Relationship between Ultrasonic Pulse Velocity and Compressive Strength of Self Compacting Concrete incorporate Rice Husk Ash and Metakaolin

V.Kannan

***Abstract*— The objective of the present investigation was to evaluate RHA and MK as supplementary cementitious materials (in both binary and ternary systems) in terms of harden properties in blended cement SCC and to identify the optimal level of replacement of ordinary Portland cement (OPC) with RHA, MK, or RHA+MK. The blended cements were prepared by replacing OPC with RHA, MK, or RHA+MK (5–40%) in dry conditions. In addition to that the interrelationship between harden properties such as compressive strength and ultrasonic pulse velocity was discussed.**

***Index Terms*— Self compacting concrete (SCC); Compressive Strength; Ultrasonic Pulse Velocity (UPV); Interrelationship**

I. INTRODUCTION

The development of self-compacting concrete (SCC) is an important achievement in the construction industry for overcoming problems associated with conventional concrete. SCC does not require skilled workers for compaction as conventional concrete does. Due to its high fluidity and resistance to segregation, SCC can be pumped long distances in closely spaced reinforced sections. The concept of SCC was proposed in 1986 by Professor Okamura [1], but the prototype was first developed in 1988 in Japan by Professor Ozawa [2] at the University of Tokyo. The SCC was named "high-performance concrete" and later changed to "self-compacting high-performance concrete" or simply, "self-compacting concrete."

SCC was developed to improve the durability of concrete structures. Since then, various investigations have been carried out, and SCC has been used in practical structures in Japan, mainly by large construction companies. Investigations for establishing a rational mix-design method and self-compactability testing methods have been carried out from the viewpoint of making it a standard concrete. SCC is cast so that no additional inner or outer vibration is necessary for the compaction. It flows in a similar manner as honey and has a very smooth surface level after placing. SCC requires a large amount of powder content (either by fine aggregate or fillers) compared to conventional vibrated concrete to produce a homogeneous and cohesive mix [3]. Okamura & Ozawa (1995) stated that the self-compactability in SCC can be obtained by increasing the fine aggregate content; by limiting the maximum aggregate size; by increasing the powder content; by using viscosity modifying admixtures (VMA) and reducing the water-to-binder ratio through superplasticizer (SP) [4, 5 and 6]. The basic principle of SCC is shown in Figure 1.

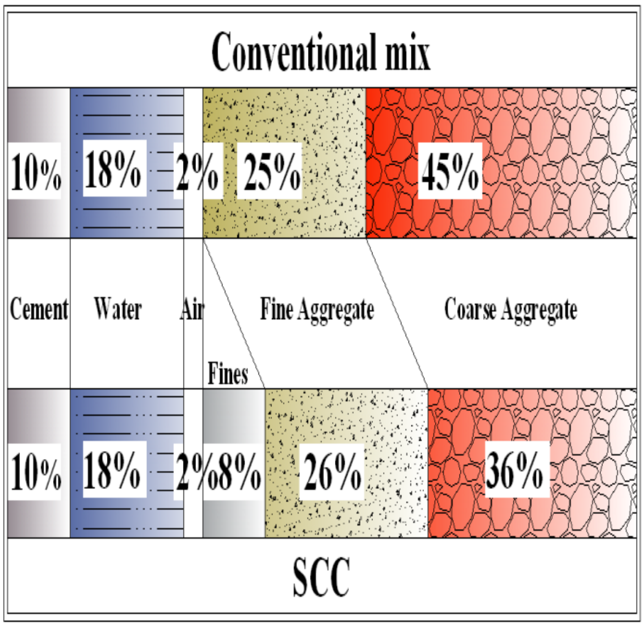

Figure 1 Principle of SCC

The main disadvantage of SCC is the high cost associated with the use of chemical admixtures and high volumes of Portland cement. One alternative to reduce the cost of SCC is to use mineral additives such as rice husk ash (RHA), metakaolin (MK), limestone powder, natural pozzolans, fly ash, and slag, which are finely divided materials added to concrete as partial replacement material [7]. As these mineral additives replace part of the Portland cement, the cost of SCC will be reduced, especially if the mineral additive is an industrial by-product or waste. It is well established that the mineral additives might increase the workability, durability, and long-term properties of concrete [8, 9 and 10].

In this work, harden properties of compressive strength test and ultrasonic pulse velocity test were conducted on all the mixes; then obtained experimental data (Compressive strength and ultrasonic pulse velocity) from tests, regression analysis is proposed to be carried out to check their interrelationship among them.

V.Kannan, Department of Civil Engineering, National College of Engineering, Tirunelveli, India, 9787211014.

II. MATERIALS AND METHODS

A. *Materials*

Ordinary Portland cement (OPC) conforming to ASTM C 150 (Type1) was used. The sieve analysis of the fine aggregate (FA) and coarse aggregate (CA) cement was carried out in accordance with the ASTM C136 standard provision. The sieve analysis results are tabulated in Table 1 and the physical properties of the FA and CA are presented in Table 1. Commercially available MK was used for the study.

Table 1 Sieve analysis and physical properties of Fine and Coarse aggregate

SIEVE SIZE (MM)	FINE AGGREGATE (% OF PASSING)	COARSE AGGREGATE (% OF PASSING)
20 12.5 10 4.75 2.36 1.18 0.60 0.30 0.15 PAN	100 100 100 99.9 99.1 83.1 58.3 10.0 0.70 0.00	100 90.1 10.4 0.00 0.00 0.00 0.00 0.00 0.00 0.00
BULK DENSITY(KG/M^3)	1752	1640
SPECIFIC GRAVITY (G/CM^3)	2.53	2.78
WATER ABSORPTION (%)	2.01	0.36
FINENESS MODULUS	2.48	6.89

Boiled fired RHA residue was collected from a modern rice mill. The mill-fired husk residue ash was further burnt in a laboratory muffle furnace at a temperature of 650°C over a one-hour period. The burnt material was ground in a laboratory pulverizer with a disc diameter of 175 mm for one hour to a mean particle size of 6.27 micron meters (μm) before it was used as a cement replacement material.

The physical and chemical analyses of OPC, RHA, and MK were carried out according to relevant Indian standard (IS) code provisions. Superplasticizers (SP) were used to increase SCC workability. For this purpose, sulphonated napthalene polymer based SP with specific gravity of 1.220–1.225 was used as a high range water reducer (conforming to IS: 9103:1999 and ASTM-C-494 Type 'F', depending on the dosage used) to improve the SCC performance.

Table 2 Sieve analysis and physical properties of Fine and Coarse aggregate

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI
OPC (%)	20.25	5.04	3.16	63.3	4.2	0.08	0.5	3.08
RHA (%)	87.89	0.19	0.28	0.73	0.47	0.66	3.4	4.36
MK (%)	51.8	43.75	0.82	0.09	0.03	0.07	0	0.34

B. *Mix Proportion and Specimen preparation*

Based on previous studies, the mixing design was modified using EFNARC guidelines [10]. In general, self-compatibility can be greatly affected by the material properties and the mix proportion. In the trial mix, the fine and coarse aggregate contents were fixed so that self-compatibility could easily be achieved by adjusting only the water powder ratio and the superplasticizer dosage. From the trial mix, a suitable mix proportion was taken for further study. In this study, the ratio of fine and coarse aggregate was fixed at 1.1, with a W / B (W / (C+RHA or MK or RHA+MK) ratio of 0.55 and 2% of the superplasticizer; the only variables were the RHA and MK to OPC.

The mix design was carried out to produce SCC without segregation and bleeding, with a target mean compressive strength of 38.5 N/mm^2 (as M30-graded normal vibrated concrete) at 28 days. For this study, a total of seventeen concrete mixtures were prepared (RHA, MK with ranges of 0%, 5%, 10%, and 30%, and a combination of RHA and MK with ranges of 10%, 20%, 30%, and 40% with one normal SCC), and all of the mixtures satisfied the target mean strength. These mixes were designated as OPC (100%) and RHA5 / MK5 / RHA5+MK5…….RHA30 / MK30 / RHA20+MK20.

For all mixes, three specimens of 100 mm^3 were cast for a compressive strength and UPV test. After casting, all of the specimens were left in casts for 24 hours, and then they were demolded and immersed in a water curing tank until they were required for testing.

C. *Testing Methods*

To check the fresh state properties such as filling ability, viscosity, and passing ability of concrete, slump flow, V-funnel, and L-box tests were conducted according to European Federation of National Associations Representing the Producers and Applicators of Specialist Building Products for Concrete (or EFNARC) specifications.
The compressive strength test was carried out after 7, 28, and 90 days, and the magnesium sulfate and corrosion resistance

tests were conducted over 28 days of water curing. The compressive strength tests were carried out according to IS 516-1956. The ultrasonic pulse velocities of blended SCC specimens were determined as per IS 13311(part1)-1992 after 28 days of moisture curing.

III. RESULTS AND DISCUSSION

A. *Physical and chemical analysis of OPC, MK and RHA*

The physical and chemical properties of the OPC, RHA, and MK were tested and the results are reported in Tables 3 and 3.2. RHA and MK are fine materials with chemical constituents of SiO_2, Al_2O_3, Fe_2O_3, and CaO; these constituents maybe responsible for their pozzolanic reactivity. This particular RHA consisted of 87.89% of silica and had a silica content that was nearly four times higher than that of the OPC. The burning process at 650°C for 1 hour brought down the carbon content of the RHA to a value of 4.36% (loss on ignition), which is slightly higher than that of the OPC. The chemical analysis of the MK shows that it consists of 51.80% silica content and has nearly two times higher silica content than the OPC. MK also contains a considerable amount of Al_2O_3, with a minimal amount of CaO.

The loss of ignition values for RHA and MK are 4.36% and 0.34%, respectively, both of which are less than the permissible value (5%) specified in IS 8118 for OPC. Among all the binding materials, MK has a low loss of ignition value.

Table 3 Physical properties of OPC, RHA and MK

Materials	Specific gravity g/cm^3	Fineness passing 45μ sieve (%)	Specific surface Area		Mean particle size in micron meter (μm)
			BLAIN'S M^2/KG	BET'S IN M^2/G	
OPC	3.13	86	318	-	23.4
RHA	2.08	91	943	36.47	6.27
MK	2.58	99	2350	-	3.79

Table 3 Chemical composition of OPC, RHA and MK (%)
LOI- Loss on ignition

B. *Fresh state properties*

The fresh state properties of SCC containing RHA, MK or a combination of RHA and MK were studied and are presented in Figures 3.1, 3.2, and 3.3, respectively.

The slump flow values of SCC with RHA, MK, and RHA+MK are shown in Figure 2. From the results, the slump flow values for different concrete mixes were calculated in the range of 495-740 mm. According to values recommended by EFNARC for fresh state properties of SCC as presented (Table 3.2), all the mixtures examined fall under the categories of slump flow classes 1 and 2 (SF1 and SF2) except RHA30 and RHA20+MK20 mixes. The SF1 and SF2 classes in concrete mixes are used to indicate that these mixes are suitable for applications such as deep foundation construction (SF1) and for normal applications such as the building of columns (SF2). The RHA30 and the RHA20+MK20 mixes did not meet the EFNARC standard specifications. From the results, it can be clearly noted that the slump flow (or filling ability) value gradually reduced with the increments of the replacement level of RHA, MK and RHA+MK. This condition may be caused by the high reactivity and higher surface area of RHA and MK when compared to OPC. It also may be due to the lowest fineness modulus of fine aggregate (FA) (see Table 1). Similar trends in the slump flow values were reported in previous studies.

The V-funnel times for different concrete mixes appear in Figure 3. From the results, it can be noted that the V-funnel times varied in the range of 3.9-8.4 seconds; all concrete mixes could be categorized into the VF1 class except for the20% RHA+20%MK mix. According to the EFNARC guidelines, a V-funnel time when exceeding 25sec only, it is not recommended. From the results, the V-funnel times for all concrete mixes were satisfied this requirement.

The L-box test results are shown in Figure 4. From the results, the blocking ratio for different mixes varied from 0.59-0.94. A satisfactory blocking ratio was observed in up to 15% RHA, 15% MK, and 30% RHA+MK mixes; the value of the ratio for the rest of the mixes was found to be outside the EFNARC-recommended values. In a previous study [11], a blocking ratio from 0.6-1 is acceptable for SCC to obtain satisfactory filling ability. In this regard, all concrete mixes were satisfactory (that is, within the prescribed range) except for the 30% MK mix. The blocking ratios of blended SCC were prone to decrease with higher RHA and MK contents, mostly due to the increased surface area of the total binder. For a given blocking ratio, the water demand increases with a greater surface area of the binder [12]. Therefore, in this research, remarkable variability in the blocking ratio of the mixes was observed.

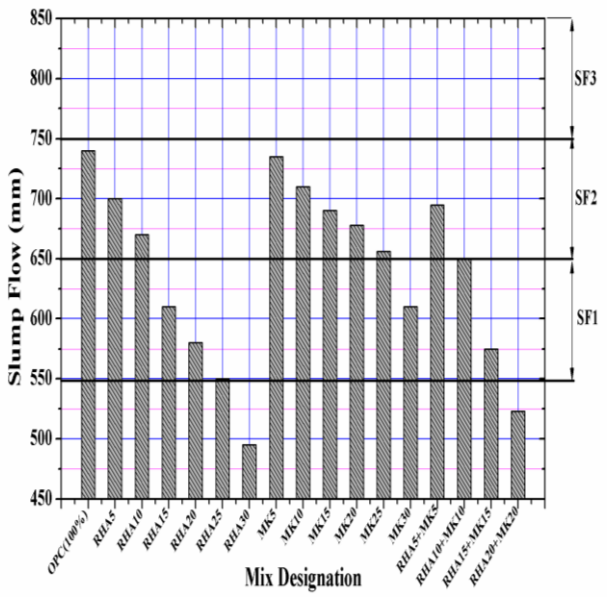

Figure 2 Slump flow values for different mixtures

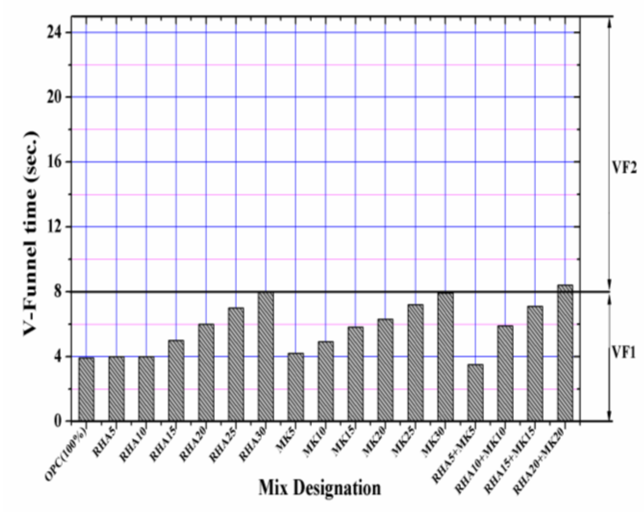

Figure 3 V-Funnel times for different mixtures

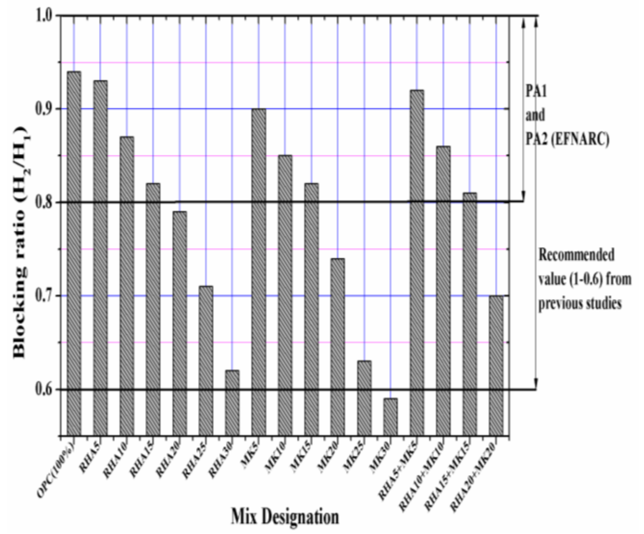

Figure 4 Blocking ratio (L-box test) for different mixtures

C. Compressive strength

The compressive strength of binary and ternary blended SCC with RHA and MK at 28 days is shown in Figure 4. Considering the binary mixtures, there was a systematic increase in compressive strength of SCC containing RHA and MK up to 15% and 25%, respectively, at both 28 and 90 days. The same trend was observed in the RHA-incorporated ternary system SCC; however, the 28-day compressive strength of the ternary systems was slightly higher than that of binary system concrete, and all of the 90-day compressive strength values were almost within the same range owing to the secondary hydration reactions due to the existence of SCMs. For example, 90-day compressive strength of binary mixture concretes (the maximum cement replacement level (CRL) is 30%) with RHA and MK ranged from 39.98 to 60.01 MPa, while it was in the range of 47.09 to 60.64 MPa for ternary blends of mixtures (maximum CRL was 40%). The binary blended SCC that included 15% RHA and 20% MK reached maximum 28-day compressive strength values of about 51.03 and 57.17 MPa, irrespective of the mixture combination. Yet, the maximum 28-day compressive strength value of 55.67 MPa was achieved at 30% of RHA+MK combined ternary blend. Equivalent or higher values of compressive strength of binary and ternary blended SCC at 28 days were obtained at 25% RHA and 30% MK for the binary system. However, for the ternary blended SCC, they were obtained at 40% of RHA+MK (20%RHA+20%MK). Therefore, 25% RHA, 30% MK, and 40% RHA+MK are considered the optimal limits.

TABLE 4 COMPRESSIVE STRENGTH OF BINARY AND TERNARY BLENDED SCC WITH RHA AND MK

Mix designation	**RHA/MK/ RHA+MK (%)**	**Compressive Strength (MPa) at 28 days**
NSCC (100%OPC)	0	40.77
R1	5	43.4
R2	10	47.71
R3	15	51.03
R4	20	44.19
R5	25	41.92*
R6	30	37.02
M1	5	48.28
M2	10	51.91
M3	15	54.53
M4	20	57.17
M5	25	53.74
M6	30	51.40*
RM1	5+5	49.52
RM2	10+10	53.22
RM3	15+15	55.67
RM4	20+20	45.00*

***Equivalent or higher strength compared to control specimen (Mix 1 : 2.2 : 2, W/B= 0.55)**

D. Ultrasonic pulse velocity

The experimental evolution of the UPV values for the binary and ternary blended SCC with RHA and MK has been presented in Table 5. The trend of variation of the UPV with CRL of blended SCC is discussed below:

Table 5 Ultrasonic pulse velocity (UPV) and Dynamic modulus of elasticity (DME) values of binary and ternary blended SCC with RHA and MK

Mix Designation	MK/RHA/ MK+RHA (%)	UPV (m/sec)	Category of UPV Values as per IS13311 (part1)-1992
NSCC (100%OPC)	0	4494.38	Good
RHA5	5	4655.493	Excellent
RHA10	10	4672.897	Excellent
RHA15	15	4873.294	Excellent
RHA20	20	4670.715	Excellent
RHA25	25	4501.45	Excellent
RHA30	30	4326.90	Good
MK5	5	4676.54	Excellent
MK10	10	4975.12	Excellent
MK15	15	5025.13	Excellent
MK20	20	5208.33	Excellent
MK25	25	5012.53	Excellent
MK30	30	4739.34	Excellent
RHA5+MK5	10	4694.836	Excellent
RHA10+MK10	20	4791.567	Excellent
RHA15+MK15	30	5013.45	Excellent
RHA20+MK20	40	4672.897	Excellent

(i) As expected, the UPV value of blended SCC increases with the increasing of replacement level up to 15% RHA, 20%MK and 30% RHA+MK then decreases, but the equivalent or higher UPV values of the unblended SCC are obtained at 25%RHA, 30%MK and 40% RHA+MK. It can be clearly noted the beneficial use of RHA in combination with MK as a cement replacement material up to 40%.

(ii) The UPV value of blended SCC has been found to be higher than the unblended SCC for all the replacement level of cement by RHA, MK and their combination at 28days excluding 30% RHA blended SCC. The reason may be due to the high rate of hydration, and lower porosity due to its higher surface area of a particular material.

E. Relationship between UPV and Compressive Strength

Past studies show that there is no unique relationship between UPV and the compressive strength of concrete (Neville 1996). However, the UPV of SCC is affected by change in the hardened cement paste, which is influenced by water/cement ratio. It has been observed and reported that the UPV travels faster through water-filled voids as compared to the concrete with air-filled voids [13]. Thus, it can be said that the UPV is also affected by the moisture condition of the concrete. With these limitations, the UPV test can be used to assess the strength of concrete. These limitations also affect the strength properties of SCC containing RHA, MK and RHA+MK. Therefore, the relationship between the compressive strength of SCC containing different percent replacement of RHA/ MK/ RHA+MK and UPV has been developed.

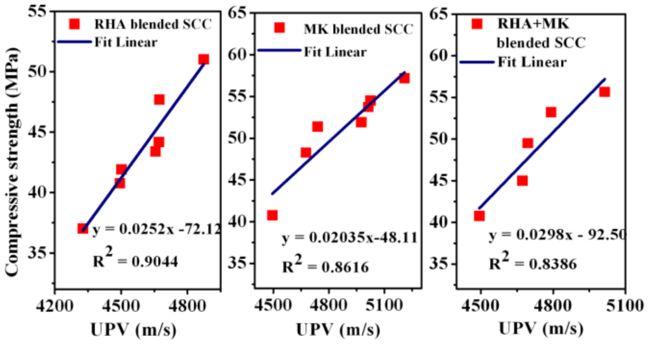

Figure 5 Correlation between UPV and compressive strength at 28 days of RHA, MK and RHA+MK blended SCC

Interrelationship between compressive strength and UPV for all the blended mixes of SCC at 28 days are developed and presented in Figure 5. From the correlation analysis (Linear fit), it can be used to assess the strength of the blended SCC in terms of UPV. Based on the experimental results, linear relationship between the combined results of cube compressive strength (f_c) and UPV (U) of SCC with RHA, MK and RHA+MK respectively has also been proposed as:

(i) For RHA blended SCC

$$\mathbf{f_c = 0.0225U-72.12} \quad (3.1)$$

(ii) For MK blended SCC

$$\mathbf{f_c = 0.0203U-48.11} \quad (3.2)$$

(iii) For RHA+MK blended SCC

$$\mathbf{f_c = 0.0298U-92.50} \quad (3.3)$$

where, f_c = compressive strength at 28 days in MPa
U = ultrasonic pulse velocity at 28 days in m/sec.

IV. CONCLUSION

From the above study, the following conclusion may be drawn

- The slump flow values for blended SCC were calculated in the range of 495-740 mm. Slump flow (or filling ability) value is gradually reduced with the increments of the replacement level of RHA, MK and RHA+MK. This condition may be caused by the high reactivity and higher surface area of RHA and MK when compared to OPC.

- V-funnel times varied in the range of 3.9-8.4 seconds. All the blended SCC could be categorized into the VF1 class except for the20% RHA+20%MK mix.

According to the EFNARC guidelines, all concrete mixes satisfied this requirement.

- The blocking ratio for the different mixes varied from 0.59 to 0.94. A satisfactory blocking ratio was observed up to 15% in RHA, 15% MK, and 30% RHA+MK mixes. The value of the ratio for the rest of the mixes was found to be outside the EFNARC-recommended values. However, all of the mixes exhibited satisfactory fresh state properties (according to the criteria established by EFNARC and previous studies) except for the 30% RHA, 30% MK, and 20% RHA + 20% MK mixes.

- Compressive strength increased with the RHA content up to 15%, MK content up to 20% and RHA+MK content up to 30 % replacement level more than normal SCC at all curing periods (7, 28 and 90 days). The compressive strength points of view 25% of RHA, 30% of MK and 40% of RHA+MK are considered as optimal limits.

- A good linear relationship was found among three measured mechanical properties, namely compressive strength and ultrasonic pulse velocity. It indicated better interrelationship.

These strong correlations clearly indicate that the combination of RHA and MK caused them to act as highly reactive pozzolanic materials in SCC.

REFERENCES

[1] Okamura H and Ouchi M. Applications of Self-Compacting Concrete in Japan, Proceedings of the 3rd International RILEM Symposium on Self-Compacting Concrete, 2003, pp. 3-5.

[2] Okamura H. Self-Compacting High-Performance Concrete, Concrete International, (1997), vol. 19, no. 7, pp. 50-54.

[3] Topcu IB and Uygunoglu T. Effect of aggregate type on properties of hardened self consolidating lightweight concrete, Construction and Building Materials, (2013), vol. 24, no. 7, pp.1286-1295.

[4] Khayat KH and Guizani Z. Use of viscosity-modifying admixtures to enhance stability of fluid concretes, ACI Materials Journal, (1997), vol. 94, no. 4, pp. 332-340.

[5] Khayat KH. Workability, testing and performance of self-consolidating concrete, ACI Materials Journal, (1999), vol. 96, no. 3, pp. 346-353.

[6] Khayat KH. Optimization and performance of air-entrained self-consolidating concrete, ACI Materials Journal, (2000), vol. 97, no. 5, pp. 526-535.

[7] Sahmaran M, Christianto HA and Yaman IO. The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars, Cement and Concrete Composites, (2006), vol. 28, no. 5, pp. 432-440.

[8] EFNARC. Specifications and Guidelines for SCC, EFNARC, 2002, Hampshire, UK.

[9] EFNARC. The European guidelines for self-compacting concrete, European project group, 2005.

[10] Alyamac KE and Ince R. A preliminary concrete mix design for SCC with marble powders, Construction and Building Materials, (2009), vol. 23 no. 3, pp. 1201-1210.

[11] Felekoglu B, Turkel S and Baradan B. Effect of water/cement ratio on the fresh and hardened properties of self-compacting concrete, Building and Environment, (2007), vol. 42, no. 4, pp. 1795-1802.

[12] Safiuddin MD, West JS and Soudki KA. Hardened properties of self-consolidating high performance concrete including rice husk ash, Cement and Concrete Composites, (2010), vol. 32, no. 9, pp. 708-717.

[13] Neville AM. Properties of Concrete', Fourth and Final Edition, John Wiley & Sons, Inc, 1996, New York, USA.

Dr.V.Kannan has a master degree in Structural Engineering and Ph.D in Civil Engineering at ANNA UNIVERSITY Chennai. He has 11 year experience in Teaching and Industry. He also carrying various civil engineering related consultancy works in and around Tirunelveli district. He has mainly intrested in concrete technology and durability studies of concrete.