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Full Length Research Paper

A conceptual approach of the mixture proportioning technique for producing self compacting concrete

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Self Compacting Concrete (SCC) refers to a highly flowable concrete composite, designed for sufficient viscosity and cohesion to avoid segregation of aggregates. A carefree concreting practice at construction site and reduction in construction time makes SCC the most popular material among civil engineers. However, the lack of good understanding of the material properties and a reliable mixture proportioning technique affected the development of SCC significantly. In order to simplify the mixture proportioning methodology of SCC, a conceptual approach was proposed in the present study. Initially, the optimum replacement of cement using flyash was obtained by the Pozzolanic Activity Index test and the optimum dosage of hyperplasticizers was obtained using Marsh cone studies. Further, the mixture proportioning for SCC was done based on the assumption that concrete was made up of two phase material (mortar and aggregate phase). The mortar phase was designed first to obtain the optimum fine aggregate content based on the maximum mortar spread. Finally, the different proportions of mortar phase and aggregate phase were arrived. The final mixture proportions were arrived based on the maximum concrete spread and stability and then validated using the standard characterization tests (J-ring, V-funnel, L-box and segregation resistance). The test results showed that consistent flow properties was realized in the mixture which had 65% of mortar phase and 35% of aggregate phase. Also, a good stability and a uniform spread of concrete without segregation of aggregates or mortar were observed.

Key words: Self compacting concrete, SCC, hyperplasticizers, flyash, marsh cone, characterization tests.

INTRODUCTION

The shortcomings in conventional concrete such as poor flow ability and subsequent segregation problems leading to poor finishing and delayed construction time led to the development of self flowing or self leveling concrete. In reality, the inadequacy of skilled laborers in Japan led Okamura to patent a concrete which can fill the form work and compact on its own internal energy (Okamura, 2003). Since then, the excellent fresh and hardened concrete properties of SCC contributed to its rapid development. Also, the effective utilization of industrial wastes (flyash, GGBS etc.) in concrete envisaged its safer disposal without polluting the environment. The ability of SCC to consolidate in dense reinforcement and faster construction makes it a socio-economic building material with high quality of infrastructure. The main concept behind the self compacting ability of concrete is that, the flow ability is enhanced by increasing the powder content and thereby reducing the coarse aggregate fractions (Okamura, 1997). However, the other aspects such as controlled bleeding of mix water and segregation of aggregates play a vital role in the mixture proportioning of SCC. The difference between Conventional Concrete (CC) and SCC lies in the careful proportioning of various ingredients. In conventional concrete, aggregate fractions are more and hence the paste fills the voids between the aggregates (Kennedy, 1940). Voids are developed in the concrete system when the relative positions of aggregates are altered during packing and thus require high amount of energy for compaction (Su et al., 2001). SCC has closely packed system where aggregates fractions are less and paste is kept high enough to ensure good packing. Hence, a better flow ability with less friction between aggregates may not require any external energy for compaction.

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In the recent past, a substantial amount of research has been carried out for the mixture design of SCC with special attention to its rheological properties. Concrete mixture design based on workability was first proposed by Kennedy in 1940 (Kennedy, 1940) which revealed that concrete can be made workable when the theoretical volume of paste is more than the voids present in the coarse aggregate. Hence, to make a highly workable concrete; the excess amount of paste required is dependent on surface characteristics of the aggregate and consistency of the cement (Su et al., 2001). Nan et al. (2001) and Su et al. (2001) studied the mixture proportioning technique for SCC in which the proportions of coarse and fine aggregates were derived from the packing factor based on the specific gravity of the particle. Flow property of paste medium is primarily influenced by the inter-particle attraction developed as a result of the Vanderwal's forces of attraction. The energy required to break these forces is known as yield stress (Ramachandran and Beaudoin, 2001). The addition of super-plasticizers in cement envisages the effective dispersion of cement particles and account for good flow properties. However, the mineral admixtures are not influenced by the plasticizing effects of the polymers, since electro-static charges developed is not sufficient enough to cause dispersion. The other aspect governing the mixture proportioning technique is the careful selection of the amount of aggregate fractions since inter particle friction reduces the flow ability due to inter locking. However, the contact area between spherical particles is less as compared to that of angular particles. The lubrication effect is provided by the finer particles (cement and flyash) and thus reduces the friction. The mix water that serves for the complete hydration of cement also helps for the good flow ability due to lubricating effect. Any excess water present in the concrete system generally results in bleeding of water. This bleeding of water can be controlled when a good proportion of fine filler materials (such as flyash) are added in which the water particles are absorbed on the surface of flyash particles.

Also, the presence of excess water may lead to bleeding in concrete at fresh stage and reduction of strength in hardened stage. Hence, it is a challenging task to preserve the water in the concrete system which can be useful to enhance the flow properties as well as to obtain a durable concrete. A general idea about particle size, shape and their packing characteristics helps to achieve good packing of the ingredients, especially to minimize the voids in the concrete system. The mixture proportioning concept proposed in this paper uses the particle packing theories for proportioning of SCC ingredients. The most important requirement for producing SCC is the suspension of coarser particles which is dependent on the viscosity of the flowing medium (mortar phase). Hence, it is essential to design the mortar phase with correct proportions of cement and flyash particles which can enhance the viscosity of the mortar phase.

MIXTURE PROPORTIONING PROCEDURE

Initially, the optimum replacement of cement by mineral admixture can be arrived from Pozzolanic Activity Index (PAI) test, and then the optimum dosage of hyper-plasticizer for the given water/binder ratio can be arrived through marsh cone studies. The proportioning of the various ingredients is based on the assumption that finer particles are flowing medium and the heavier particles are suspended in it. In the mortar phase, fine aggregates are assumed to be suspended in the cement-flyash paste, while in concrete phase coarse aggregates are assumed to be suspended in mortar phase. It can also be realized that, the mortar phase has to be kept more than 50% for better flowability. For the different combinations of these two phases, a number of possible proportions for the SCC can be arrived and shown in Tables 1 and 2. The proportioning of the various ingredients is calculated in terms of absolute volume required to fill a 1 m^3 volume of concrete. However, it is also appropriate to calculate the ingredients based on weight basis. But the volume batching is considered to be effective since the powder content is more compared to weight basis. Hence, it is always suggested to go for volume batching to ensure more powder content which is the essential requirement for SCC. The validation tests such as the filling ability, passing ability and segregation resistance test were then determined for all the designed mixtures.

Compatibility studies

Compatibility studies become important especially in the case of utilization of admixtures in concrete (Chiara et al., 2000; Pierre and Aitcin, 2004; Agullo et al., 1999), since they have huge influence on workability and strength properties. Compatibility issue needs to be checked for the various ingredients of a concrete composite. Mineral admixtures are typically used to reduce the cement consumption and subsequently to bring down the cost of concrete. In addition to this, it also helps to improve the viscosity of the paste significantly due to their high fineness and more specific surface. The optimum level of replacement for cement with mineral admixture can be found by conducting Pozzalonic Activity Index (PAI) test as per IS3812-1983 (Indian Standard Designation, IS 3812-1981). The marsh cone flow is a standard test as prescribed by ASTM C939.

This is a characteristic test used to measure the flow properties of cement paste and it is considered appropriate for use in both the field as well as in laboratory. Recently, the development of organic admixtures has remarkably contributed to the improvement in the performance of concrete in various

Table 1. Mixture proportions arrived.

Mixture ID	Proportions		Cement (kg/m^3)	Flyash (kg/m^3)	Sand (kg /m^3)	Coarse Agg (kg/m^3)	Water (lit/m^3)	HP (lit/m^3)
	Concrete (Mortar: CA)	Mortar (Paste: Sand)						
M1	70:30	60:40	455	157	753	810	213.6	4.83
M2		65:35	492	170	660	810	231.2	5.23
M3		70:30	530	183	565	810	249.2	5.63
M4		75:25	570	197	468	810	267.6	6.05
M5	65:35	60:40	422	146	699	945	198.3	4.48
M6		65:35	457	158	612	945	215	4.86
M7		70:30	493	170	525	945	231.5	5.23
M8		75:25	528	182	437	945	248	5.60
M9	60:40	60:40	390	135	646	1080	183.1	4.14
M10		65:35	422	146	565	1080	198.3	4.48
M11		70:30	455	157	484	1080	213.6	4.83
M12		75:25	487	168	404	1080	228.8	5.17

Table 2. Slump flow results.

Mixture ID	Cement (kg/m^3)	Flyash (kg/m^3)	Sand (kg /m^3)	Coarse Agg (kg/m^3)	Spread "mm"
M1	455	157	753	810	706
M2	492	170	660	810	770
M3	530	183	565	810	750
M4	570	197	468	810	710
M5	422	146	699	945	645
M6	457	158	612	945	662
M7	493	170	525	945	640
M8	528	182	437	945	640
M9	390	135	646	1080	465
M10	422	146	565	1080	571
M11	455	157	484	1080	540
M12	487	168	404	1080	520

aspects and hence becomes very essential for the production of high quality concrete. The efficiency of super plasticizers depends on length of the polymer chain and number of repetitive structural units. It is well known that different type of cements causes incompatibility issues with wide range of super-plasticizers for effective cement dispersion. Hence, in the present study special attention has been given to study the cement hyper-plasticizer interaction to avoid any inconsistency. The compatibility issue has been investigated using Marsh cone apparatus with a 5 mm nozzle for different water to binder ratios.

Characteristics of mortar study

The addition of fine aggregates such as sand can alter the paste characteristics since the particle size is relatively larger than powder materials (Banfill, 1994).

Fine aggregate fills the voids between the coarse aggregate and powder materials. The spherical shape helps in ball bearing effect which can enhance the rheological properties in the mortar phase. The presence of fine aggregate in the concrete enables the stability and controls towards the flow of paste. The optimum fine aggregate content that can be added without affecting the flow is estimated with the help of mini slump test.

Assessment of self compacting properties

The important requirements of SCC in its fresh stage are its ability to fill the formwork (filling ability), ability to pass through the congested reinforcements (passing ability), and ability to hold aggregates in suspension (segregation resistance). In general slump flow test is used to measure the flowing and spreading ability of SCC, passing ability of SCC can be assessed through J-ring and L-Box test and the segregation resistance capacity can be evaluated through sieve segregation test.

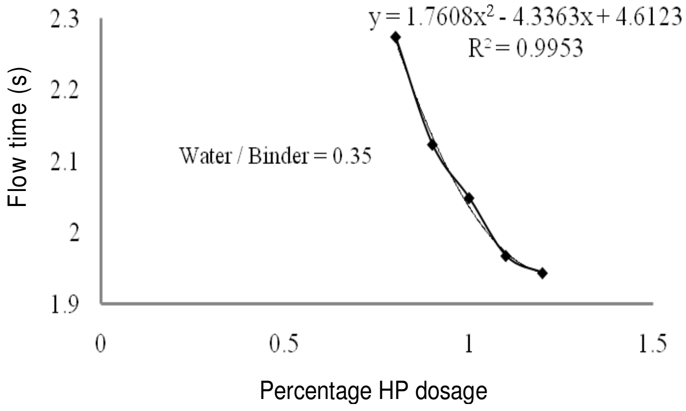

Figure 1. Cement–hyper plasticizer compatibility.

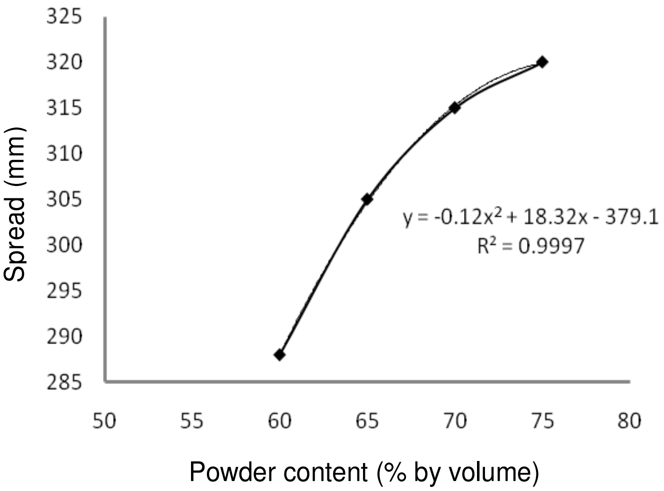

Figure 2. Mortar spread vs. powder content.

EXPERIMENTAL VALIDATION OF NEW MIXTURE DESIGN METHODOLOGY

Materials used

An ordinary Portland cement of 53 Grade with a specific gravity of 3.18 and standard consistency of 29.5% was used as cementing material. Class C flyash from Neyveli lignite corporation-India, was used as fine fillers with a specific gravity of 2.53. River sand passing through 2.36 mm sieve; with a specific gravity of 2.69 and fineness modulus of 2.55 was used as fine aggregate; crushed aggregate of size 12.5 to 10 mm were used as coarse aggregate in this study. A new generation hyper-plasticizer upto 1.0 (polycarboxylate based) with high molecular weight; and work on steric hindrance mechanism with the presence of long chain trunk polymer with a heavily grafted side chain was used to improve the flow ability and longer slump retention. The solid content as prescribed by the manufacturer (Cera-chem Pvt. Ltd, India) was found to be 36% with a specific gravity of 1.13.

Mixing method

The mixing of cement paste was carried out in a portable Hobart mixer to obtain a uniform blending and the flow studies was assessed in Marsh cone test and mini slump cone test. Similarly, mortar and concrete mixing was carried out in the specially designed portable electrically operated paddle type mixer. The mixing time for mortar and concrete was allowed for 5 min duration and flow properties were tested immediately.

RESULTS AND DISCUSSION

Cement study

Cement - Flyash compatibility

In order to determine the optimum utilization of flyash in SCC, Pozzolanic Activity Index (PAI) test (as per IS 3812-1983) has been performed on the mortar cube of size 7.5 cm at different level of replacement of cement with flyash. The compressive strength of cement mortar was tested at the 7th and 28th day. Mortar cubes with 30% flyash showed higher compressive strength compared to other replacement levels. The optimum addition of mineral admixture was determined in other to obtain good hardened properties, as well as to obtain good rheological properties of SCC.

Cement – Hyper plasticizer compatibility

To study the interaction of cement with hyper-plasticizer, marsh cone studies were carried out. To obtain good hardened concrete properties a low water/binder ratio 0.35 was adopted. Mixing of paste was done using a portable blender and a required quantity of 1 L was then poured into Marsh cone and the time taken to collect 0.5 L of the paste was noted down. The graph was drawn between the dosage of HP and flow time and shown in Figure 1. From the graph, the optimum dosage was found to be 1.2% (by weight of cement).

Mortar studies

Based on the assumption that paste is flowing, medium and fine aggregate particles were suspended in the following proportions 75:25, 70:30, 65:35, 60:40 were arrived for the mortar study and tested in mini slump (Figure 2). The mixing methodology is similar to that of paste studies and diameter of the spread as well as time of spread is noted. The variation of spread and the time of spread for different proportions are shown in Figures 3 and 4, respectively. It could be observed from Figure 3 that, as the paste content increases, the diameter of the spread increases. Whereas the time of spread (Figure 4) shows that, stability of mortar increases with the increase of sand content up to some level and then the stability of mortar decreases. From the aforestated studies on the

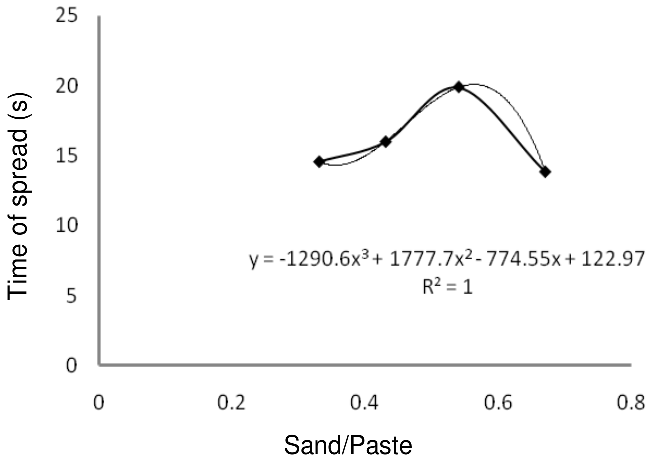

Figure 3. Time of spread vs. sand/paste ratio.

Figure 4. Slump flow of concrete.

Figure 5. J-Ring test apparatus.

mortar, the proportioning of concrete was also done in a similar method based on the different combinations of flowing and suspending medium. The calculated volumetric proportions for the 12 mixtures are given in Table 2.

Evaluation of self compacting properties of concrete

Slump flow studies

Slump flow helps to determine the stable flow properties of concrete which is exhibited by the maximum diameter of spread (Sonebi et al., 2007). A more uniform spreading of concrete can reveal the ideal qualities of a plastic concrete which tends to flow with a minimum yield stress that is required to initiate the flow. The results of the slump flow have been tabulated in Table 3. From the test results, it was observed that various proportions of the concrete mixtures were selected in order to satisfy various criteria such as bleeding and segregation. Based on the feasibility, characterization studies were not carried out for the mixtures 2, 3 and 4 due to high cement content. Similarly, mixtures 9, 10, 11 and 12 were omitted due to poor spreading ability in slump flow and mixture 1 was eliminated due to high bleeding of mortar. Therefore, mixtures 5, 6, 7 and 8 were selected for further characterization studies to evaluate the passing ability and segregation resistance.

Characterization studies

The important characteristics of SCC like passing ability and segregation resistance are examined through J-Ring (Figure 5) test. This test exhibits the flow behavior of concrete through congested reinforcements. The test results are given in Table 4 and satisfy the standard requirements with a blocking ratio of not more than 50; hence mixture 5 has been chosen for further assessment of the flow behavior. V- Funnel (Figure 6) test helps us to interpret the ability of concrete to flow through the chutes,

Table 3. Characteristic test results for concrete mixtures.

Mixture ID	Slump flow (A) (mm)	J-ring flow (B) (mm)	Blocking (A-B) (mm)	% Blocking ((A-B)/A)*100	Compressive strength (N/mm^{2})
M5	645	610	35	5.42	46.2
M6	662	530	132.5	20.01	38.2
M7	640	565	75	11.72	29.5
M8	640	560	80	12.5	32.9

Test results provided are average of 5 concrete mixture proportions.

Table 4. J-Ring test results.

Mixture ID	Slump flow (A)	J-ring flow (B)	Blocking (A-B)
M5	645	610	35
M6	662.50	530	132.5
M7	640	565	75
M8	640	560	80

Figure 6. V- Funnel test apparatus.

Figure 7. L-Box test apparatus.

the flow time was found to be 10 s which in accordance to European guidelines (EFNARC, 2002) is meeting the requirements of SCC. Evaluation of passing ability of concrete to flow through the reinforcements without segregation and blocking is being assessed with the help of L-Box (Figure 7) test. The correlation could be flow through small openings and congested reinforcements. The test is similar to that of slump cone with J- ring which can give details on the flow properties while moving in a close conduit. The test has been conducted as per European guidelines (EFNARC, 2002) and the passing ability was found to be 0.98 which is conforming to the requirements for a self flowing concrete. The hardened compressive properties of various concrete mixtures showed a highly consistent strength which is given in Table 4.

Conclusions

The salient conclusions that could be made from the study are that, flow properties of either mortar or concrete phase is highly dependent on the powder properties and packing characteristics of materials. The flow properties of the mortar increases with increase in cement flyash paste and on the other hand a negative trend was observed with increase in sand content. However, the rheological properties of the paste are more of a concern for the quantity of fine particles and hence adequate viscosity will primarily keep the coarser particles in suspension. Also, stability of the concrete mix refers to complete absence of the aggregate segregation as well as bleeding and also a uniform maximum spread. In the present study the proportions (60:40) of powder to fine aggregates resulted in good correlation in terms of a more stable and uniform spread with respect to mini slump. Further characterization studies were carried out based on the best performing mixtures in concrete spread. Out of the four mixes that were identified, Mix 5 which has 65:35 of the mortar phase and coarse aggregate and 60:40 of binder and fine aggregate, showed good flow ability and passing ability compared to all other mixes and also exhibited the highest compressive strength of 46 N/mm^2. A good understanding on the particle packing concept and material properties can be suitably used to design the concrete to the ultimate performance in terms of workability and strength.

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