A Study on the Rheology of Scc with the Addition of Fly Ash in Opc, Ppc and, Psc Cements with Different Mixing Times

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Abstract: In this paper, a study was performed on the rheological properties of self-compacting concrete by the addition of Supplementary Cementitious Material (SCM) as Fly Ash with various percentages of 15%, 20%, 25%, and 30% in the different types of cement OPC, PPC, and PSC. The mix designs of self-compacting concrete were done by two methods of constants: Water-Binder Ratio Constant and Weight and Volume of Aggregates Constant for varying percentages of addition of Fly Ash with a fixed cement content of 380 kg per cubic meter. Flow ability (Flow Table and V Funnel) and Passing Ability (L-Box and U-Box) tests were carried out on fresh concrete in accordance to EFNARC with three different mixing times 5(initial), 30, and 90 minutes were done to find the self-compactibility of designed concrete mixes. Varying dosages of Super Plasticizer (Auromix 450) were added to obtain the required flow ability and passing ability of SCC without bleeding of water and segregation of aggregates. Self-compactibility of the designed SCCs was obtained for 20%, 25%, and 30% addition of SCM in Water-Binder Ratio Constant Method and 15%, 20%, and 30% addition of SCM in Weight and Volume Constant Method.

Keywords: Self-Compacting Concrete, Fresh Properties, Supplementary Cementitious Materials, Fly Ash, Constant methods, Mixing Time.

1. Introduction

With the rapid expansion of numerous structures throughout the world, the demand for self-compacting concrete (SCC) application is growing. Now a day's majority of the construction sites have issues of congestion of reinforcement in the structural members. The considerable seismic danger in the area, the facilities' susceptibility to cyclonic storms, and their massive capacity of expansion, all exacerbate the design flaws. SCC has become the only choice in such difficult site environments. Ideally, the development of concrete mix where placing and compaction have minimal dependence on the Standard of workmanship available on a particular site should improve the true quality of the concrete in the final structure, and hence its durability. This was an important driving force behind the development of self-compacting concrete (SCC). Self-compacting concrete is considered as a breakthrough in concrete technology due to its improved performance and working environment. It has wide application from thin elements to huge structures. SCC can be taken as the greatest technical advancement and most revolutionary development in concrete technology over the years. SCC is the concrete of the future, as it will be replacing normal concrete due to its distinct advantages.

The European Federation for Specialist Construction Chemicals and Concrete Systems (EFNARC) has developed guidelines for SCC, known as the "EFNARC Specification and Guidelines for Self-Compacting Concrete." These guidelines provide recommendations on mix design, fresh and hardened properties, and testing methods for SCC.

SCC can be produced using the same ingredients as that of normal concrete. A closer tolerance is required to ensure strict control of workability characteristics. The proportioning of SCC mix is much more scientific than that of conventional concrete mixes. SCC mix requires high powder content, lesser quantity of coarse aggregate, high range super plasticizer, and VMA (Viscosity Modifying Agent) to give stability and fluidity to the concrete mix. The workability of SCC is the equilibrium of fluidity, deformability, filling ability, and resistance to segregation. This equilibrium has to be maintained for a sufficient time period to allow for its transportation, placing, and finishing. Combinations of tests are required to characterize the workability properties.

The most commonly used cement in self-compacting concrete (SCC) is Ordinary Portland Cement (OPC). OPC is widely available and has been extensively used in various concrete applications, including SCC. In self-compacting concrete, the cement content is usually adjusted based on the specific requirements of the project and the desired properties of the SCC mix. The selection of cement type may also depend on factors such as the project's location, local availability, and any specific performance requirements. The use of alternative types of cement is becoming more prevalent in the construction industry to address environmental concerns. For example, in some regions, where environmental regulations are stricter, or sustainability is a top priority, blended cements such as Portland Slag Cement (PSC) and Portland Pozzolana cement (PPC), have gained popularity due to their reduced carbon footprint and improved performance characteristics. Blended cements are already a combination of Ordinary Portland Cement (OPC) and supplementary materials, such as fly ash and slag. Adding more SCMs to these blended cements further enhances their properties and performance in SCC mixes such as Improved Workability, Reduced Permeability and Improved Durability, Reduced Heat of Hydration, Sustainable Solution, Setting Time, and Strength Development. The addition of SCMs to blended cements can also bring challenges to the mix design process. The interaction between various materials can affect the rheological behavior, setting time, and strength development of the SCC. Precise mix proportioning and testing are essential to ensure the desired performance of the concrete. The Percentage of dosage of SCMs in blended cements for SCC depends on various factors such as the type of SCM, Cementitious content, water-to-binder ratio, desired strength, and workability. Mix designs should be tested thoroughly to verify the fresh and hardened properties of the SCC to meet project specifications and requirements. In this study, the effect of fresh properties of SCC on addition of SCM to blended cement with different design mix methods was done.

Concrete, in general, loses workability over time because of the evaporation of water, the absorption of water through the aggregates, the hydration of cement, and increased mixing temperature. The properties of SCC deteriorate with prolonged mixing, casting, and finishing time. The effect of mixing time on concrete can be avoided or reduced by adding alternative cement materials or/and by increasing the dosage. Many researchers reported that the addition of high super plasticizer dosage may increase workability and decrease its negative effects that are caused by long mixing time. The increase in super plasticizer dosage may lead to wet surroundings, which increase workability, and the hydration process accelerates as water spreads between the cement granules. Thus, reducing concrete consistency increases bleeding and segregation. The effects of mixing time and suitable super plasticizer dosage still need further investigations to maintain the workability and consistency of concrete for a long time. In this study, workability was measured with 5, 30, and 60 minutes of mixing times with an optimized super plasticizer dosage for each mix.

2. Materials.

2.1. Cement:

In Production of SCC, Ordinary Portland Cement (OPC) - 53 grade, Portland Pozzolona Cement (PPC), and Portland Slag Cement (PSC) were used in this study. Some physical and chemical properties of cements which are collected from the cement manufacturer are shown in Table 1.

Table 1: Physical and Chemical Properties of Cements

Description	OPC		PPC		PSC	
	Tested Value	IS 12269:2013	Tested Value	IS 1489:2015 (Part 1)	Tested Value	IS 455: 2105
Physical Properties						

Fineness	Specific surface (sq m/kg)	308	>225	327	>300	372	>225
	Normal consistency (%)	28.3	-	31	-	-	-
Soundness	Le Chatelier Method (mm)	1.5	<10	1	<10	0.5	<10
	Autoclave (%)	0.05	0.8	0.039	<0.8	0.03	0.8
Setting time	Initial setting time (mins)	210	>30	180	>30	145	>30
	Final setting time (mins)	300	<600	280	<600	195	<600
Specific Gravity		3.15		2.9	-	2.91	-
Chemical Properties							
Lime Saturation Factor		0.93	>0.8 & <1.02	-	-	-	-
Alumina Iron Ratio		1.13	>0.66	-	-	-	-
Insoluble Residue (%)		1.98	<4.0	30.74		1.22	<4.0
Magnesia (%)		1.16	<6.0	0.79	<6.0	4	<10.0
Sulphuric Anhydride (%)		2.4	<3.5	1.82	<3.5	1.97	<3.5
Sulphide Sulphur (%)		-	-	-	-	0.16	<1.5
Loss of Ignition (%)		2.16	<4.0	1.55	<4.0	1.43	<4.0
Alkalies (%)		0.64	-	-	-	-	-
Chlorides (%)		0.02	<0.10	0.001	<0.10	0.006	<0.10
C_3A		5.82	-	-	-	-	-
Fly Ash (%)		-	-	33.5	-	-	-
GGBS (%)		-	-	-	-	45	-

2.2. Fly Ash

For this Study, Class F Fly Ash was used which is procured from Sri Damodaram Sanjeevaiah Thermal Power Station is located in Nelatur Village, near Krishnapatnam, Andhra Pradesh, India. The power plant is one of the coal-based power plants of Andhra Pradesh Power Development Company Limited (APPDCL) and is in compliant with India Standard IS 3812:2003.

Table 2: Physical and Chemical Properties of Fly Ash

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	SO_3	LOI	K_2O	Na_2O	Specific Gravity	Blaines's Fineness
%	65.80	21.32	4.87	1.00	0.53	0.50	0.20	0.16	0.81	0.21	2.14	321

2.3. Aggregates

2.3.1. Fine Aggregate

Locally available river sand is used as fine aggregate. The sand was dried before use to avoid the problem of bulking. The fine aggregate complies with Zone 2 from the sieve analysis as per Indian Standard IS 383:2016

2.3.2 Coarse Aggregate

Locally available granite with a size ranges from 12.5 mm and down was used as coarse aggregate.

Table 3: Physical Properties of Fine Aggregate

Aggregate	Specific Gravity	Fineness Modulus	Water absorption	Bulk Density	Dry Rodded Unit Weight
Fine Aggregate	2.63	3.65	0.50%	1582.85 kg/m^3	-
Course Aggregate	2.66	6.66	0.10%	1472 kg/m^3	1495 kg/m^3

2.5 Super Plasticizer

For this study, the super plasticizer used in Auramix 450 manufactured by FOSROC Chemicals which complies with Indian Standards IS 9103: 1999. Properties of Auramix 450 which are collected from the manufacturer are shown in Table 7.

Table 4: Properties of Super Plasticizer

Specific Gravity	pH	Chloride Content	Appearance
1.07	6.1	Nil	Light yellow colour liquid

2.6 Water

Potable water is used in this study.

3. Mix Design of Self Compacted Concrete

Mix design procedure of self-compacting concrete is adopted by taking guidelines from the reference of works by Dr. Okamura and Dr. Ouchi, Japanese researchers who first developed Self Compacting concrete and the norms given in EFNARC. These guidelines are not intended to provide specific advice on mix design but give an indication of the typical range of constituents in SCC by weight and by volume. These proportions are in not restrictive and SCC mixes may fall outside this range for one or more constituents.

3.1. Self Compacting Concrete Proportions

Generally, most of the researches are conducted by simple replacement method. Replacement of cement is done in different percentages of Supplementary Cementitious Material (SCM) either by volume or Weight (Mass). In this method the quantity of Binder Material (BM) is fixed and when replacement of SCM is done in different percentages of quantities, there will be change in the cement quantity and SCM quantity. The replacement method is represented in the form of equations as

C_0 + 0% SCM = BM i.e. C_0 = BM

C_1 + 5%SCM = BM

C_2 + 10%SCM = BM

C_3 + 15%SCM = BM etc

C_0, C_1, C_2, C_3 etc of quantities of Cement and %SCM is of BM

However, in this work, the addition method is adopted which involves the direct addition of SCM without changing the quantity of cement which is fixed and SCM is added with an increase of percentages of 15%, 20%, 25%, and 30% for binder material in SCC. The percentage of SCM is of the quantity of Binder Material.

$C + 15\%SCM = BM_1$

$C + 20\%SCM = BM_2$

$C + 25\%SCM = BM_3$

$C + 30\%SCM = BM_4$

C = Cement is taken as 380kg in this work. The experiments are conducted taking OPC, PPC, and PSC Cements, and SCMs are Fly Ash (F) and GGBS (G) added separately to each individual kind of cement in percentages given above

Further, the design of concrete in this work is done by addition method by taking two methods of constants.

1. Water Binder Ratio Constant Method
2. Aggregate Weight and Volume Constant Method

3.1.1. Water Binder Ratio Constant Method.

In this method as mentioned above the binder material is varied in all the types of cement (OPC, PPC, and PSC) by adding SCM percentages. The design is done by keeping the water-binder ratio constant for all quantities of binder material. The quantities of aggregates are adjusted accordingly for the volume of 1 cum of SCC satisfying the EFNARC norms and the dosage of super plasticizer is adjusted for getting the required fresh properties of SCC.

The equation of design will be as following in this method.

$SCC_1 = BM_1 + CA_1 + FA_1 + W\% + SP$

$SCC_2 = BM_2 + CA_2 + FA_2 + W\% + SP$

$SCC_3 = BM_3 + CA_3 + FA_3 + W\% + SP$

$SCC_4 = BM_4 + CA_4 + FA_4 + W\% + SP$

$W\% = 0.4\ BM_{1\ to\ 4}$

After few trails the suitable water binder ratio for this work was fixed at 0.4

3.1.2. Aggregate Weight and Volume Constant Method

In this method similar to the earlier method the binder material is varied in all the types of cement (OPC, PPC, and PSC) by adding SCM percentages. The design is done by keeping the quantities of aggregates constant. The weight and volume of aggregates are kept constant for all mixes and the water binder ratio is changed accordingly for 1 cum of SCC satisfying the EFNARC norms and the dosage of super plasticizer is adjusted for getting the required fresh properties of SCC.

The equation of design will be as following in this method.

$SCC_5 = BM_1 + CA + FA + W_1\% + SP$

$SCC_6 = BM_2 + CA + FA + W_2\% + SP$

$SCC_7 = BM_3 + CA + FA + W_3\% + SP$

$SCC_8 = BM_4 + CA + FA + W_4\% + SP$

CA = Coarse Aggregate is constantly taken as 50% weight of Dry Rodded Unit Weight, and

FA = Fine Aggregate is constantly taken as 55% of the total aggregate weight.

These values of aggregate quantities are also constant in terms of the volume of aggregates satisfying the EFNARC norms.

SP, the super plasticizer dosage was fixed on trial and error basis with number of trials to achieve at he mix with satisfactory fresh properties in both methods.

Table 5. Mix Proportions with Water Binder Ratio Constant method

MIX	Cement	Fly Ash	Fine Aggregate	Course Aggregate	Water	Super Plasticizer		Unit Weight
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	%	kg/m^3
OPC - SCC_1	380.00	70.00	953.00	790.00	180.00	8.10	1.80	2381.10
OPC - SCC_2	380.00	95.00	920.00	770.00	190.00	6.65	1.40	2361.65
OPC - SCC_3	380.00	126.67	877.00	747.50	202.67	3.55	0.70	2337.39
OPC - SCC_4	380.00	162.86	796.00	747.50	217.14	2.71	0.50	2306.21
PPC - SCC_1	380.00	70.00	940.00	775.00	180.00	8.10	1.80	2353.10
PPC - SCC_2	380.00	95.00	900.00	768.00	190.00	4.28	0.90	2337.28
PPC - SCC_3	380.00	126.67	877.00	747.50	202.67	3.55	0.70	2337.39
PPC - SCC_4	380.00	162.86	796.00	747.50	217.20	2.71	0.50	2306.27
PSC - SCC_1	380.00	70.00	953.00	790.00	180.00	8.10	1.80	2381.10
PSC - SCC_2	380.00	95.00	910.00	785.00	190.00	4.75	1.00	2364.75
PSC - SCC_3	380.00	126.67	878.00	747.50	202.67	3.55	0.70	2338.39
PSC - SCC_4	380.00	162.86	796.00	747.50	217.20	2.71	0.50	2306.27

Table 6. Mix Proportion with Aggregate Weight and Volume Constant Method

MIX	Cement	Fly Ash	Fine Aggregate	Course Aggregate	Water	Super Plasticizer		Unit Weight
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	%	kg/m^3
OPC - SCC_5	380.00	70.00	913.50	747.50	214.94	3.60	0.80	2329.54
OPC - SCC_6	380.00	95.00	913.50	747.50	202.62	4.28	0.90	2342.90
OPC - SCC_7	380.00	126.67	913.50	747.50	186.14	6.08	1.20	2359.89
OPC - SCC_8	380.00	162.86	913.50	747.50	167.30	8.14	1.50	2379.30
PPC - SCC_5	380.00	70.00	913.50	747.50	214.94	3.60	0.80	2329.54
PPC - SCC_6	380.00	95.00	913.50	747.50	202.62	4.28	0.90	2342.90
PPC - SCC_7	380.00	126.67	913.50	747.50	186.14	6.08	1.20	2359.89

PPC - SCC_8	380.00	162.86	913.50	747.50	167.30	8.14	1.50	2379.30
PSC - SCC_5	380.00	70.00	913.50	747.50	212.41	6.30	1.40	2329.71
PSC - SCC_6	380.00	95.00	913.50	747.50	199.52	7.60	1.60	2343.12
PSC - SCC_7	380.00	126.67	913.50	747.50	182.35	10.13	2.00	2360.15
PSC - SCC_8	380.00	162.86	913.50	747.50	161.21	14.66	2.70	2379.73

4. Results

4.1. Fresh Properties of Self Compacted Concrete

The fresh properties of Self Compacting Concrete designed and mixed with different cements and addition SCMs as per the tables given above are tested for Flow Ability and Passing Ability. The flow ability is tested by Slum Flow, T_{500} Slump Flow and V Funnel methods and passing ability is tested by L-Box and U-Box methods.

4.1.1. Slump Flow

The slump flow of fresh Self Compacting Concrete is measured on flow table using Abraham Cone. Unit of measurement of slump flow is millimeters. The acceptance levels as per EFNARC are 650 mm to 800 mm. In this work the acceptance levels of slump flow are taken from 600 mm and above.

Table 7. Slump Flow (mm) (Water Binder Constant)					Table 8. Slump Flow (mm) (Aggregate Weight and Volume Constant)			
Mix	5 Mins	30 Mins	60 Mins		Mix	5 Mins	30 Mins	60 Mins
OPC - SCC_1	600	580	550		OPC - SCC_5	630	630	610
OPC - SCC_2	600	610	630		OPC - SCC_6	610	660	670
OPC - SCC_3	660	670	680		OPC - SCC_7	600	650	690
OPC - SCC_4	650	680	640		OPC - SCC_8	570	600	590
PPC - SCC_1	600	560	540		PPC - SCC_5	570	630	630
PPC - SCC_2	600	660	650		PPC - SCC_6	600	660	650
PPC - SCC_3	650	680	660		PPC - SCC_7	660	640	640
PPC - SCC_4	700	680	640		PPC - SCC_8	600	580	580
PSC - SCC_1	590	610	580		PSC - SCC_5	640	620	600
PSC - SCC_2	630	660	620		PSC - SCC_6	660	600	580
PSC - SCC_3	650	680	640		PSC - SCC_7	650	610	590
PSC - SCC_4	660	680	640		PSC - SCC_8	630	590	570

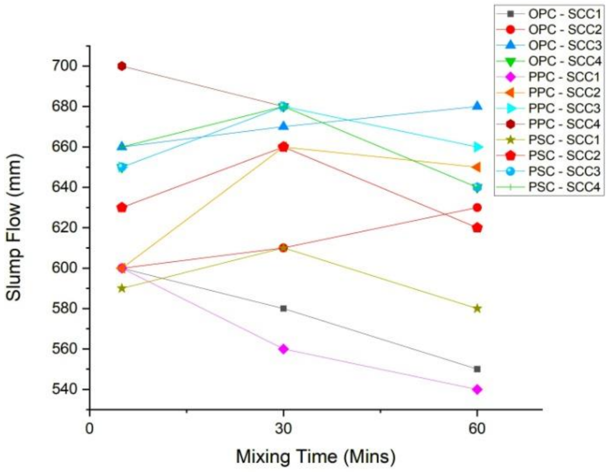

Fig. 1. Slump Flow (Water Binder Constant)

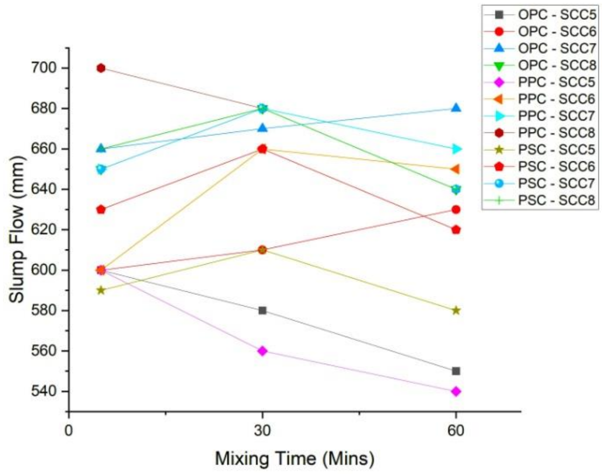

Fig.2. Slump Flow (Aggregate Weight and Volume Constant)

4.1.2. Slump Flow – T_{500}

Viscosity of the Self Compacting Concrete can be assessed by T_{500} time during slump flow test. The time value obtained does not measure the viscosity of SCC but is related to it by describing the rate of flow. Concrete with a low viscosity will have a very quick initial flow and the stop. Concrete with high viscosity may continue to creep forward over an extended time. The acceptance levels as per EFNARC are 2 sec to 5 sec. In this work the acceptance levels of slump flow are taken from 2 sec and 7 sec.

Table 9. Slump Flow – T500 (sec) (Water Binder Constant)					Table 10. Slump Flow – T500 (Sec) (Aggregate Weight and Volume Constant**)**			
Mix	5 Mins	30 Mins	60 Mins		Mix	5 Mins	30 Mins	60 Mins
OPC - SCC_1	7.8	7.9	8		OPC - SCC_5	2.5	2.5	2.6
OPC - SCC_2	5.0	4.5	2.3		OPC - SCC_6	2.7	2.0	2.0
OPC - SCC_3	3.2	2.8	2.8		OPC - SCC_7	5.0	4.0	2.0
OPC - SCC_4	3.0	2.0	0.4		OPC - SCC_8	6.2	5.8	6.1
PPC - SCC_1	4.0	7.2	7.6		PPC - SCC_5	3.5	2.4	2.7
PPC - SCC_2	4.0	2.8	3.0		PPC - SCC_6	4.0	2.8	3.0
PPC - SCC_3	2.4	2.2	2.1		PPC - SCC_7	4.2	4.9	2.9
PPC - SCC_4	2.0	2.0	3.2		PPC - SCC_8	4.0	5.0	5.3
PSC - SCC_1	4.0	3.5	4.3		PSC - SCC_5	3.1	3.4	4.1
PSC - SCC_2	3.0	2.0	3.6		PSC - SCC_6	2.0	3.6	4.4
PSC - SCC_3	2.0	2.0	3.0		PSC - SCC_7	2.0	3.2	4.0
PSC - SCC_4	2.0	2.0	3.2		PSC - SCC_8	4.0	6.0	-

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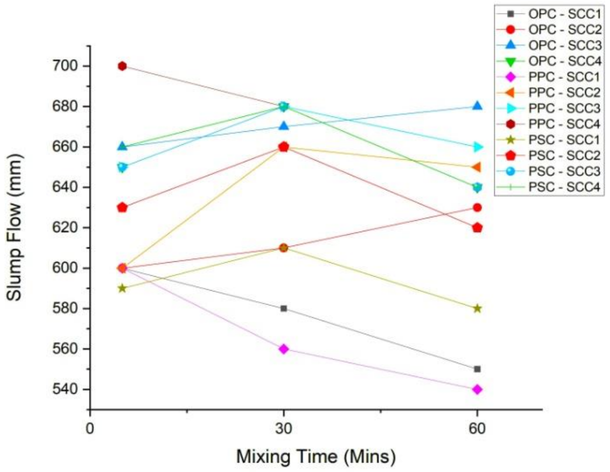

Fig. 3. Slump Flow – T500 (Water Binder Constant)

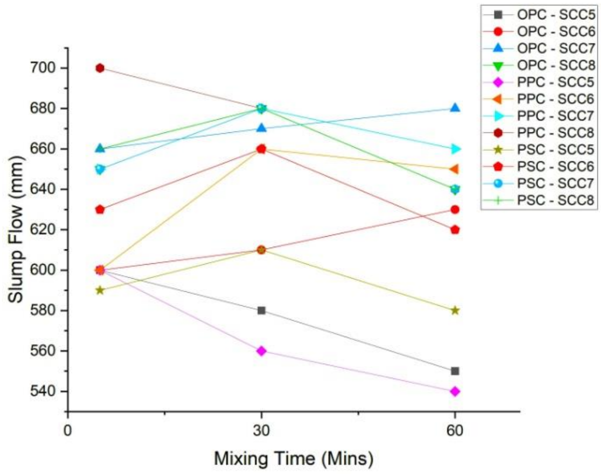

Fig.4. Slump Flow-T_{500} (Aggregate Weight and Volume Constant)

4.1.3. V-Funnel Test

Flowing ability and viscosity of the Self Compacting Concrete can be assessed by V-Funnel flowing time. The acceptance levels as per EFNARC are 6 sec to 12 sec.

Table 11. V Funnel Flow (Sec) (Water Binder Constant)					Table 12. V Funnel Flow (Sec) (Aggregate Weight and Volume Constant)			
Mix	5 Mins	30 Mins	60 Mins		Mix	5 Mins	30 Mins	60 Mins
OPC - SCC_1	6.4	6	6.3		OPC - SCC_5	4.7	6	6.4
OPC - SCC_2	5.2	5.4	5.7		OPC - SCC_6	5.3	4.9	5.2
OPC - SCC_3	5	5.2	5.1		OPC - SCC_7	8	6	5.6
OPC - SCC_4	5.4	5	5		OPC - SCC_8	11.3	9	11.1
PPC - SCC_1	7.3	9.4	14.7		PPC - SCC_5	11	5.7	6.2
PPC - SCC_2	7	4.1	4.4		PPC - SCC_6	7	4.1	4.4
PPC - SCC_3	6.5	4.3	4.7		PPC - SCC_7	5.2	6.1	7.3
PPC - SCC_4	4	4.1	5.3		PPC - SCC_8	7.2	6.7	7.2
PSC - SCC_1	11	9.3	14		PSC - SCC_5	6.1	9	13
PSC - SCC_2	7.1	5.2	6.9		PSC - SCC_6	6.1	13	16
PSC - SCC_3	5.3	5	5.6		PSC - SCC_7	6.2	12	14
PSC - SCC_4	6	4.8	5		PSC - SCC_8	7.4	14	18

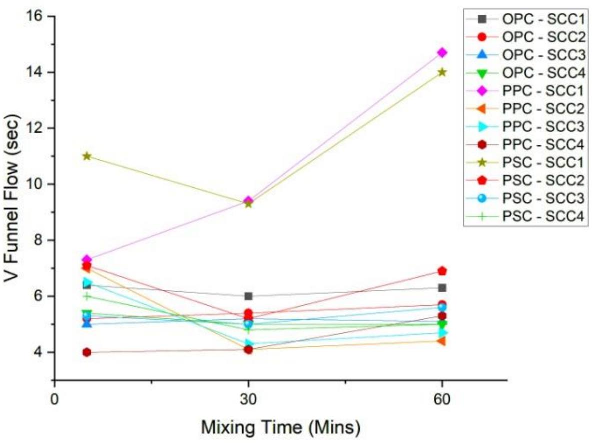

Fig.5. V Funnel Flow (Water Binder Constant)

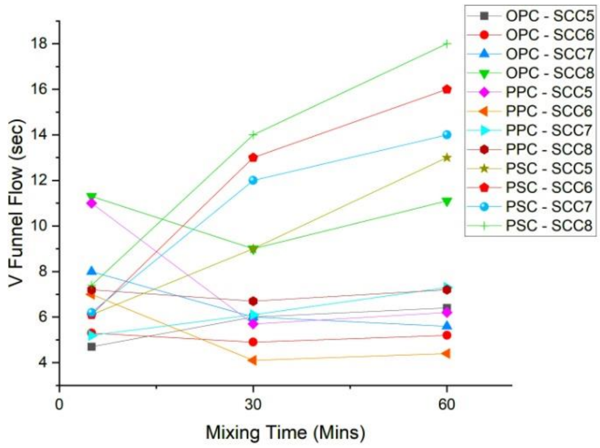

Fig.6. V Funnel Flow (Aggregate Weight and Volume Constant)

4.1.4. L-Box Test

Aggregate blocking must be avoided as Self Compacting Concrete flows through the reinforcement and the L-Box Test is indicative for passing ability of Self Compacting Concrete mix. The acceptance levels as per EFNARC are 0.8 to 1.0 (Ratio of h_2/h_1, h_1 is interior height and h_2 exterior height in L-Box base line after concrete stops flowing).

Table 13. L-Box (Water Binder Constant)					Table 14. L-Box (Water Binder Constant)			
Mix	5 Mins	30 Mins	60 Mins		Mix	5 Mins	30 Mins	60 Mins
OPC - SCC_1	0.75	0.79	0.80		OPC - SCC_5	0.82	0.83	0.83
OPC - SCC_2	0.78	0.79	0.83		OPC - SCC_6	0.79	0.87	0.90
OPC - SCC_3	0.84	0.89	0.93		OPC - SCC_7	0.77	0.89	0.96
OPC - SCC_4	0.88	0.94	1.00		OPC - SCC_8	0.68	0.71	0.70
PPC - SCC_1	0.83	0.84	0.77		PPC - SCC_5	0.72	0.79	0.91
PPC - SCC_2	0.72	0.97	0.96		PPC - SCC_6	0.72	0.97	0.96
PPC - SCC_3	0.89	0.93	0.98		PPC - SCC_7	0.86	0.82	0.84
PPC - SCC_4	1.00	1.00	1.00		PPC - SCC_8	0.76	0.72	0.73
PSC - SCC_1	-	0.68	-		PSC - SCC_5	0.76	0.72	-
PSC - SCC_2	0.74	0.88	0.82		PSC - SCC_6	0.85	0.79	-
PSC - SCC_3	0.89	1.00	0.95		PSC - SCC_7	0.84	0.77	-
PSC - SCC_4	1.00	1.00	1.00		PSC - SCC_8	-	-	-

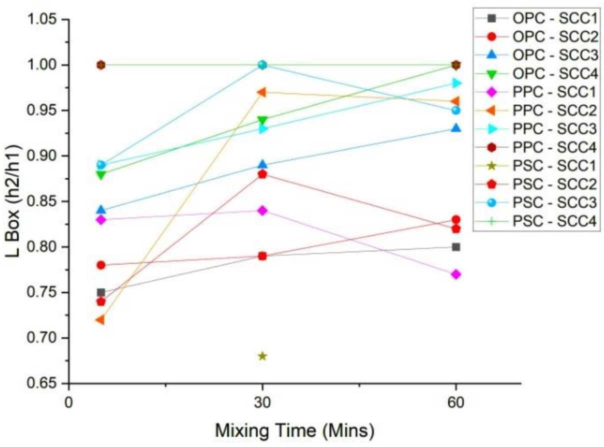

Fig.7. L-Box (Water Binder Constant)

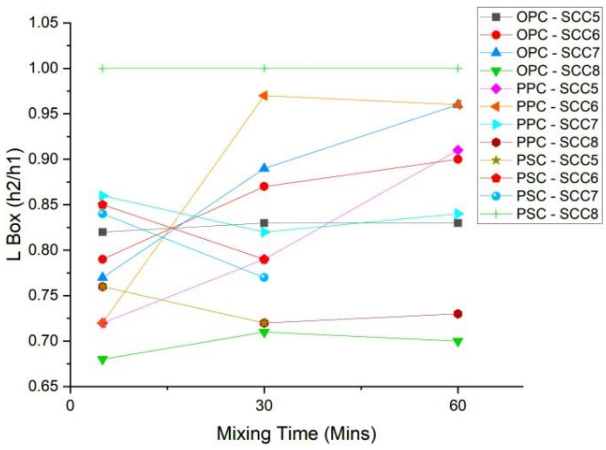

Fig.8. L-Box (Aggregate Weight and Volume Constant)

4.1.5. U-Box Test

U-Box test is also an indicative for passing ability of Self Compacting Concrete to avoid aggregate blocking during the flow. The acceptance levels as per EFNARC are 0 to 30 mm (h2-h1, the level difference of concrete in the two legs of U-box after stop of flow)

Table 16. U-Box (mm) (Water Binder Constant)					Table 16. U-Box (mm) (Aggregate Weight and Volume Constant)			
Mix	5 Mins	30 Mins	60 Mins		Mix	5 Mins	30 Mins	60 Mins
OPC - SCC_1	45	34	39		OPC - SCC_5	35	29	21
OPC - SCC_2	32	15	0		OPC - SCC_6	29	0	0
OPC - SCC_3	22	0	0		OPC - SCC_7	25	0	0
OPC - SCC_4	18	0	7		OPC - SCC_8	-	-	-
PPC - SCC_1	40	25	15		PPC - SCC_5	35	0	0
PPC - SCC_2	35	0	0		PPC - SCC_6	35	0	0
PPC - SCC_3	25	0	0		PPC - SCC_7	0	15	20
PPC - SCC_4	0	0	12		PPC - SCC_8	45	55	60
PSC - SCC_1	-	-	-		PSC - SCC_5	40	-	-
PSC - SCC_2	35	10	15		PSC - SCC_6	25	40	-
PSC - SCC_3	0	0	10		PSC - SCC_7	25	40	-
PSC - SCC_4	0	0	10		PSC - SCC_8	-	-	-

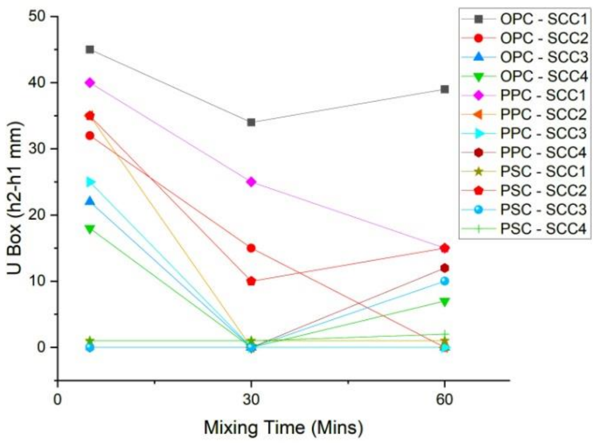

Fig.7. U-Box (Water Binder Constant)

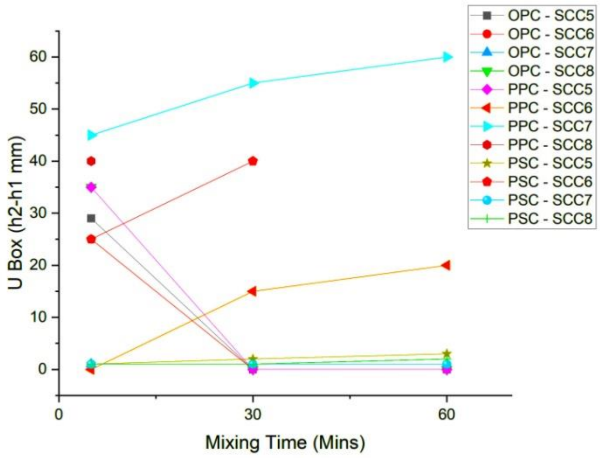

Fig.8. U-Box (Aggregate Weight and Volume Constant)

4.2. Discussion

The fresh properties of the mixes were mostly within the acceptance levels for the 20%, 25% and 30% addition with Water Binder Ratio constant method and 15%, 20% and 25% addition with Aggregate Weight and Volume Constant Method.

The slump flow in almost all mixes was observed with slight bleeding after resting of flow with initial mixing of 5 minutes. On Continuous mixing for 30 minutes the flow was good and no bleeding was observed in any of the mixes. After 60 minutes of continuous mixing the flow reduced when compared to 30 minutes with no bleeding.

The values of Slump flow –T_{500} for almost all the mixes were was within the range of acceptance levels.

The V Funnel flow was good for all the mixes which had satisfactory slump flow. No blockage was found at the bottom of funnel for any of the mixes during the flow. The $T_{5Minutes}$ flow in V Funnel were also within the range of acceptance levels for all the mixes.

The values of L Box flow and U-Box Flow were observed to be good with addition of fly ash in OPC and PPC. Addition in PSC was observed with blockage and bleeding of water.

5. Conclusions

From the results and observations in this study the following conclusions may be made:

1. In Water Binder Ratio Method for 15% addition of fly ash in all types cements the quantity of aggregates was at higher side and the water was not sufficient for the binder material for getting the sufficient viscosity to get the required flow. If the super plasticizer was added more to get the flow, bleeding was observed with very low values of flow. The similar kind of observation was found in Aggregate Weight and Volume Method with addition of 30% of fly ash in all types of cements. The water content was not sufficient for the powder to get the viscosity and there were mixes with no flow. All other percentages of addition of fly ash in both the methods of mix design the results were all within the range of acceptance levels.
2. The mixing time in this study was one of the major factors. The initial mix for 5 minutes of continuous mixing in the pan mixer for all the mixes are within the acceptances levels but observed with some bleeding after the flow rested. After 30 minutes of continuous mixing almost all the mixes showed very good results with all the values within the acceptance levels. After the 60 minutes of continuous mixing almost all the flows slowed down when compared to the values 30 minutes of mixing but within the acceptance levels.
3. The mixes SCC2, SCC3, SCC4, SCC5, SCC6 and SCC7 were found to be self compactable almost satisfying the acceptance levels. All these mixes are found to be highly good with 30 minutes of continuous mixing.
4. The mixes which satisfied self compactibility can be further tested for strength properties

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