requirement of filling ability, passing ability and resistance to segregation.

Table 1.2 Typical acceptance criteria for SCC

Test Method	Property	Permissible range of values	
		Min	Max
Slump flow	Filling Ability	650 mm	800 mm
T50 cm slump flow	Filling Ability	2 sec	5 sec
V-Funnel	Filling Ability	8 sec	12 sec
Orimet	Filling Ability	0	5 sec
J-Ring	Passing Ability	0	10 mm
L-Box	Passing Ability	0.8	1
U-Box	Passing Ability	0	30
V-Funnel at T5 min	Segregation Ability	0	3 sec

1.4.1 Filling ability:

The property of SCC to fill all corners of a formwork under its own weight is known as filling ability. (Measured by slump test)

1.5 Passing ability:

The property of SCC to flow through reinforcing bars without segregation or blocking (Measured by L-box test).

1.6 Resistance to segregation:

The property of SCC to flow without segregation of the aggregates (Measured by V-funnel test).

1.7 Constituents of SCC

- Water powder ratio by volume is to be 0.8 to 1.0
- Total powder content to be 400-600 kg per m^3
- The sand content may be more than 38% of the mortar volume
- Coarse Aggregate content should normally be 28-35% by volume of the mix.
- Water Cement ratio is selected as 0.4 based on the strength. In case water content should not exceed 2000 lit per m^3

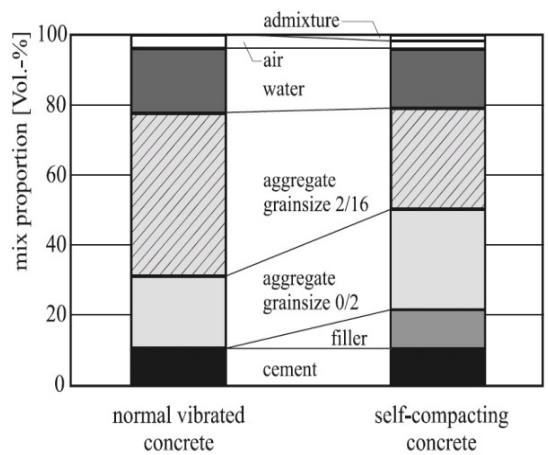


Fig 1.1 Mix Proportion for normal concrete and for SCC

2. RESEARCH SIGNIFICANCE

In the recent times, construction activity has increased several times in many parts of the world. Fast growth in the construction industry relies on the use of natural resources for infrastructure development. Large-scale production of Portland cement and the rapid exploitation of the environment for aggregates in the last few decades, have a dramatic impact on the environment. This leads to change in climatic conditions, depletion of ground water table and irregular rain fall pattern.

The availability of natural resources is reducing, slowing down the growth in construction activity. In day to day life, several types of byproducts and waste materials are generated through commercial, industrial activities. These waste materials need to be effectively recycled or safely disposed. The utilization of such materials in concrete not only makes it economical but also helps in reducing disposal problems [13]. Hence a suitable technology is needed to know their optimum use in concrete. Utilizing these waste materials for the manufacture of SCC, makes SCC economical, reduces disposal problems and eliminates our dependence on new raw materials for the manufacture of SCC.

The objective of their study is the mixture proportion of SCC to find the properties of self-compacting concrete experimentally. Portland cement was replaced with fly ash, granulated blast furnace slag, limestone powder, basalt powder and marble powder in various proportioning rates. The influence of mineral admixtures on the workability, compressive strength and sulphate resistance of SCC was investigated. The test results showed that among the mineral admixtures used, FA and GBFS significantly increased the workability and compressive strength of SCC mixtures. Replacing 25% of PC with FA resulted in strength of more than 105Mpa at 400 days. Moreover, the presence of mineral admixtures had a beneficial effect on the strength loss due to sodium and magnesium sulphate attack. On the other hand, the best resistance to sodium and magnesium sulphate attacks was obtained from a combination of 40% GBFS with 60% PC.

Several investigators reported that how to develop high and ultra-high performance of SCC with and without fiber. For the self-compacting concrete mixes without steel fibers the fulfillment of flow and cohesiveness criteria are sufficient for the mix design. However, for the design of self-compacting concrete mixes with steel fibers it is found as expected, that they must additionally meet the passing ability criterion. The plastic viscosity of the mixes with and without steel fibers has been estimated from the known plastic viscosity of the cement paste using simple micromechanical relations.

This study aims to develop an economical procedure for to produce HSSCC and its optimum dosage.

3. EXPERIMENTAL PROGRAM

In the present investigation, a self-compacting concrete mix, proportioned for a characteristic strength of 50 MPa had been studied with different proportions. Super plasticizer and viscosity modifying agent were used to obtain the SCC characters at fresh state. Compressive, tensile, flexural strength and modulus of elasticity of the SCC mix were investigated to determine the optimum proportion of HSSCC.

3.1 Materials:

Ordinary Portland cement OPC – 53 grade, confirming to ASTM C150 / C150M – 12[34] was used for casting the specimen. Locally available river sand with a maximum size of 4.75 mm, confirming to ASTM C33 / C33M – 13[31] was used as fine aggregate. Crushed blue granite, 12.5 mm size, angular shape confirming to ASTM C33 / C33M – 13 was used as coarse aggregate. Potable water as per ASTM C1602 / C1602M – 12[39], suitable for drinking was used for casting as well curing. A polycarboxylic ether based Superplasticiser – Glenium B233 and Viscosity Modifying agent – Glenium Stream II were used to improve the workability.

3.1.1 Cement:

Ordinary Portland cement OPC – 53 grade with the following properties.

- Fineness (wt. of residue) 7%
- Specific Gravity 3.09
- Initial setting time 35 min
- Final setting time 10 hours
- Soundness 3.6 mm
- Compressive Strength of 31.5 MPa on 3rd day, 46 MPa on 7th day, 58 MPa on 28th day.

3.1.2 Fine Aggregate:

The Fine aggregate to be used in the SCC has the following properties.

- Natural river sand
- Specific Gravity 2.78
- Fineness Modulus 2.65
- water absorption 1.05%
- Density 2.3 gm/cm^3
- Dry rodded Bulk Density 1610 kg/m^3
- Loose Bulk Density 1430 kg/m^3

3.1.3Coarse Aggregate:

The Coarse aggregate to be used in the SCC has the following properties.

- Crushed blue granite
- 12.5 mm size
- Angular shape
- Specific Gravity 2.61
- Fineness modulus 5.9
- Dry rodded bulk density 1480 kg/m^3
- Loose bulk density 1290 kg/m^3

3.1.4Fly ash:

The Coarse aggregate to be used in the SCC has the following properties.

- Specific Gravity 2.20
- Passing through 75 micron sieve
- Fineness 290 kg /m^2
- Light grey in color

3.1.5Water:

Potable water as per ASTM C1602 / C1602M – 12[39] specifications.

3.1.6Super Plasticizer:

The Super Plasticizer to be used in the SCC has the following properties.

Light brown Color with Specific Gravity 1.2

- Relative Density at 25°C is 1.09 ± 0.0
- Chloride iron content < 0.2%
- pH > 6.

3.1.7 Viscosity Modifying Agent:

The Viscosity Modifying Agent to be used in the SCC has the following properties.

- Colorless free flowing liquid with Specific Gravity 1.2
- Relative Density at 25°C is 1.01 ± 0.0
- Chloride iron content < 0.2%
- pH > 6

3.2 Mix Proportioning:

The SCC mix had been proportioned for a characteristic strength of 50 MPa. The mix proportioning of SCC was obtained by changing the paste volume (i.e. powder and water content) with a constant volume of coarse and fine aggregate.

The four-stage mix design method for SCC has been developed as follows.

- Determination of optimum super plasticizing dosage
- Determination of filler dosage
- Determination of the aggregate skeleton
- Determination of paste cement based on the requisites at self-compaction and strength.

The mix proportion was arrived based on the EFNARC guidelines. The coarse aggregate contains 8~10 mm and 12.5 mm in the ratio 9:6. The total powder content has been fixed in between 400-600 Kg/m3. Water content generally does not

Grade	Cement	Fly Ash	FA	CA	H_2O	SP	VMA
M30	225	223	892	860	180	1.4	0.4
M35	245	228	886	862	178	1.4	0.4
M40	271	233	887	863	178	1.6	0.4
M45	291	236	868	864	178.	1.7	0.5
M50	315	240	851	868	176	1.8	0.5
M55	331	241	856	873	176	1.9	0.5
M60	352	250	819	875	176	2.1	0.6
M65	384	250	824	875	176	2.3	0.6
M70	412	254	820	880	175	2.4	0.7
M75	432	260	803	881	175	2.6	0.7
M80	468	261	780	889	175	2.8	0.8

exceed 200 lt/m^3. The mix design details of self-compacting concrete are given in Table 3.1

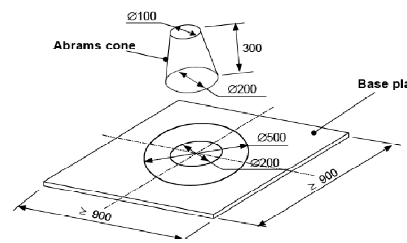
Table 3.1 Mix Proportioning of SCC

3.3 Tests on fresh concrete

After mixing, tests were conducted to determine the properties of fresh concrete as per EFNARC Guidelines. Slump flow test, L – Box test, U – Box test, V funnel test were used to evaluate the fresh concrete properties of SSC.

3.3.1 Slump flow test:

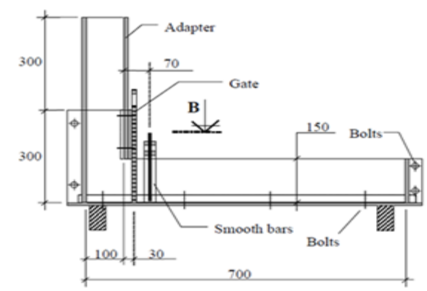
It is the most commonly used test and gives a good assessment of filling ability. The slump cone is held down firmly. The cone is then filled with concrete. No tamping is done. Any surplus concrete is removed from around the base of the concrete. After this, the cone is raised vertically and the concrete is allowed to flow out freely. The diameter of the Concrete in two perpendicular directions is measured. The average of the two measured diameters is calculated.



This is the slump flow in mm, the higher the slump `under its own weight. The range is from 600 mm to 800 mm.

3.3.2 L Box test:

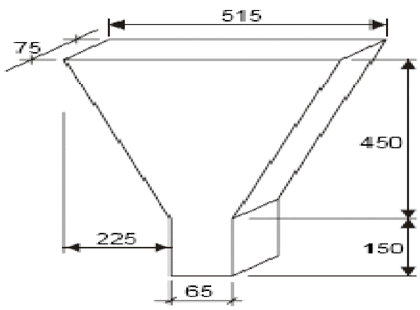
It assesses filling and passing ability of SCC. The vertical section is filled with concrete, and then gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the heights 'HI' and 'H2' are measured. Closer to unit



value of ratio 'H2/ H1' indicates better flow of concrete.

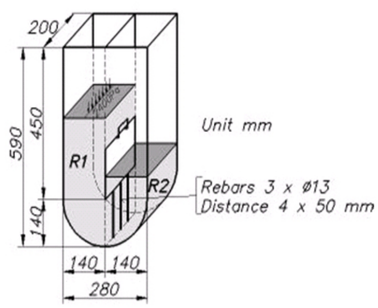
3.3.3 V-Funnel test:

The test measures flow ability and segregation resistance of concrete. The test assembly is set firmly on the ground and the inside surfaces are moistened. The trap door is closed and a bucket is placed underneath. Then the apparatus is completely filled with concrete without compacting. After filling the concrete, the trap door is opened and the time for the discharge is recorded. This V-funnel determines the filling ability of concrete. This is taken to be when light is seen from above through the funnel. To measure the flow time at T 5minutes, the trap door is closed and V-funnel is refilled immediately. The trap door is opened after 5 Minutes and the time for the discharge is recorded. This is the flow time at T 5 minutes. Shorter flow time indicates greater flow ability. V- Funnel at T 5mm indicates the resistance to segregation. It should be 0-3 sec. if concrete segregates, time increases.



3.3.4 U-Box test:

This method used for evaluating Self-Compatibility, the U-type test proposed by the Taisei group is the most appropriate, due to the small amount of concrete used, compared to others. In this test, the degree of compatibility can be indicated by the height that the concrete reaches after flowing through obstacles.



Concrete with the filling height of over 300mm can be judged as Self-Compacting. Some companies consider the concrete Self-Compacting if the filling height is more than 85% of the maximum height possible.

3.4 Preparing and Casting the test specimens:

To prepare the concrete mix, coarse aggregate was placed inside the concrete mixer followed by fine aggregate. Then 20% of the total quantity of water was added. The concrete mixer was allowed to rotate a few times after which fly ash and cement were added. Approximately 40% of the total quantity of water was poured into the concrete mixer and the materials were mixed for 1 minute. Superplasticiser and VMA were added to the remaining quantity of water and added to the mixer. Mixing was continued for another 2 minutes.

3.5 Curing the specimen:

After casting, the specimens were given a smooth finish with a steel trowel. The specimens were stored in room temperature approximately 26°C for 24 hours. After hardening, the specimens were demoulded, placed in potable water for curing. After necessary curing, specimens were taken out from the curing tank, allowed to dry and tested.

Fig 3.1 curing the specimen

4. TESTS RESULTS AND DISCUSSION

4.1 Fresh Concrete:

Test methods used to study the characteristics of fresh concrete include slump test, U – tube, V – funnel and L – Box. These tests had been conducted to determine the filling ability, passing ability and resistance to segregation of the SCC mix.

Table 4.1 Test results of fresh concrete propertiesof SCC

S. No	Detail	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
1	Slump flow	673 mm	675 mm	682 mm	684 mm	688 mm	690 mm	698 mm	699 mm	700 mm	700 mm
2	T50cm Slump flow	5 Sec	4 Sec	3 Sec	3 Sec	2 Sec	2 Sec	2 Sec	2 Sec	2 Sec	2 Sec
3	V funnel Test	10 Sec	10 Sec	10 Sec	8 Sec	8 Sec	7 Sec	7 Sec	7 Sec	7 Sec	7 Sec
4	V funnel at T5 minutes	13 Sec	13 Sec	12 Sec	11 Sec	10 Sec	9 Sec	9 Sec	9 Sec	9 Sec	9 Sec
5	L Box Test	0.84	0.83	0.87	0.89	0.9	0.91	0.91	0.91	0.91	0.91
6	U Box Test	26	26	24	24	23	21	21	21	21	21

4.2 Hardened concrete

4.2.1 Compressive strength

Each measuring 150 x 150 x 150 mm cubes had been tested for each mix to determine the compressive strength on 3, 7, 14, 28 56 and 90 days.

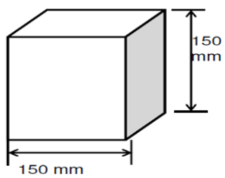
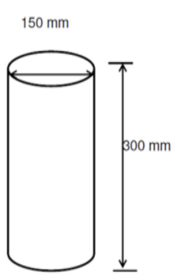


Fig 4.1 Compressive Testing Machine

Table 4.2 Test results for Compressive Strength

MIX	3rd Day	7th Day	14th Day	28th Day	56th Day	90th Day
	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
M30	15.10	21.30	23.45	24.15	25.60	27.60
M35	17.60	24.80	25.10	26.60	29.40	31.85
M40	20.10	25.45	28.40	30.40	34.40	37.20
M45	22.60	28.90	31.50	36.90	39.15	41.40
M50	26.32	37.57	40.5	42.75	43.50	46.50
M55	27.60	39.00	41.25	42.90	47.85	49.50
M60	30.43	42.51	44.55	46.80	49.20	54.65
M65	32.60	45.10	46.75	50.70	53.30	58.55
M70	34.25	46.80	48.25	52.50	57.40	63
M75	39.50	47.20	51.75	56.25	61.50	67.50
M80	44.25	51.10	56.50	62.75	69.25	73.65

Fig 4.2 Chart for



Compressive Strength

4.1.2 Split Tensile Strength:

Each measuring 150 mm diameter and 300 mm height cylinders had been tested for each mix to determine the compressive strength on 3, 7, 14, 28, 56 and 90 days.

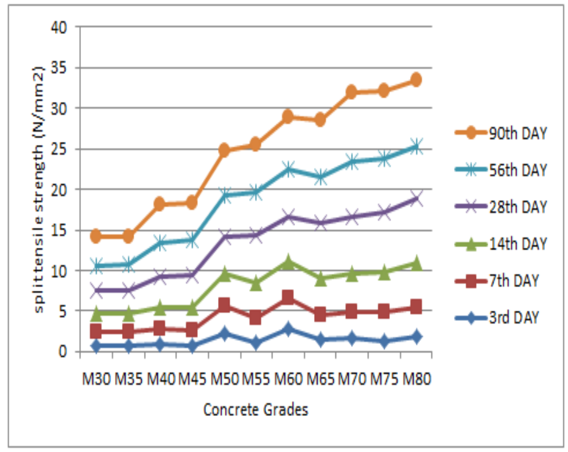


Fig 4.2 Compressive Testing Machine

Table 4.3 Test results for Split Tensile Strength

MIX	3rd Day	7th Day	14th Day	28th Day	56th Day	90th Day
	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
M30	0.72	1.65	2.24	2.94	3.06	3.53
M35	0.78	1.71	2.20	2.89	3.11	3.47
M40	0.97	1.91	2.52	3.82	4.24	4.59
M45	0.73	1.94	2.78	4.00	4.30	4.60
M50	2.33	3.27	3.94	4.58	5.17	5.46
M55	1.16	2.96	4.41	5.81	5.27	5.97
M60	2.81	3.80	4.57	5.41	5.89	6.37
M65	1.55	3.04	4.43	6.83	5.66	7.00
M70	1.63	3.30	4.61	7.11	6.76	8.54
M75	1.37	3.58	4.93	7.31	6.63	8.37
M80	1.91	3.51	5.51	7.94	6.53	8.13

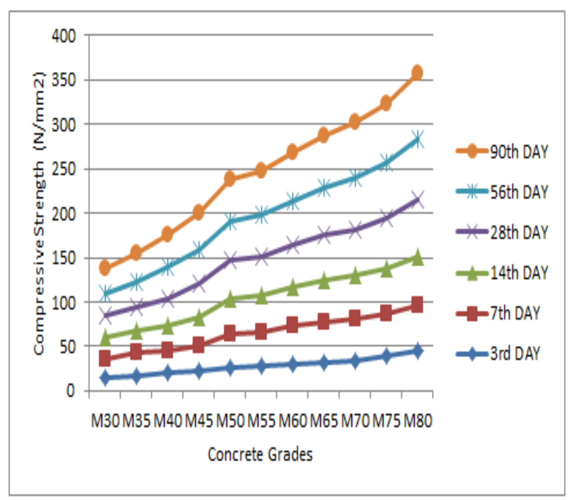


Fig 4.4 Chart for Split Tensile Strength

4.1.3 Flexural Strength:

Each measuring 150 x 150 x 150 mm cubes had been tested for each mix to determine the compressive strength on 3, 7, 14, 28, 56 and 90 days.

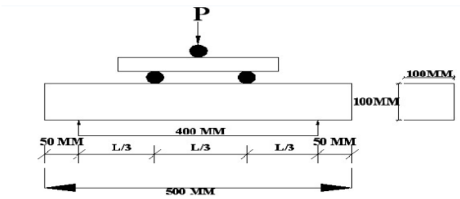


Fig 4.5 Flexural Loading Device

Table 4.4 Test results for Flexural Strength

MIX	3rd Day	7th Day	14th Day	28th Day	56th Day	90th Day
	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2
M30	0.36	1.234	2.40	3.11	3.17	3.75
M35	0.43	1.48	2.56	3.46	3.29	4.45
M40	0.46	1.71	2.91	3.78	4.37	4.81
M45	0.526	1.88	3.06	4.61	4.54	5.56
M50	0.59	1.91	3.40	4.41	5.30	5.96
M55	0.67	2.01	3.70	5.00	5.84	6.11
M60	0.70	2.07	4.21	6.02	5.91	7.01
M65	0.76	2.21	4.26	6.22	6.90	7.46
M70	0.83	2.67	4.58	6.20	7.41	7.69
M75	0.89	2.90	4.91	6.48	7.56	8.08
M80	0.94	3.11	5.37	7.60	8.46	8.56

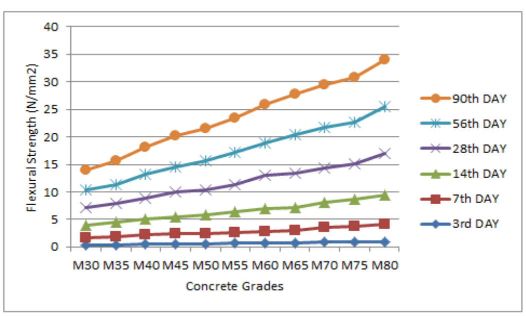


Fig 4.6: Graph of split tensile strength

5. MATHEMATICAL MODEL

5.1 Developing the design matrix

The design matrix was developed using the software called SYSTAT10.2. This software increases the analytical power with more statistics by delivering extensive list of algorithms. All the variables at the intermediate level (0) constitute the highest (+2) level with other three variables at the intermediate levels constituting the start point. Thus the 31 experimental run allowed the estimation of the linear, quadratic and two-way interactive effect of the process parameters.

5.2 Recording of response

The ingredients for the various mixes were weighed and mixing was carried out using pan type concrete mixer. Precautions were taken to ensure uniform mixing of ingredients. The specimen were cast in steel mould and compacted on a table vibrator. 100 mm cube specimens were cast for the determination of compressive strength at 28 days. 100x100x500 mm beam specimens and 100mm diameter x 200mm long cylinder specimens were cast for the determination of flexural and split tensile strength at 28 days respectively. Curing of specimen was started as soon as the top surface of the concrete in the mould was stiff (hard) enough. Spreading wet gunny bag over the mould was carried out for the initial curing. 24 hours after the casting, the specimen were demoulded and placed immediately in water tank for further curing. Compaction factor

5.3 Development of mathematical model

Process control parameters

i) B = Binder content

ii) W/B = Water - Binder ratio

iii) F = Fly ash

iv) S = Superplasticiser

The values of the coefficients were calculated by regression analysis using SYSTAT 10.2 software.

5.4 Final mathematical model

The values of the regression coefficient give an idea as to what extent the control variables affect the responses quantitatively. In significance coefficient using student t-test can be dropped along with responses to which they are associated without affecting much of the accuracy of the model. As per this test, when the calculated value of t corresponding to a coefficient exceeds the standard tabulated value for the desired level of confidence (say 95%) the coefficient becomes significant. The significant regression coefficient was recalculated and the final models were developed using only these significant coefficients: The final models for the various responses as determined by the above analysis are represented below:

$$C=73.421+3.148-2.850(W/B)+1.572F+1.2+1.734S^2$$

$$+1.046B \text{ X } (W/B)-1.023(W/B) \text{ X } F$$

$$T=6.480+1.050B-0.418(W/B)+0.346F+0.183B^2$$

$$+0.40+0.401S \times (W/B)-0.437FS$$

$$F=10.271+0.178B-0.427(W/B)+0.413F+0.317B^2$$

$$+0.23(W/B)^2+0.483F^2+0.493SW^2$$

6. CONCLUSIONS

Based on the experimental investigation, the following conclusions are drawn within the limitations of the test results.

- The test results of fresh concrete are within the limits of SCC i.e., flow ability, passing ability and resistance against segregation.
- In Experimental Investigation, the concrete have been casted for M30 to M80 in order to check the Compressive strength, Split tensile strength and Flexural strength
- Statistical experimental design can be used to systematically investigate the selected range of combination of ingredients for the desired characteristics.
- The mathematical models furnished in this investigation can be used to predict the proportions of various constituents of concrete, by substituting the value, in coded form, of respective factors.
- The five level factorial techniques can be employed easily for developing mathematical model for predicting the strength and workability within the workable region of control parameters for required characteristics.
- Optimum binder composition concrete mixtures for the designed strength can be identified from the proposed models.
- RSM can be used effectively in analyzing the cause and effect of the process parameters on response.

7. REFERENCES

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