Development of Self Compacting Concrete with Mineral and Chemical Admixtures – State of the Art

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Abstract- **Concrete is the construction material widely used throughout the world. Construction materials used in the industry should be friendly with the environment during its usage. Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogenous and has the same engineering properties and durability as traditional vibrated concrete. In order to obtain the properties of fresh concrete for SCC, proportion of mineral and chemical admixtures to be added. A review is presented based on the development of self-compacting concrete with mineral and chemical admixtures. Compiled test data revealed distinct difference in mechanical properties of normal and high strength self compacting concrete. To understand the behaviour of Self Compacting Concrete, it is necessary that several factors be taken into account for designing the mix proportions. Strength of concrete, type of cement, type of aggregate, water cement ratio, type of admixture are some of the important factors that affect the performance of concrete.**

Keywords- Self Compacting Concrete, Rice Husk Ash, Marble Dust, Fly ash, Viscosity modifying agent.

I. INTRODUCTION

Self-compacting concrete (SCC) was developed in Japan in the late 1980's. It is the concrete which is fully compacted without segregation without external energy. SCC has economic, social and environmental benefits over conventionally vibrated concrete. SCC is made from the same basic constituents as conventional concrete but with the addition of a viscosity modifying admixture and high levels of superplasticising admixtures to impart high workability. The cement (powder) content of SCC is relatively high. The ratio of fine to coarse aggregates is more in self-compacting concrete. Fine fillers such as flyash, silica fume, slag, metakaoline, marble dust and rice husk ash may be used in addition to cement to increase the paste content.

II. REVIEW OF LITERATURE

Bertil Persson (2001) carried out an experimental and numerical study on mechanical properties, such as strength, elastic modulus, creep and shrinkage of self-compacting concrete and the corresponding properties of normal compacting concrete. The study included eight mix proportions of sealed or air-cured specimens with water binder ratio (w/b) varying between 0.24 and 0.80. Fifty percent of the mixes were SCC and rests were NCC. The age at loading of the concretes in the creep studies varied between 2 and 90 days. Strength and relative humidity were also found. The results indicated that elastic modulus, creep and shrinkage of SCC did not differ significantly from the corresponding properties of NCC.

Nan Su et al (2001) proposed a new mix design method for self-compacting concrete. First, the amount of aggregates required was determined, and the paste of binders was then filled into the voids of aggregates to ensure that the concrete thus obtained has flowability, self-compacting ability and other desired SCC properties. The amount of aggregates, binders and mixing water, as well as type and dosage of super plasticizer to be used are the major factors influencing the properties of SCC. Slump flow, V-funnel, L-flow, U-box and compressive strength tests were carried out to examine the performance of SCC, and the results indicated that the proposed method could be used to produce successfully SCC of high quality. Compared to the method developed by the Japanese Ready-Mixed Concrete Association (JRMCA), this method is simpler, easier for implementation and less time-consuming, requires a smaller amount of binders and saves cost.

Bouzoubaa and Lachemi (2001) carried out an experimental investigation to evaluate the performance of SCC made with high volumes of fly ash. Nine SCC mixtures and one control concrete were made during the study. The content of the cementitious materials was maintained constant (400 kg/m^3), while the water/cementitious material ratios ranged from 0.35 to 0.45. The self-compacting mixtures had a cement replacement of 40%, 50%, and 60% by Class F fly ash. Tests were carried out on all mixtures to obtain the properties of fresh concrete in terms of viscosity and stability. The mechanical properties of hardened concrete such as compressive strength and drying shrinkage were also determined. The SCC mixes developed 28-day compressive strength ranging from 26 to 48 MPa. They reported that economical SCC mixes could be successfully developed by incorporating high volumes of Class F fly ash.

Sri Ravindra rajah et al (2003) made an attempt to increase the stability of fresh concrete (cohesiveness) using increased amount of fine materials in the mixes. They reported about the development of self-compacting concrete with reduced segregation potential. The systematic experimental approach showed that partial replacement of coarse and fine aggregate with finer materials could produce self-compacting concrete with low segregation potential as assessed by the V-Funnel test. The results of bleeding test and strength development with age were highlighted by them. The results showed that fly ash could be used successfully in producing self-compacting high-strength concrete with reduced segregation potential. It was also reported that fly ash in self-compacting concrete helps in improving the strength beyond 28 days.

Hajime Okamura and Masahiro Ouchi (2003) addressed the two major issues faced by the international community in using SCC, namely the absence of a proper mix design method and jovial testing method. They proposed a mix design method for SCC based on paste and mortar studies for super plasticizer compatibility followed by trail mixes. However, it was emphasized that the need to test the final product for passing ability, filling ability, flowability and segregation resistance was more relevant

Mohammed Sonebi (2004) developed medium strength self-compacting concrete by using pulverised fuel ash (PFA) with a minimum amount of super plasticizer. A factorial design was carried out to mathematically model the influence of key parameters on filling ability, passing ability, segregation resistance and compressive strength, which are important for the successful development of medium strength self-compacting concrete incorporating PFA. The parameters considered in the study were the contents of cement and PFA, water-to-powder (cement + PFA) ratio (W/P) and dosage of SP. The responses of the derived statistical models are slump flow, fluidity loss, Orimet time, V-funnel time, L-box, rheological parameters, segregation resistance and compressive strength at 7, 28 and 90 days. Twenty-one mixes were prepared to derive the statistical models, and five were used for the verification and the accuracy of the developed models. The models are valid for mixes made with 0.38 to 0.72 W/P, 60 to 216 kg/m^3 of cement content, 183 to 317 kg/m^3 of PFA and 0% to 1% of SP, by mass of powder. The influences of W/P, cement and PFA contents, and the dosage of SP were characterised and analysed using polynomial regression equations, which can identify the primary factors and their interactions on the measured properties. The results showed that MS-SCC can be achieved with a 28-day compressive strength of 30 to 35 MPa by using up to 210 kg/m^3 of PFA.

Mustafa Sahmaran et al (2006) evaluated the effectiveness of various mineral additives and chemical admixtures in producing self-compacting mortars (SCM). For this purpose, four mineral additives (flyash, brick powder, limestone powder and kaolinite), three super plasticizers and two viscosity modifying admixtures were used. Within the scope of the experimental program, 43 mixtures of SCM were prepared keeping the amount of mixing water and total powder content (portland cement and mineral additives) constant. Workability of the fresh mortar was determined using mini V-funnel and mini slump flow tests. The setting time of the mortars, was also determined. The hardened properties that were determined included ultrasonic pulse velocity and strength at 28^{th} and 56^{th} days. It was concluded that among the mineral additives used, fly ash and limestone powder significantly increased the workability of SCMs. On the other hand, especially fly ash significantly increased the setting time of the mortars, which can be eliminated through the use of ternary mixtures, such as mixing fly ash with limestone powder. The two polycarboxyl based SPs yield approximately the same workability and the melamine formaldehyde based SP was not as effective like other SPs.

Mustafa Sahmaran and Ozgur Yaman (2007) studied the fresh and mechanical properties of a fiber reinforced self-compacting concrete incorporating high-volume fly ash that does not meet the fineness requirements of ASTM C 618. A poly carboxylic based super plasticizer was used in combination with a viscosity modifying admixture. In mixtures containing fly ash, 50% of cement by weight was replaced with flyash. Two different types of steel fibers were used in combination, keeping the total fiber content constant at 60 kg/m^3. Slump flow time and diameter, V-funnel, and air content were found to assess the fresh properties of the concrete. Compressive strength, splitting tensile strength, and ultrasonic pulse velocity were determined for the hardened concrete. The results indicated that high-volume coarse fly ash can be used to produce fiber reinforced self-compacting concrete, even though there is some reduction in the strength because of the use of high-volume coarse fly ash.

Burak Felekoglu (2007) made an investigation on five self-compacting concrete mixtures with different combinations of water/cement ratio and super plasticizer dosage levels. Slump flow, V-funnel and L-box tests were carried out to determine the optimum parameters for the self-compactibility of mixtures. Compressive strength development, modulus of elasticity and splitting tensile strength of mixtures were also studied. It was reported that optimum water/cement ratio for producing SCC was in the range of 0.84–1.07 by volume. The ratios above and below this range may cause blocking or segregation of the mixture. The Splitting tensile strengths of the SCC mixes were found to be higher and the values of Modulus of elasticity were found to be lower than that of NCC.

Binu Sukumar et al (2007) replaced high volume fly ash in the powder, based on a rational mix design method to develop self-compacting concrete (SCC). High fly ash content necessitated the study on the development of strength at early ages of curing which is a significant factor for the removal of formwork. Rate of gain of strength at different periods of curing such as 12 h, 18 h, 1 day, 3 days, 7 days, 21 days and 28 days were studied for various grades of different SCC mixes and suitable relations were established for the gain in strength at the early ages in comparison to the conventional concrete of same grades. Relations were also formulated for the compressive strength and the split tensile strength for different grades of SCC mixes. It was observed that the rate of gain in strength for different grades of SCC was slightly more than the expected strength of conventional concrete of the same grades

Burak Felekoglu and Hasan Sarıkahya (2007) synthesized three Poly Carboxylate (PC) based super plasticizers by using radical polymerisation techniques. The effect of these admixtures on setting time of cement pastes, time dependent workability and strength development of SCC was investigated. Test results showed that, from the viewpoint of chemical structure, workability retention performance of PC-based Super Plasticizers could be manipulated by modifying the bond structure between main backbone and side-chain of copolymer. PC-based SPs with ester bonding were found to be ineffective in maintaining the workability of fresh concrete workability due to the alkali attack vulnerability of this bond structure. It was also reported that, by directly bonding the polyoxyethylene side-chain to the backbone of copolymer, the workability of fresh can be effectively maintained at least for a period of 2 h. It was found that, in addition to the types of SP, water/powder ratio of SCC mixtures were also responsible for the long workability retention performances. Best results were derived from mixtures incorporating 2.3 weight % of SP.

Ahmadi et al (2007) studied the development of Mechanical properties up to 180 days of self-compacting and ordinary concrete mixes with rice-husk ash (RHA), from a rice paddy milling industry. Two different replacement percentages of cement by RHA, 10%, and 20%, and two different water/cementitious material ratios (0.40 and 0.35) were used for both of self-compacting and normal concrete specimens. The results were compared with those of the self-compacting concrete without RHA. SCC mixes show higher compressive and flexural strength and lower modulus of elasticity rather than the normal concrete. Replacement up to 20% of cement with rice husk ash in matrix caused reduction in utilization of cement and expenditures, and also improved the quality of concrete at the age of more than 60 days. It was concluded that RHA provides a positive effect on the Mechanical properties after 60 days.

Andreas Leemann and Frank Winnefeld (2007) studied the influence of different viscosity modifying agents on the flow properties and the rheology of self-compacting mortars. Additionally, their effect on the early hydration of cement pastes and on the development of strength of concrete was determined. Inorganic VMA micro silica (MS), nano silica slurry (NS), organic VMA based on high molecular ethylene oxide derivate (EO), natural polysaccharide (PS) and starch derivate (ST) were used. The different VMAs were combined with a super plasticizer (SP). At constant water-to-binder ratio (w/b), the addition of VMA caused a decrease of mortar flow and an increase of flow time (V-funnel test). At a constant dosage of super plasticizer (SP) mixtures with VMA require a higher w/b to keep the same flow properties as the reference mixtures without VMA. In spite of the higher w/b flow time and plastic viscosity respectively are only slightly reduced. This property is especially beneficial for the production of stabilizer-type self-compacting concrete where the amount of fines can be reduced with the use of VMA. However, only the use of VMA PS and ST leads to smaller changes of flow when w/b is changed. The organic VMA show almost no influence on early cement hydration and the development of compressive strength. However, the inorganic VMA caused an acceleration of hydration and higher compressive strength at the age of 1 day.

Halit Yazici (2007) developed self-compacting concrete by replacing cement with a Class C fly ash in various proportions from 30% to 60%. Durability properties of various self-compacting concrete mixtures such as, freezing and thawing, and chloride penetration resistance were found. Similar tests were carried out with the incorporation of 10% silica fume to the same mixtures. Test results indicated that SCC could be obtained with a high-volume FA. Addition of 10% SF to the system improved both the fresh and hardened properties of high-performance high-volume FA SCC. These mixtures had good mechanical properties, freeze–thaw and chloride penetration resistance. Moreover, these mixtures also had great environmental and economical benefits. The heat of hydration and shrinkage of these mixtures were lower than that of the SCC mixtures made with high-volume Portland cement.

Khatib (2008) investigated the influence of including fly ash (FA) on the properties of self-compacting concrete. Portland cement was partially replaced with 0–80% FA. The water to binder ratio was maintained at 0.36 for all mixes. Properties like workability, compressive strength, ultrasonic pulse velocity, absorption and shrinkage were found. The results indicated that high volume FA can be used to produce high strength and low shrinkage SCC. Replacing 40% of Portland cement with FA resulted in a strength of more than 65 N/mm^2 at 56 days. High absorption values were obtained with increasing amount of FA. There is a systematic reduction in shrinkage as the FA content increases and at 80% FA content, the shrinkage at 56 days reduced by two third compared with the control. A linear relationship existed between the 56^{th} day shrinkage and FA content. Increasing the admixture content beyond a certain level led to a reduction in strength and increase in absorption. The correlation between strength and absorption indicated a sharp decrease in strength as absorption increased from 1 to 2%. Beyond 2% absorption, the reduction in the strength was found to be at a slower rate.

Shazim Ali Memon et al (2008) studied the use of Rice Husk Ash (RHA) to increase the amount of fines and hence achieving self-compacting concrete in an economical way. They compared the properties of fresh SCC containing varying amounts of RHA with that containing commercially available viscosity modifying admixture. The comparison was done at different dosages of super plasticizer keeping cement, water, coarse aggregate, and fine aggregate contents constant. Test results substantiate the feasibility to develop low cost SCC using RHA. Cost analysis showed that the cost of ingredients of specific SCC mix is 42.47 percent less than that of control concrete.

Paratibha Aggarwal et al (2008) presented a procedure for the design of self-compacting concrete mixes based on an experimental investigation. At the water/powder ratio of 1.180 to 1.215, slump flow test, V-funnel test and L-box test results were found to be satisfactory, i.e. passing ability, filling ability and segregation resistance are well within the limits. SCC was developed without using VMA in this study. Further, compressive strength at the ages of 7, 28, and 90 days was also determined. By using the OPC 43 grade, normal strength of 25 MPa to 33 MPa at 28-days was obtained, keeping the cement content around 350 kg/m^3 to 414 kg/m^3

Seshadri Sekhar and Srinivasa Rao (2008) studied the properties like Compressive Strength, Split Tensile Strength and Flexural Strength of SCC mix proportions ranging from M30 to M65 grades of concrete. An attempt was made to obtain a relationship between the splitting tensile strength, Flexural Strength and Compressive strength from the test results. The increase in the compressive strength for all the grades of SCC mixes compared with the 28^{th} day compressive strength varied between 20 to 30%. The increase in flexural strength for all the grades of SCC mixes compared with the 28^{th} day flexural strength varied between 15 to 25%. The increase in split tensile strength for all the grades of SCC mixes compared with the 28^{th} day split tensile strength varied between 15 to 25%.

Al-Feel and Al-Saffar (2009) carried out an experimental investigation to study the effect of curing methods on the compressive, splitting, and flexural strengths (modulus of rupture) of self-compacting concrete and compared the same with that of normal concrete. The self-compacting concrete was made with Portland cement, limestone powder, sand, gravel and super-plasticizer. The specimens were cured in the air and water, for the period of 7, 14, and 28 days. Three specimens were tested for each point of each property. It is reported that the compressive strength, splitting tensile strength and flexural strength of the water cured specimens were 11%, 10% and 11% respectively more than that of the specimens cured in air. From the failed specimens it was found that there was no segregation and the bond between aggregate and matrix was good.

Kursat Esat Alyamac and Ragip Ince (2009) studied the relationship between properties of the fresh SCC and the hardened SCC containing marble powder. For this purpose, the mix design approach based on monogram developed by Monteiro and co-workers for normal vibrated concrete was adapted to SCC mixes. In order to obtain this monogram, a series of SCC mixes with different water/cement ratios and water/powder ratios were prepared. Several tests such as slump-flow, T500 time, L-box, V-funnel and sieve segregation resistance were applied for fresh concrete and tests such as compressive strength and split-tension strength at 7,28 and 90 days were performed for hardened concrete. In conclusion, the mix design method based on monogram can be used for preliminary design of SCC mixes.

Ilker Bekir Topcu et al (2009) developed self-compacting concrete, using waste Marble Dust (MD) as a filler material. MD was used directly without any additional processing. MD was used to replace the binder of SCC in proportions of 0, 50, 100, 150, 200, 250 and 300 kg/m^3. Slump-flow test, L-box test and V-funnel test were carried out on the fresh concrete. Compressive strength, flexural strength, ultrasonic velocity, porosity and compactness were also determined at 28 days. The effect of waste MD usage as filler material on capillarity properties of SCC was also investigated. It was concluded that the workability of fresh SCC has not been affected up to 200 kg/m^3 MD content. However, the mechanical properties of hardened SCC were found to decrease while using MD, especially when the content of MD was more than 200 kg/m^3.

Hemant Sood et al (2009) highlighted the use of European standards for testing self-compacting concrete in Indian conditions. They carried out an experimental investigation of Self Compacting Concrete using Flyash and Rice husk ash as mineral admixtures and testing rheological properties as per European Standards. Addition of flyash in SCC increased the filling and passing ability of concrete, whereas rice husk ash imparted viscosity to concrete improving segregation resistance of concrete mix. From this experimental study it was inferred that Flyash and RHA blend well improving overall workability, which is the prime important characteristics of SCC. Increase in Rice husk ash content increased the water demand and reduced the compressive strength of concrete.

Girish et al (2010) presented the results of an experimental investigation carried out to find out the influence of paste and powder content on self-compacting concrete mixtures. Tests were conducted on 63 mixes with water content varying from 175 l/m^3 to 210 l/m^3 with three different paste contents. Slump flow, V funnel and J-ring tests were carried out to examine the performance of SCC. The results indicated that the flow properties of SCC increased with an increase in the paste volume. As powder content of SCC increased, slump flow of fresh SCC increased almost linearly and in a significant manner. They concluded that paste plays an important role in the flow properties of fresh SCC in addition to water content. The passing ability as indicated by J-ring improved as the paste content increased.

Nicolas Ali Libre et al (2010) studied the effect of chemical and mineral admixtures, including super plasticizer, viscosity modifying agent (VMA), limestone powder and fly ash with different W/C ratios on fluidity, viscosity, and stability of self-consolidating mortar. The results indicated that W/C is the most significant parameter influencing the rheological properties of cementitious mixtures, specially their stability. Furthermore, the maximum allowable W/C ratio for preventing in homogeneity could not be a fixed value for all the mixtures and should be adjusted for the target fluidity. They reported that addition of VMA was an effective method for stabilizing self-consolidating mortars and preventing any kinds of instability. Limestone powder and fly ash mainly affected bleeding and aggregate blockage. Besides, these mineral admixtures improved the fluidity of the mixtures to some extent.

Venkateswara Rao et al (2010) developed standard and high strength self-compacting concrete with different sizes of aggregate based on Nansu's mix design procedure. The results indicated that Self Compacting Concrete can be developed with all sizes of graded aggregate satisfying the SCC characteristics. The mechanical properties such as compressive strength, flexural strength and split tensile strengths were found at the end of 3, 7 and 28 days for standard and high strength SCC with different sizes of aggregate. The optimum size of aggregate was found to be 10mm for standard self-compacting concrete (M30), while it was 16mm for high strength self-compacting concrete (M70) though all other sizes also could develop properties satisfying the criteria for SCC. A comparison of M30 and M70 grade concrete confirmed that the filling ability, passing ability and segregation resistance were better for higher grade concrete for the same size of aggregate. This is due to the higher fines content in M70 concrete. It was noted that 10mm size aggregate and 52% flyash resulted in highest mechanical properties in standard SCC, whereas 16 mm size aggregate with 31% flyash content resulted in highest strength in case of high strength SCC.

Mucteba Uysal and Kemalettin Yilmaz (2011) studied the benefits of using limestone powder (LP), basalt powder (BP) and marble powder (MP) as partial replacement of Portland cement to develop the self-compacting concrete. Furthermore, LP, BP and MP were used directly without any additional processing in the production of self-compacting concrete (SCC). The water to binder ratio was maintained at 0.33 for all mixtures. The examined properties include workability, air content, compressive strength, ultrasonic pulse velocity, static and dynamic elastic moduli. Workability of the fresh concrete was determined by using both the slump-flow test and the L-box test. The results proved that it is possible to successfully utilize waste LP, BP and MP as mineral admixtures in producing SCC. It was reported that the employment of waste mineral admixtures improved the economical feasibility of SCC production.

III. CONCLUSION

The elimination of vibrating equipment improves the environment protection near construction sites where concrete is being placed, also reducing the exposure of workers to noise and vibration. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for civil engineering construction. Twenty six case studies on the development of self compacting concrete were analysed. From the literatures it can be seen that various properties of materials and mix proportions makes SCC to behave differently in its fresh and hardened state when it is used. Case studies have confirmed that, there are currently no standardized tests or limits for the specification of SCC. Considerable scope exists for the optimization of SCC mixes with efficiency and economy for the benefit of construction industry in the future.

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