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Evaluation Of Normal Strength Self-Compacting Concrete

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Abstract— **The objective of this study is to determine if adjustment of the four factors viz. cement content (C), water to powder (w/p) ratio, fly ash (FA) content, and superplasticizer (SP) will increase the compressive strength of self-compacting concrete (SCC) by using contrast constant factorial design and response surface methodology. The method of the analyzing 2k factorial design that is a design with k factors each at two levels was used with 16 factorial points.**

I. INTRODUCTION

Self compacting concrete (SCC) is considerably a new concrete technology that was developed last two decades ago. Okamura in Japan first proposed the necessity of SCC in 1986 to address the issues like long production times, unavailability of skilled workers and durability of concrete (Ozawa et al., 1989)152. The first prototype of SCC was developed by Ozawa and Maekawa in the university of Tokyo in 1988 (Ozawa et al., 1989)152. As per ACI 237R-07 (2007)6, SCC is defined as highly flowable and non-segregating concrete that can fill the formwork and encapsulate the reinforcement without any mechanical consolidation.

Various professional societies like American Concrete Institute (ACI), the American Society for Testing and Materials (ASTM), Center for Advanced Cement-Based Materials (ACBM), Precast Consulting Services (PCI), European Federation of National Trade Associations (EFNARC) etc., have recommended the guidelines for the design and applications of SCC. Among the available standards, the most commonly used standard is EFNARC standard for SCC mix design.

The workability of SCC is characterized by the three fresh properties (EFNARC, 2002)49: filling ability, passing ability and segregation resistance. Filling ability is the ability of SCC to flow under its own weight and to completely fill the formwork. Passing ability is the ability of SCC to flow through restricted spaces without blocking. Segregation resistance is the ability of SCC to remain uniform and cohesive during and after transporting and placing. The other two properties such as robustness and consistence retention are also important in SCC. Robustness refers to the ability of SCC to retain its fresh property when the quality and quantity of constituent materials and the environmental conditions change.

Consistence retention refers to the period of duration of the fresh properties. Just like the conventional concrete (CC), there is not a single test method to measure the above mentioned workability parameters. Therefore, EFNARC (2002)49 proposed list of test methods to determine the workability properties of SCC. Among these slump flow, J-ring, V-funnel, L-box, and U-box are the most widely accepted and used tests.

Proper stability of SCC can be secured by lowering the free water content, increasing the concentration of fines (cementitious and sand particles < 0.125 mm), or incorporating a viscosity modifying agent (VMA) (Khayat and Guizani, 1997; Sakata et al., 1996)101, 168. In general, high dosages of high range water reducing (HRWR) superplasticiser (SP) are needed to minimize the free water content and to achieve the required deformability. VMAs are not only used to increase the viscosity, but also used to provide mixture robustness.

The modulus of elasticity (MOE) is defined as the slope of the stress-strain curve of concrete within the proportional limit of a material (IS 516, 1959). The secant modulus of a concrete material is defined as the slope of the straight line drawn from the origin of axes to the stress-strain curve at some percentage of the ultimate strength. As per IS 516 (1959), secant modulus is most commonly used in the structural design. MOE is a very important mechanical parameter reflecting the ability of the concrete to deform elastically (Neville, 1996). Any variation in coarse aggregate content, coarse aggregate type or mix proportions will result in the change of MOE (Stock et al., 1979)189. It has already reported that the aggregate content and properties affect the magnitude of the modulus of elasticity (Neville, 1996; Huo et al., 2001; Bonen and Shah, 2004).

Neville (1996) mentioned that for a concrete of given strength, a higher aggregate content results in a higher MOE of the concrete. Bonen and Shah reported that because SCC typically has a lower coarse aggregate content than CC, MOE will be lower for SCC than that of CC of the same strength (Bonen and Shah, 2004)21. Schlumpf (2004)170 stated that MOE of SCC was 20% lower than that of CC with the similar strength. Chi et al. (2003)29 also indicated that the aggregate fraction in concrete had a considerable effect on the MOE of the concrete. Several researchers found that the MOE of SCC was slightly lower than that of CC (Dehn et al., 2000; Felekoglu and Sarikahya, 2008; Ma et al., 2002). MOE of fly ash concrete continued to increase with the age (Siddique, 2003).

The tensile strength of the concrete is important to predicting the initiation of cracking of concrete member when it is subjected to external loads (Walraven, 2005)205. Several factors influence the tensile strength of concrete. The strength of paste and the bond between the aggregate and paste influence the tensile strength (Cetin et al., 1998)27. Liu (2010)118 indicated that the replacement of cement with fly ash decreased STS at early ages. This is attributed to the slower pozzolanic reaction of the fly ash with free lime of the hydrated cement (Liu, 2010). Siddique (2003)182 stated that splitting tensile strength of fly ash concrete continued to increase with age. Traditionally, tensile strength is defined as a function of compressive strength, but it also depends on the other properties such as aggregate particle strength, surface characteristics, concrete's moisture and content distribution (Holm, 1995).

Mahdy et al. (2002)121 reported that concrete with higher coarse aggregate ratio showed slightly higher STS than that of lower coarse aggregate ratio. The interfacial transition zone (ITZ) characteristics tend to affect the tensile and flexural strength to a greater degree than compressive strength (Mehta and Monterio, 2006)125. The splitting test is very simple to perform and requires the same compression testing equipment (Neville, 1971).

Concrete was considered as a purely two-phase material: paste and aggregate. Later a realistic approach took into account the existence of a particular zone of hydrated paste in the proximity of aggregates. This is called Interfacial Transition Zone (ITZ). From the microstructural point of view, hardened concrete can be considered as three phases viz. aggregate, bulk cement paste and ITZ (Mehta and Aitcin, 1990)124. ITZ mainly contains a water film, calcium hydroxide layer on the aggregate side and a porous paste matrix layer between calcium hydroxide layer and bulk paste matrix (Hearn et al., 1997)68. Many properties of concrete should be analyzed by considering it as a three-phase composite material: aggregate, ITZ and matrix (Ollivier et al., 1995).

II. MATERIALS AND EXPERIMENTATION

Ordinary Portland cement of 43 grade of Ultra-tech Cement confirming to IS: 8112-1989 standards was used.

The locally available sand confirming to Zone-II grade of Table 4 of IS 383-1970 has been used as Fine Aggregate.

The locally available crushed granite has been used as coarse aggregate in this investigation.

Superplasticizer used was Polycarboxylicether (PCE) based free flowing liquid having specific gravity of 1.15 conforming to ASTM C 494-92 (2006).

Potable tap water conforming to BS 3148 (1981) was used for mixing and curing.

The mix proportions are presented in Table 1 along with the response that provides evidence for the experiments setup which were done on compressive strength by using the SCC constituents' materials. All concrete mixes were prepared in 40 L batches in a rotating planetary concrete mixer. The batching sequence consisted of homogenizing the sand and coarse aggregate for 30 s, then adding about half of the mixing water into the mixer and continuing to mix for one more minute. The mixer was covered with a plastic cover to minimize the evaporation of the mixing water and to let the dry aggregates in the mixer absorb the water. After 5 min, the cement and fly ash were added and mixed for another minute. Finally, the SP and the remaining water were introduced and the concrete was mixed for 3 min. A concrete mix can be classified as SCC if the requirement for all fresh properties is conformed to EFNARC (2002); filling ability under own weight SCC flows within the framework. Test of slump flow is used for measuring filling ability of SCC according to ASTM C 1611 (2006). Compressive strength was tested using a 2000 kip (4448 kN) capacity compression machine. According to the BS 1881: Part 5 (1981) compressive strength was determined by using cubic specimens of 100 x 100 x 100 mm. Proportions and Test Specimens were removed from the molds after 1 day, and cured in water at 20oC for 28 days, the surfaces were then smoothed by grinding to achieve a leveled appearance then tested for strength, average of three results is reported in the investigation.

Table 1 Mix design parameters and response of fresh and hardened properties of SCC

Mix no.	C (Kg/m^3)	w/p ratio	FA (Kg/m^3)	SP (Kg/m^3)	fC28 (MPa)	Slump flow (mm)
1	426.5	0.32	120	7.2	42.38	630
2	446.7	0.32	120	7.2	41.00	730
3	426.5	0.36	120	7.2	36.03	801
4	446.7	0.36	120	7.2	37.89	925
5	426.5	0.32	140	7.2	38.50	790.6
6	446.7	0.32	140	7.2	44.50	833
7	426.5	0.36	140	7.2	47.50	767
8	446.7	0.36	140	7.2	48.98	830
9	426.5	0.32	120	8.8	47.38	830
10	446.7	0.32	120	8.8	40.23	845
11	426.5	0.36	120	8.8	41.24	820
12	446.7	0.36	120	8.8	42.78	830
13	426.5	0.32	140	8.8	37.89	880
14	446.7	0.32	140	8.8	38.67	840
15	426.5	0.36	140	8.8	41.45	830
16	446.7	0.36	140	8.8	41.0	820

III. RESULTS AND DISCUSSION

Factorial experiment is carried out to study the factors which are thought to influence fresh and hardened properties of SCC. The four factors are cement content (A) in kg/m3, water to powder (B) as a ratio, fly ash content (C) in kg/m3, and superplasticizer (D) in kg/m3. Each factor is present at two levels. The design matrix and the response data obtained from a single replicate of the factorial point 24 experiment are shown in Table 2 and Fig. 1. The 16 runs are made in random order. The aim is to have maximum strength and slump flow within the range according to EFNARC Criteria (2002). The analysis of the data was done by constructing a normal probability plot of the effect estimates. The table of plus (+) and minus (-) signs for the contrast constants for the 24 design For comparison purposes, the effect of HCl on the setting times of OPC is also presented in Fig. 7.1. The results of OPC were taken from the experimentation of Reddy (2004). It can be observed from the figure that the setting times of BC and OPC differed marginally and the effect of HCl is very much similar on both OPC and BC. The setting times of blended cement (BC) are slightly higher when compared to OPC at all HCl concentrations. This is expected due to the presence of fly ash in the BC.

The main effects are defined as the difference in the average response between the high and low levels of a factor. Using plus and minus signs to represent high and low levels of a factor, the Effect of A as an example is defined as seen in Table 2

$E(A) = (\text{Ave. of} \sum Y+) - (\text{Ave. of} \sum Y-)$ (Eq. (1))
$= 41.698 – 43.077 = -1.378$

From these contrasts, an estimate to the 15 factorial effects and the sums of squares were made as shown in Table 2. The normal probability plot is a graphical technique for normality testing: assessing whether or not a data set is approximately normally distributed. The normal probability plot of these effects is shown in Fig. 2. All of the effects that lie along the line are negligible, whereas the large effects are far from the line. The important effects that emerge from analysis of the estimate effect are the main effects of AD, BD, CD and ACD interactions. The data are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this straight line indicate departures from normality.

The largest effects are observed for water to powder to super plasticizer (BD = 10.353), fly ash to super plasticizer (CD =8.646), cement to super plasticizer (AD =8.953), and cement to fly ash to super plasticizer (ACD =8.744) triple effect.

The total sum of squares is 1515.71609. Table 3 summarizes the effect estimates and sum of squares. The percent contribution column measures for each model term to the total sum of squares. The percentage contribution is often a rough but effective guide to the relative importance of each model term. The mean effect of interaction BD (w/p to Sp) really dominates this process, accounting for over 28.286 of the total variance, the other interactions effects are AD, CD, and ACD account for about 21.153%, 18.906%, and 20.177%, respectively.

IV. CONCLUSIONS

The following conclusions can be drawn from the investigation:

1. The interaction parameters of AD, BD, CD, and ACD are the only significant effects and that the underlying assumptions of the analysis satisfied the object.
2. To maximize the compressive strength, variables like cement content A(x1), water to powder ratio B(x2), fly ash content C(x3), and super plasticizer dosage D(x4) should be kept at a high level and the process is relatively robust to content of super plasticizer D. The highest compressive strength is obtained when cement contents, w/p, FA contents are high and SP is low.
3. Full factorial design needs to add center point to handle the curvature from second order effects and to allow an independent estimate of error to be obtained.
4. The projection of an unreplicated factorial into a replicated factorial in fewer factors is very useful.

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