Effect of Binder Volume on Fresh and Harden Properties of Self Compacting Concrete

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***Abstract*— Self Compacting Concrete (SCC) is new type of concrete that posse's property of high flow ability, passing ability and stability. Fresh behavior of SCC was measured as per European guidelines. Filling ability, passing ability and resistance to segregation of SCC were measured by Slump flow, J-Ring, V-funnel, L-box, U-box and GTM tests as per the European Federation of National Associations Representing for Concrete (EFNARC) specification. This paper presents an experimental study on self-compacting concrete (SCC) with different quantity of binder volume and water binder ratio. Binder volume varies in range of 450 kg/m^3 to 700 kg/m^3. Water binder ratio varies between 0.29 to 0.34 (by weight). After taking different trail mixes for self compacting concrete, the cubes and beams were casted for selected proportion. Result show that the concrete fresh state performance increases due to the increase of binder volume as well as increased in water binder ratio. It was noticed that there is slightly change in compressive strength.**

Keywords*— Self Compacting Concrete, Packing density, Void ratio

I. INTRODUCTION

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding of fresh concrete. Also, with the increased use of heavily reinforced concrete, there is a growing need for highly flowable concrete to ensure proper filling of the formwork. Heavy reinforcement restricts the access of vibrators that are required to adequately consolidate normal concrete (NC). Moreover, excessive vibration can cause undesirable segregation and bleeding. Self-consolidating concrete (SCC) offers a solution to these problems; it is a high-performance concrete that spreads easily under its own weight into tight and restricted areas without segregating or requiring vibration, while achieving good consolidation [1,2,3,4,5,6].

SCC was developed in Japan [7] in the late 1980s to be mainly used for highly congested reinforced structures in seismic regions. Recently, this concrete has gained wide use in many countries for different applications and structural configurations. SCC can also provide a better working environment by eliminating the vibration noise.

The production of SCC is normally achieved by increasing the fines of the mixture using mineral admixtures (such as fly ash, slag cement, limestone powder, etc.) and/or viscosity-modifying admixtures [2, 3, 4, 5, 6, 8]. In addition, the coarse aggregate content in SCC is usually less than that used in normal concrete (NC) to enhance concrete workability and flowability.

SCC mixes usually contain superplasticiser, high content of fines and/or viscosity modifying additive (VMA). Whilst the use of superplasticiser maintains the fluidity, the fine content provides stability of the mix resulting in resistance against bleeding and segregation. The use of fly ash and blast furnace slag in SCC reduces the dosage of superplasticiser needed to obtain similar slump flow compared to concrete mixes made with only Portland cement [9].

It is estimated that SCC may result in up to 40% faster construction than using normal concrete [10, 11]. Also, the use of fly ash improved the rheological properties and reduced thermal cracking of the concrete [12]. Kim et al. [13] studied the properties of super-flowing concrete containing fly ash and reported that the replacement of cement by 30% fly ash resulted in excellent workability and flowability. MIURA et al. [14] evaluated the influence of supplementary cementitious materials on workability and concluded that the replacement of cement by 30% of fly ash can significantly improve rheological properties.

II. EXPERIMENTAL STUDY

A. Constitute Materials

Materials used under study are given in Table I. The physical properties of the fine aggregates and particle size distribution are given in Table II.

TABLE I. CONSTITUTE MATERIALS USED IN STUDY

Sr. no.	material	specification
1.	Ordinary Portland Cement (OPC)	As describe in IS: 12269, specific gravity of the cement was 3.12.
2.	Fly Ash	Dark, pozzocrete 60 confirming to IS: 3812 (Part 1) 2013, Specific gravity of this fly ash was 2.0.
3.	Superplasticiser	Master Glenium SKY 8276, BASF confirming ASTM C 494,
4.	Fine Aggregate	Locally available river sand passing through 4.75 mm IS sieve confirming to IS: 3812 (Part 1) 2013,
5.	Coarse Aggregate	Locally available Crushed Granite – maximum sizes 20 mm and 10 mm confirming to IS: 3812 (Part 1) 2013,

TABLE II. PHYSICAL PROPERTIES OF AGGREGATES

Properties	Sand	Coarse aggregate 10 mm maximum size	Coarse aggregate 20 mm maximum size
Specific gravity	2.62	2.8	2.78
Bulk Density (Loose, kg/m^3)	1708	1450	1414
Bulk Density (Compact, kg/m^3)	1868	1652	1632
Water absorption %	1.39	0.65	0.56

B. Mixture Proportions

In the present investigation, experiments were conducted for different binder volume ranging from contents 450 kg/m^3 to 700 kg/m^3 and W/B ratios (0.29 to 0.34 by weight) with corresponding variation in the paste volume to investigate the influence of binder quantity and water binder ratio on the fresh and hardened properties of SCC. The paste volume varied from 310 liter to 480 liter. The aggregate combination of 50:20:30 (Fine aggregate: Coarse aggregate 10 mm maximum size : Coarse aggregate 20 mm maximum size) by volume was keep constant for all mixes. A polycarboxylate-based high range water reducing admixture (HRWRA) was also used in the mixtures, dosage of superplasticiser was kept constant. i.e. 0.5% by weight of binder for providing the desired fluidity of the SCC. For all test, cement to fly ash ratio, in total binder quantity, was kept constant. (Cement: Fly ash = 70:30 by volume).

C. Optimisation of Aggregate Combination

Proportioning of aggregates for concrete is influenced by geometrical characteristics of aggregates such as shape, angularity, texture, particle size distribution (PSD), wall effect and method of compaction. These parameters are collectively reflected in terms of the packing density [18, 19]. Packing density of aggregates is an indicator of the voids content. Aggregates with higher packing density result in lesser void content, in turn minimising the volume of paste to fill up the voids. Apart from economic benefit due to lower cement content, research has shown that the packing density has significant influence on the fresh and hardened properties of concrete [20]. Experiments were conducted to determine the packing density of different combination of aggregates

The packing density of aggregates was determined experimentally, using a modified version of the test procedure described in [21].

The test procedure is as follows [22]

Step 1: A mass equivalent of 30 liter of aggregates (10 mm max. size and 20 mm max. size and river sand) was taken according to the corresponding volume proportions in separate plastic trays.

Step 2: This three types of aggregates were mixed manually for obtaining a proper blend.

Step 3: The mixed aggregates were poured into bucket without any compaction.

Step 4: Then, mixed aggregates were filled in a cylindrical container of known volume. The container diameter should be more than 10 times the diameter of the maximum size of aggregates used to eliminate the wall effect. The distance between bucket and cylinder top was maintained approximately 200 mm while filling the aggregate in container.

TABLE III. PROPORTIONS OF AGGREGATES WITH CORRESPONDING EXPERIMENTAL PACKING DENSITY

Sr. No.	Fine Aggregate (% Vol))	10 mm max size (% Vol)	20 mm max. size (% Vol)	Experimental Packing Density
1	100	0	0	0.665
2	70	0	30	0.669
3	30	0	70	0.667
4	0	100	0	0.515
5	30	70	0	0.615
6	70	30	0	0.644
7	0	0	100	0.485
8	0	30	70	0.506
9	0	70	30	0.541
10	30	30	40	0.635
11	30	40	30	0.642
12	40	20	40	0.667
13	40	30	30	0.665
14	40	40	20	0.666
15	50	10	40	0.672
16	50	20	30	0.677
17	50	30	20	0.665
18	50	40	10	0.668
19	55	20	25	0.675
20	55	30	15	0.672
21	60	20	20	0.675
22	60	30	10	0.674
23	10	80	10	0.620
24	10	10	80	0.623
25	80	10	10	0.652
26	20	60	20	0.615
27	20	40	40	0.625
28	20	20	60	0.620

Step 5: The excess aggregates remaining above the top level of the cylinder were struck off. The mass of the cylinder along with the aggregates filled in was measured and the empty weight of the cylinder was deducted to determine the exact quantity of combined aggregates filled in the bottom container.

Knowing the mass of the individual aggregate type added and the volume of the container, the void content was calculated. The packing density of the aggregates was calculated from the void content. The equations for calculating the void content and packing density are as follows [22]:

$$\text{Void content} = (Vc-((M_1/S_1) + (M_2/S_2) +(M_3/S_3)))/Vc \qquad (1)$$

Where Vc is the volume of the container, M_1, M_2, M_3 are mass of each aggregate type, and S_1, S_2, S_3 are the specific gravity of corresponding aggregate type.

$$\text{Packing density} = 1- \text{Void content} \qquad (2)$$

To achieve maximum packing density, experiments were conducted for different proportions of aggregates. Based on eq. (1) and (2), the packing density of the aggregates was determined. The aggregate combination of 50:20:30 (Fine aggregate: Coarse aggregate 10 mm maximum size: Coarse aggregate 20 mm maximum size) by volume resulted in maximum packing density (0.677), and was used in all the experiments. This indicates a void content of 0.323 (or 323 l) of the total volume of concrete.

TABLE IV. FRESH PROPERTIES OF SELF COMPACTING CONCRETE

Sr. No	Binder in kg	W/B by weight	Paste Volume in Liter	Slump Flow mm	T_{50} cm Slump Flow in Sec	J Ring	J Ring Flow in mm	V-Funnel Flow in Sec	L Box Blocking Ratio	U Box Filling Height	GTM Screen stability test (Segregation ratio)	Block assessment in mm	Remarks
1	450	0.34	313	610	7.4	12	580	22	0.71	34	7.33	30	NS
2		0.36	321	680	5.3	11	655	12	0.85	21	12.34	25	NS
3		0.37	329	735	3.1	9	710	8.5	0.92	10	16.33	25	NS
4		0.39	337	830	1.2	8	815	6.5	0.98	3	18.66	15	S
5	500	0.34	348	600	6.3	11	570	18	0.70	28	10.73	30	NS
6		0.36	357	710	4.8	10	690	5	0.85	14	14.28	20	NS
7		0.37	365	855	2.5	8	835	5.5	0.98	10	15.73	20	S
8		0.39	374	880	2.3	5	865	5	1.00	5	22.52	15	MS
9	550	0.30	363	620	5.8	15	595	19	0.75	35	10.32	25	NS
10		0.32	373	680	4.6	11	660	12.5	0.80	22	13.33	20	NS
11		0.34	382	785	3.2	7	770	10	0.88	15	15.54	15	NS
12		0.36	392	885	1.9	3	875	8.5	1.00	9	19.32	10	S
13	600	0.30	396	635	4.5	12	605	15	0.82	35	13.53	30	NS
14		0.32	406	795	3.8	7	775	10	0.92	28	12.86	20	NS
15		0.34	417	825	2.3	4	815	9	0.98	22	17.1	10	S
16		0.36	428	880	1.9	0	875	5.5	1.00	15	19.72	5	MS
17	650	0.30	429	670	4.2	8	645	14	0.88	30	10.23	25	NS
18		0.31	433	795	3.8	5	775	12	0.91	19	12.48	20	NS
19		0.32	440	830	3.1	3	820	6	1.00	17	13.33	10	NS
20		0.34	452	885	2.0	1	875	5	1.00	6	23.35	10	MS
21	700	0.29	449	785	5.6	5	765	15	0.85	25	12.33	20	NS
22		0.30	462	830	2.7	5	820	12	0.95	22	13.22	10	NS
23		0.32	474	900	2.0	1	895	6	1.00	10	17.65	5	S
24		0.34	487	970	1.5	0	965	5	1.00	0	21.35	5	MS

NS=No Segregation, S=Segregation, MS=More Segregation

III. RESULTS AND DISCUSSION

The ability of SCC for compacting under its own weight is generally the main subject of such studies according to appropriate criteria given by the EFNARC [23]. In the present study, such properties of SCC produced keeping constant cement fly ash ratio in total binder quantity. Also ratio of different size of aggregate in total aggregate kept constant for all SCC mixes. Table IV depicts the results of fresh concrete tests such as slump flow, T_{50} cm slump flow, J ring, J ring flow, V-funnel flow, L box blocking ratio, U box filling height and GTM Screen stability test.

A. Fresh concrete properties of SCC

To evaluate workability of fresh self compacting concrete like filling ability, passing ability and segregation resistance, different test were carried out as per EFNARC [23] specifications. Filling ability of SCC was measured using slump flow and V – funnel test. Passing ability of SCC was measured using J- ring, L- box and U – box test. Similarly resistance to segregation of self compacting concrete was measured with the help of GTM Screen stability test.

1) Slump flow and T_{50} cm slump flow

The slump-flow test is a value-system for the ability of concrete to deform under its own weight against the friction of the surface with no external restraint present [24]. All mixtures exhibited good workability with flow values of at least 600 mm. Slump flows of 650 mm to 800 mm are typically required for SCC [23], and all the mixtures under investigation fall into this category. The variations in slump flow for different binder quantity, immediately after mixing process, are shown in Fig 1. The results of slump-flow tests show that, increased in binder quantity, the slump flow were also increased for same water binder ratio. This was happened due to increased in binder quantity, the paste volume was also increased and, so excess paste is available for flow of concrete. It was also observed that as water binder ratio increased, slump flow increased for all binder volume. This was happened due to increased in volume of paste due to increased in water quantity in mixed. It was also reported that for higher slump flow (more than 810 mm), segregations were take place in concrete. This thing was observed in case of higher water binder ratio. The doses of superplasticiser were kept constant for all of the mixtures.

The T_{50} time is the time required to reach 50 cm slump flow. It indirectly indicates the viscosity of the concrete – higher the time to reach 500 mm, higher the viscosity [25]. Results shows that T_{50} time varies between 1.3 to 7.5 sec are shown in Fig. 2. The T_{50} time is a secondary indication of flow. A lower time indicates greater flowability. As slump flow increased T_{50} time was decreased for all mixes proportion.

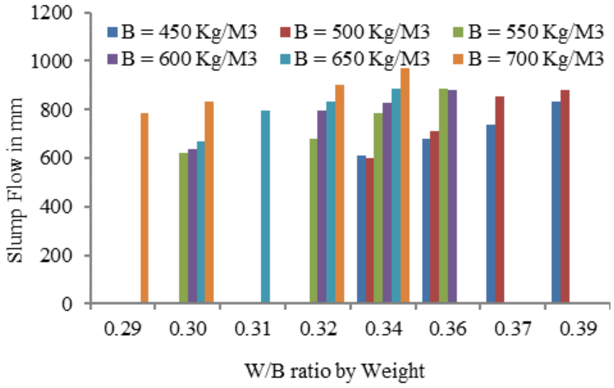

Fig. 1 Relationship between the slump flow and W/B ratio

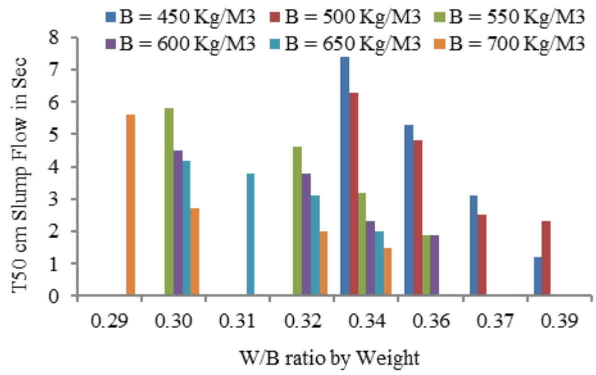

Fig. 2. Relationship between the T_{50} cm slump flow and W/B ratio

2) J-Ring and J-Ring Flow

For assessing the passing ability of SCC, J-ring test was conducted according to EFNARC [23]. The values of J ring difference, J ring flow, and J ring blocking assessment are plotted in Figs. 3-5. It was observed that the J-ring flow (slump flow with J-ring) increase with increase in paste volume. This could be attributed to the fact that with increase in paste volume, the aggregates are dispersed efficiently and hence the concrete passes through the reinforcement without congestion of the aggregates. The blocking assessment was calculated as the difference between the slump flow and J-ring flow. From the results, it was observed that, the difference between slump flow and J-ring flow was in the range of 5-30 mm. The more blocking was observed in proportion having higher volume of aggregate.

3) V - Funnel Flow

The V-funnel test is used to determine the filling ability of the concrete with a maximum aggregate size of 20 mm. The results of V-funnel flow time are presented in Fig 6. It was observed that V- funnel time is very sensitive to water binder ratio. At particular change in water binder ratio, there is large variation in V- funnel time was observed. For self compacting concrete the range of this time is 6 to 12 sec as per EFNARC [23]. It was also observed that as W/B ratio increased, V-funnel time was decreased for all mixes proportion. This was happen for each group of binder as W/B ratio increased, paste volume was also increased.

4) L-Box Ratio

The L-box ratio characterizes the filling and passing ability of SCC. There is generally a blocking risk of the mixture when

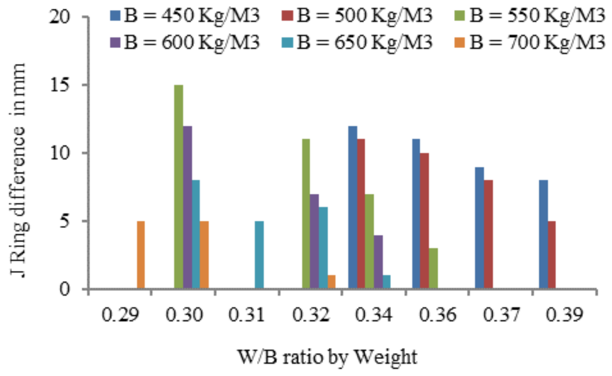

Fig. 3 Relationship between the J Ring difference and W/B ratio

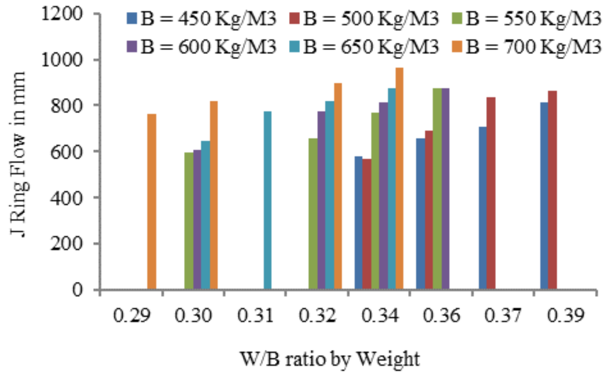

Fig. 4. Relationship between the J Ring Flow and W/B ratio

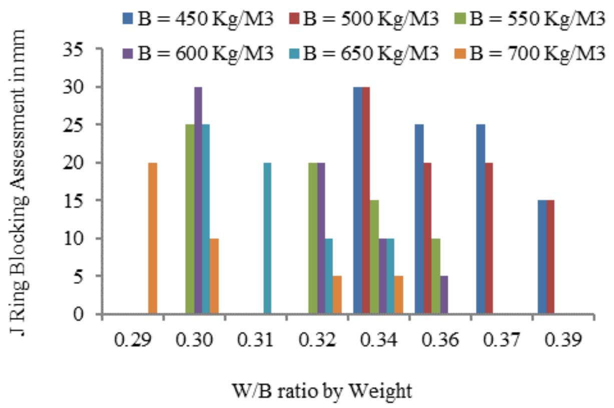

Fig. 5. Relationship between the J Ring Blocking and W/B ratio

the L-box blocking ratio is below 0.8. The L- box blocking ratio of SCCs produced with different binder volume are shown Fig. 7. The blocking ratio (h_2/h_1) should be between 0.8 and 1.0 according to EFNARC [23]. All mixtures of SCC are within this target range except proportion whose paste volume is very low and aggregate volume is very high. However, It can be noted that each SCC investigated in the present study as adequate filling capability and passing ability.

5) U-Box

U box test is used to measure the filling ability of self-compacting concrete. U box test results for different mixes proportion were shown in Fig 8. It was observed that with increased in binder quantity or increased in W/B ratio there is decreased in difference in U box filling height.

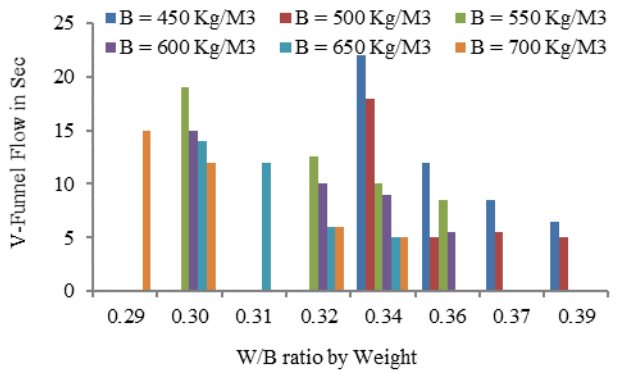

Fig. 6.Relationship between the V-Funnel Flow and W/B ratio

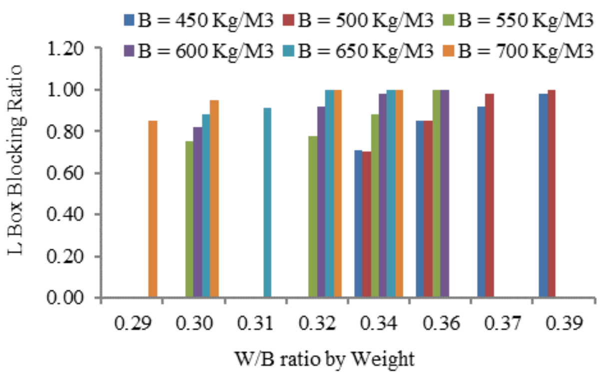

Fig. 7. Relationship between the L Box Blocking Ratio and W/B ratio

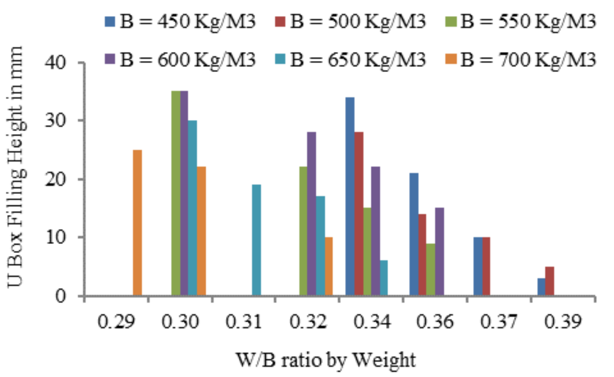

Fig. 8. Relationship between the U Box Filling Height and W/B ratio

Reason behind this is as binder quantity or water quantity was increased in mix proportion.

6) GTM Screen Stability Test

GTM screen stability test is a very effective way of assessing the stability of SCC. It gives indication of segregation in self compacting concrete. If segregation ratio is less than 15%, the mix is suitable for self compacting concrete as suggested by the EFNARC [23]. It was observed that as water quantity increased in mixes, there is probability to increase in segregation. (See Fig. 9).

B. Compressive Strength and Flexural Strength

After taking different trail mixes for self compacting concrete, the cube and beam were casted for selected proportion. The selection was done from each group having different binder quantity which satisfied full criteria of the EFNARC.

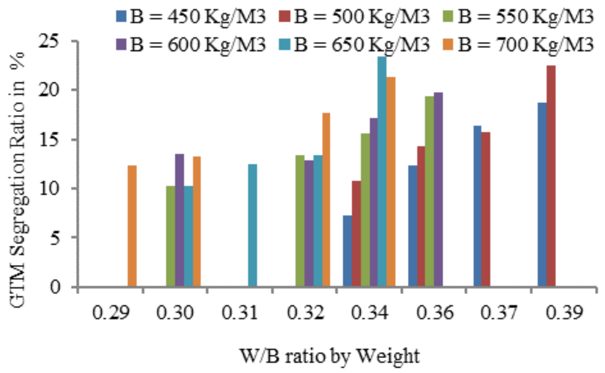

Fig. 9. Relationship between the GTM Segregation ratio and W/B ratio

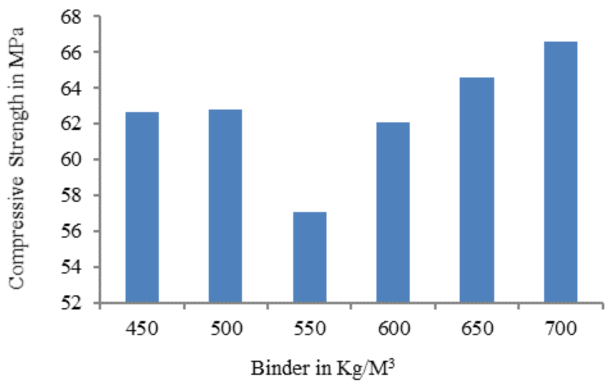

Fig 10. Compressive Strength Vs Binder Volume

Concrete cubes of dimension 150 mm × 150 mm × 150 mm was cast and moist cured for 28 days. The compression test of concrete cube was performed as per IS 516 [26]. Table 5 presents average compressive strength of three cubes for different binder quantity at 28 days curing, plotted against the binder quantity were shown in Fig. 10 indicates a good correlation between the compressive strength and W/B ratio. The compressive strengths for the different mixtures varied from 57 MPa to 66 MPa. The compressive strength for 450 kg/m^3 binder and 0.36 W/B ratio was observed around 62.65 MPa. The compressive strength was decreased as binder quantity increased up to 550 kg/m^3. This thing was may be happened due to decreased in aggregate volume in mix proportion. After 550 kg/m^3 binder, compressive strength was increased. Increased in compressive strength for higher binder volume may be due to very strong bond between aggregate and cement. For higher volume of binder quantity and lower water binder ratio, the strength of concrete cube was increased.

TABLE V. HARDENING PROPERTIES OF SELF COMPACTING CONCRETE

Sr. No	Binder in Kg/m^3	W/B ratio by weight	Paste Volume in Liter	Volume of Aggregate in Liter	Average Compressive Strength in MPa	Average Flexural Strength in MPa
1	450	0.36	321	679	62.65	4.38
2	500	0.36	357	643	62.77	4.59
3	550	0.34	382	618	57.07	3.85
4	600	0.32	406	594	62.06	4.33
5	650	0.31	433	567	64.62	4.47
6	700	0.30	462	538	66.57	4.89

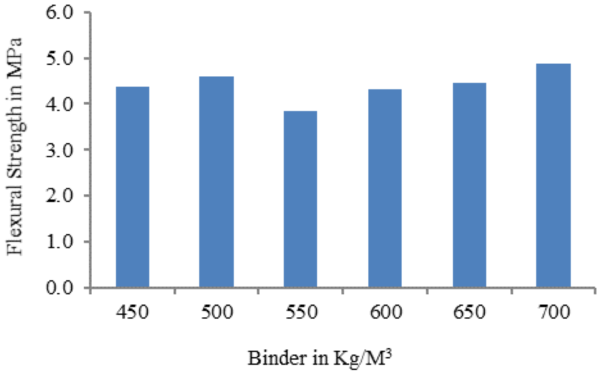

Fig 11 Flexural Strength Vs Binder Volume

Flexural strength of concrete was measured by testing of beam of size 100 mm × 100 mm × 500 mm under four point bending test using Digital Universal Testing Machine having capacity 60 tone. The results of flexural strength of concrete beam are presented in Table 5. Flexural strength of beam was decreased as compressive strength of concrete decreased up to 550 kg/m^3 volume of binder. Then after it was increased and flexural strength of concrete reach up to 4.89 MPa.

IV. CONCLUSIONS

The following conclusions can be drawn, based on the results of this experimental work:

1. It was observed from packing density test that; individual aggregate has more void contain then combination of all aggregate. The coarse aggregate (20 mm maximum size) contain more voids then 10 maximum size coarse aggregate as well as sand.
2. The aggregate combination of 50:20:30 (Fine aggregate: Coarse aggregate 10 mm maximum size: Coarse aggregate 20 mm maximum size) by volume give minimum void contain. So it gives maximum packing density compare to other combination of aggregate. This aggregate combination of 50:20:30 was selected for all mixes of self compacting concrete.
3. It was also observed that for a given paste volume, with increase in water binder ratio, the slump flow increased and for a given W/B ratio, the slump flow increased with increase in powder content.
4. The reason for the above observations could be attributed to the fact that the paste volume increased when the W/B ratio or the binder content increased, with the given combination of aggregates having a packing density of 0.677
5. Similarly, J-ring flow (slump flow with J-ring) increase with increase in paste volume. Also more blocking was observed in proportion having higher volume of aggregate.
6. Self compacting concrete is very sensitive concrete. At particular change in water binder ratio, there is large variation in V- funnel time was observed.
7. L box results shows that all mixtures of SCC are within target range except proportion whose paste volume is very low and aggregate volume is very high. However, it can be noted that each SCC investigated in the present study as adequate filling capability and passing ability.
8. The results of U box test for different mixes proportion shows that with increased in binder quantity or increased in W/B ratio there is decreased in difference in U box filling height.
9. The results for hardened properties of the SCC mixtures for different binder volume were investigated, all mixes shows very good compressive strength. The compressive strengths for the different mixtures varied from 57 MPa to 66 MPa. For higher volume of binder quantity and lower water binder ratio, the strength of concrete cube was increased.

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