Effect of Superplasticizer dosage on SCC: Correlation between compressive strength and rheological properties

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Abstract- In civil engineering works, the use of self-compacting concrete has become a good option which produces assertive cohesive concrete. The study investigates the relation between the rheological properties and compressive strength of self-compacting concrete. In the present study, SCC mix with different dosages of superplasticizer are considered. The fresh concrete is categorized using its rheological properties – slump flow, V-funnel, L-box, Plastic viscosity and Yield stress whereas compressive strength were measured to evaluate the mechanical property of the hardened concrete. The effect of super plasticizer on these rheological properties and strength will be studied in detail. The obtained results show that the slump-flow diameter, L-box ratio, V-Funnel time, Plastic viscosity, Yield stress and compressive strength were correlated at a high level based on experimental tests. The best fit-curve representing the relation between the rheology and compressive strength at 1 day, 7 days, 28 days is performed. It can be concluded that the compressive strength of SCC can be estimated from its rheological tests.

Keywords – Self-Compacting Concrete, rheological properties, correlation, compressive strength

I. INTRODUCTION

Self-compacting concrete is capable to consolidate under its self-weight while upholding its homogeneity and totally filling the form work even in the existence of congested reinforcement. Environmental friendly, reduction in time for placing, improved aesthetics, better durability are the benefits which are making SCC highly satisfactory throughout the world. SCC was first introduced in Japan (1988) to develop the concrete reliability and uniformity [1]. However, designing a proper SCC mixture is not an easy task. Petersson and Billberg (1999) and Emborg (1999) in Sweden, introduced an advanced alternative method for mix design with the criterion of void, blocking, paste volume and also derived rheology studies based on test results. Specific requirements for Self Compacting Concrete material, its application, its composition is defined by EFNARC. Some of the design measures have been prepared by European federation from the acceptable tests procedures and devoted to specialist construction chemicals and concrete systems [2]. SCC is prepared from the similar basic ingredients as conventional concrete, however mix proportions for SCC

vary from those of conventional concrete. SCC comprises less coarse aggregates, more powder content, high range water reducing super plasticizer in higher amounts and frequently a viscosity modifying agent (VMA) in lesser dosages in comparison to conventional concrete. SCC is considered as Bingham fluid.

Information from latest studies on the rheological and mechanical properties indicated that the self-compacting concrete has an improved performance when compared with conventional concrete Effect of SP dosage on the rheological properties of concrete mix was the focus of several studies by the authors. The results revealed that the enhancement of the rheological and mechanical properties by the superplasticizer is because of the liberation of water among cement particles and increase of the water films covering the particles in the mix [3] [4]. It is observed that the filling ability diameter is evaluated by slump-flow test and is correlated with the yield stress. From the studies it shows that the time of flow of the mix is measured by V-Funnel test and it is directly proportional to the plastic viscosity. L-box and J-ring tests are used to evaluate the passing ability and the resistance to segregation of SCC [5].

In the present work, the total binder content of 520 kg/m^3 out of which cement content is 350 kg/m^3 and limestone filler content is 170 kg/m^3 and W/B ratio of 0.37 which is kept constant. The main focus of the study is to characterize the fresh and hardened properties of the mixes with the effect of superplasticizer dosage. Then, the relation between compressive strength and the rheological properties (slump flow, V-funnel, L-box, yield stress, and plastic viscosity) are concluded.

II. EXPERIMENTAL PRORAM

2.1. Materials and Methodology

In the present study, nine mixes are considered out of which one mix is normally vibrated concrete and other eight mixes are SCC with different dosages of superplasticizer (SP). Physical properties and Chemical composition of the OPC, Limestone Filler and the super- plasticizer are given in Table 1.

Table-1 Physical proprieties and Chemical composition of the materials

Chemical compound	OPC	Limestone Filler	SP
C_2S (%)	12	-	-
C_3S (%)	67	-	-
C_3A (%)	9	-	-
C_4AF (%)	9	-	-
SiO_2 (%)	20.5	-	-
Al_2O_3 (%)	5.0	<0.4	-
Fe_2O_3 (%)	2.6	0.04	-
SO_3 (%)	3.5	-	-
MgO (%)	1.2	-	-
CaO (%)	65.2	-	-
NaO_2 eq. (%)	0.44	-	<1.5
Loss on ignition (%)	1.1	43.10	–
Cl−	0.0	-	<0.1
Blaine (cm^2/g)	4750	5550	–
pH	-	-	≥6
Density	3.10	2.75	1.09
Dry extract (%)	-	-	30

Experimental work is carried out to study the fresh and hardened properties of Self Compacting Concrete by casting specimens with different dosages of superplasticizer. Normal type concrete designated as N and SCC with different SP percentages such as 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%. 0.9% and 1% designated as SP1-SCC, SP2-SCC, SP3-SCC, SP4-SCC, SP5-SCC, SP6-SCC, SP7-SCC, SP8-SCC. In the present study nine mix proportions are considered to evaluate the performance of concrete. The concrete mixture proportions are presented in Table-2. Cement used in this study is purchased which is confirming to EN 197-1 European Standard. Limestone Filler is used as a mineral admixture confirming to EN 12620 European Standard. ViscoCrete 20 HE is used as SP manufactured by Sika India Pvt. Ltd.

Table-2 Concrete Mix Proportions for 1 m^3

Mix	OPC (kg/m^3)	Limestone filler (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	W/B ratio	SP dosage %
N-SCC	350	170	890	900	0.37	–
SP1-SCC	350	170	890	900	0.37	0.3
SP2-SCC	350	170	890	900	0.37	0.4
SP3-SCC	350	170	890	900	0.37	0.5
SP4-SCC	350	170	890	900	0.37	0.6
SP5-SCC	350	170	890	900	0.37	0.7
SP6-SCC	350	170	890	900	0.37	0.8
SP7-SCC	350	170	890	900	0.37	0.9
SP8-SCC	350	170	890	900	0.37	1

2.2. Test program

1) Tests on fresh SCC properties

For different mixes of self-compacting concrete with varying superplasticizer, tests are conducted to identify the fresh properties. According to EFNARC standard, characteristic properties of the workability of Self Compacting Concrete include the filling ability, segregation resistance and passing ability which all relate to the slump flow, V-funnel and L-box test and these tests are sown in Figure 1. Concrete rheometer is used to measure plastic viscosity and yield stress. Plastic viscosity and yield stress values are summarized in Table 3.

Figure 1. Fresh properties of the SCC mix

2) Tests on hardened SCC properties

Hardened property i.e., compressive strength for various mixes are mentioned in Table-4 and sown in Figure 2. For each property, average of five tests values was considered.

Figure 2. Hardened properties of the SCC mix

Table-3 Fresh properties of the mixes

Mix	Filling ability - Slump flow diameter (cm)	Passing ability - L-Box H2/H1 ratio	Segregation resistance – V-Funnel flow time (s)	Plastic Viscosity (Pa s)	Yield stress (Pa)
NC	26	–	–	286	85.6
SP1-SCC	65.25	0.814	20.8	139.34	39.64
	64.8	0.826	19.6	137.65	38.2
	65	0.832	18.2	135.1	37.27
	64.5	0.848	17.8	133.83	36.2
	64.2	0.852	17.2	129.67	34.62
SP2-SCC	65.65	0.858	16.5	127.46	33.6
	65.5	0.868	15.2	120.21	32.84
	65.9	0.872	16	115.32	30.62
	65.2	0.882	15.6	109.76	28.92
	66	0.891	14.5	82.25	25.25
SP3-SCC	67.72	0.894	13.2	78.46	23.76
	68.4	0.892	11.8	74.12	23.25
	69.6	0.898	12.4	70.52	22.87
	72.8	0.89	10.2	64.98	22.55
	72	0.892	9.8	60.54	22.12
SP4-SCC	74.48	0.9	10.4	56.72	21.86
	74	0.912	9.6	51.98	20.72
	77	0.92	8.8	47.21	19.46
	75	0.924	8.2	43.82	18.16
	76.2	0.928	8.6	40.16	15.69
SP5-SCC	78	0.93	9	37.84	12.88
	78.8	0.948	8.8	36.52	10.25
	77.6	0.952	7.6	33.18	8.72
	79.4	0.958	8.1	30.41	7.69

	80.6	0.962	7.8	26.83	6.21
SP6-SCC	81.62	0.968	8.2	24.34	5.74
	80.6	0.972	8	23.65	5.68
	82.4	0.98	7.5	22.14	5.52
	83.8	0.986	8	21.72	5.27
	84.5	0.992	7.6	20.46	4.82
SP7-SCC	84.83	1	7.8	19.65	4.16
	82.8	1	7.6	19.42	3.85
	84.6	1	7	19.1	3.67
	86	1	6.8	18.84	3.28
	85.2	1	6.6	18.52	2.68
SP8-SCC	86.46	1	6.2	18.11	2.26
	85.8	1	6	17.92	2.2
	86.2	1	5.8	17.51	2
	85.4	1	5.8	17.42	2.24
	86.2	1	6.2	17.36	2.22

III. Results and Discussions

3.1. Fresh properties of Self Compacting Concrete

Firstly, all the SCC mixes have a slump flow diameter confirming to recommendation of EFNARC except for NC mix. Fresh properties for all the SCC mixes are shown in Table 3. It is noticed from the Figure 3. that with increase in SP dosage, the slump flow diameter increases. Secondly, Figure 4. shows that with increase in dosage of SP, the ratio of H2/H1 rises. Thirdly, Figure 5. show that with increase in dosage of SP, the duration taken by the mix to empty the funnel reduces. Except for NC mix, all other fresh mixtures values obtained are confirming to recommendation of EFNARC. Finally, Figure 6. shows that with increase in dosage of SP the values of plastic viscosity and yield stress decreases. Usage of superplasticizer improves the rheological and mechanical properties because it releases the water among cement particles and increases the water films covering the particles in the mix.

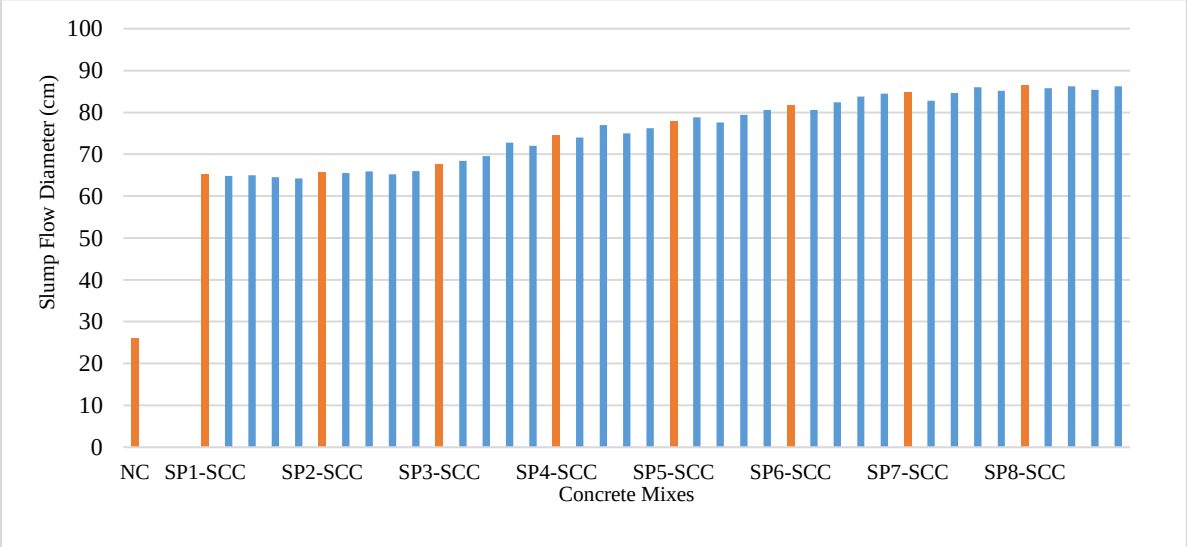

Figure 3. Slump flow test results for all mixes

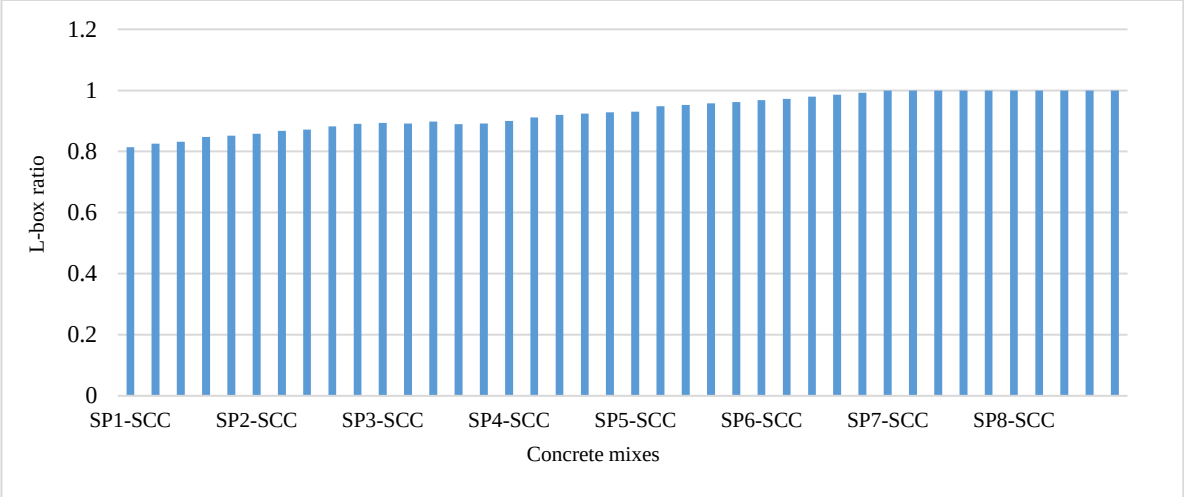

Figure 4. L-Box test results for all mixes

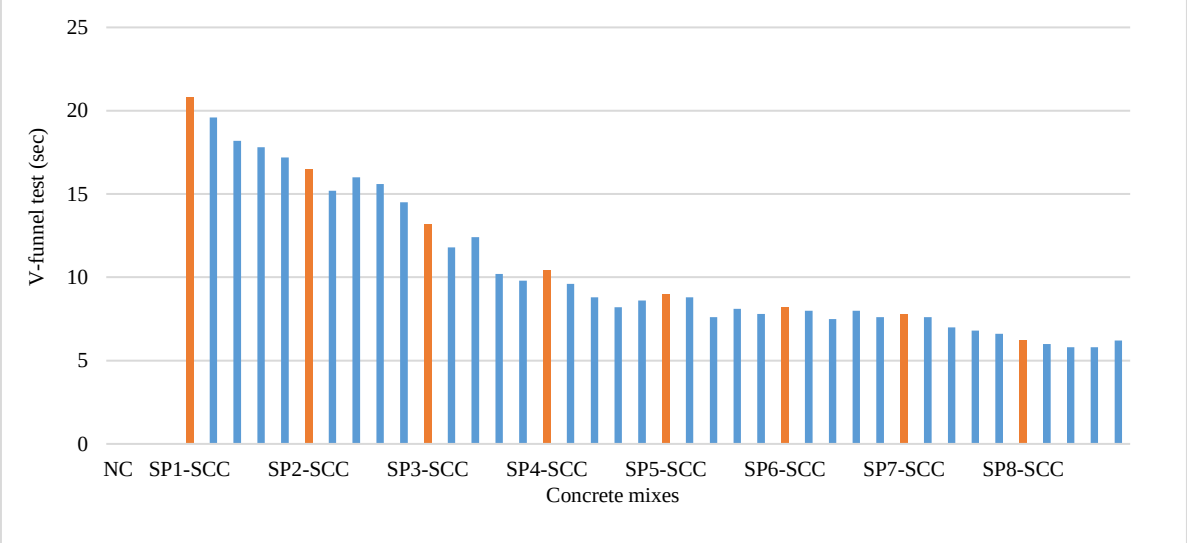

Figure 5. V-funnel test results for all mixes

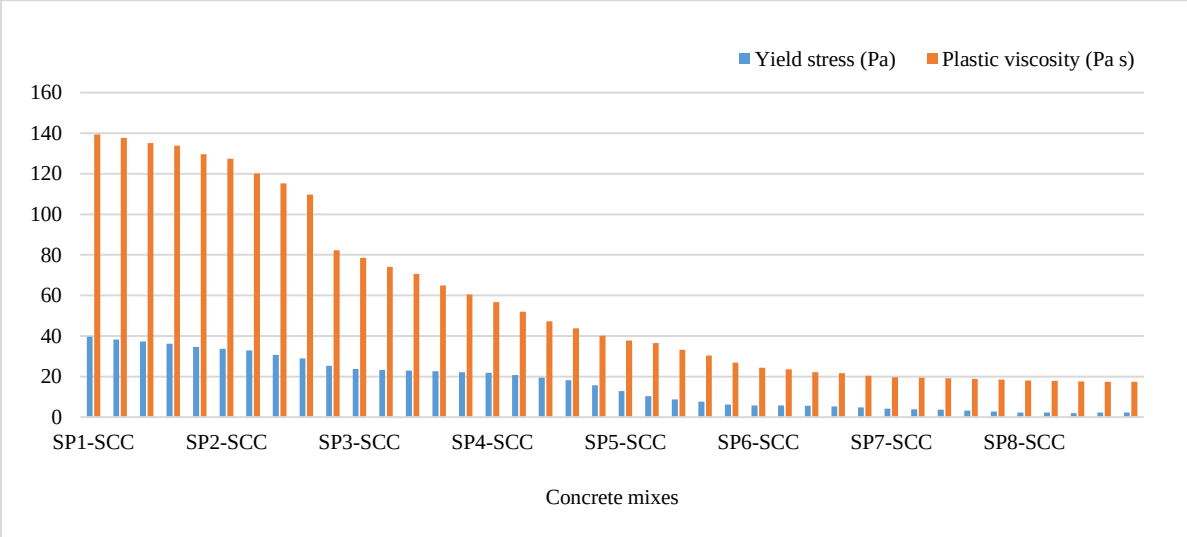

Figure 6. Plastic viscosity and Yield stress results for all mixes

3.2. Hardened properties of Self Compacting Concrete

For all the mixes, compressive strength values at 1 day, 7 days and 28 days is shown in Table-4. It is noticed that, with increase in dosage of SP there is a reduction in compressive strength values.

Table-4 Mechanical Properties of the mixes

Mix	Compressive strength		
	1 day	7 days	28 days
N-SCC	29.62	33.3	50.8
SP1-SCC	46.15	60.72	74.26
SP2-SCC	40.64	55.7	71.26
SP3-SCC	35.32	46.43	65.78
SP4-SCC	32.25	41.42	59.88
SP5-SCC	29.42	37.65	53.10
SP6-SCC	26.46	33.55	45.86
SP7-SCC	18.86	27.62	38.56
SP8-SCC	15.84	20.68	30.16

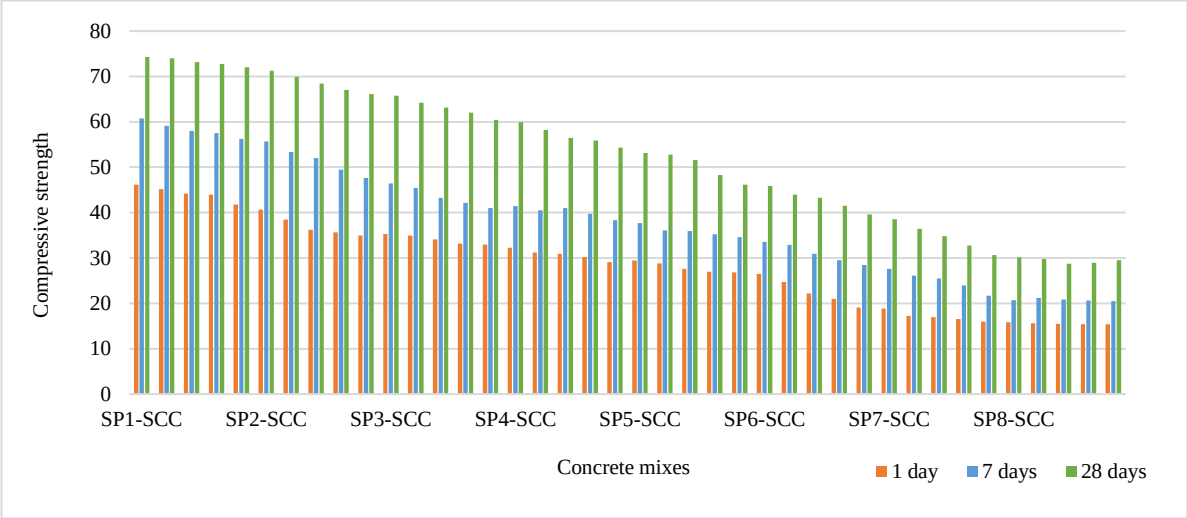

Figure 7. Compressive strength results for all mixes

3.3. Correlation between mechanical and rheological properties

It is noticed from Table-3 and Table-4 that with increase of SP dosage, rheological properties of all the mixes enhanced whereas the hardened properties reduced. Relation between rheological properties (slump flow, V-funnel time, L-box ratio, Plastic viscosity and yield stress) and compressive strength at 1 day, 7 days and 28 days of all the SCC mixes are shown in Figure 8-Figure 12.

1. Correlation between slump flow and compressive strength

Results obtained from Figure 8. shows that the slump flow and compressive strength was correlated high level:
$R^2 = 0.926$ at 1 day, $R^2 = 0.943$ at 7 days and $R^2 = 0.953$ at 28 days
At 1 day, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [−1.1388 × slump flow diameter value] + 115.24
At 7 days, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [−1.4819 × slump flow diameter value] + 150.94
At 28 days, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [−1.841 × slump flow diameter value] + 192.3

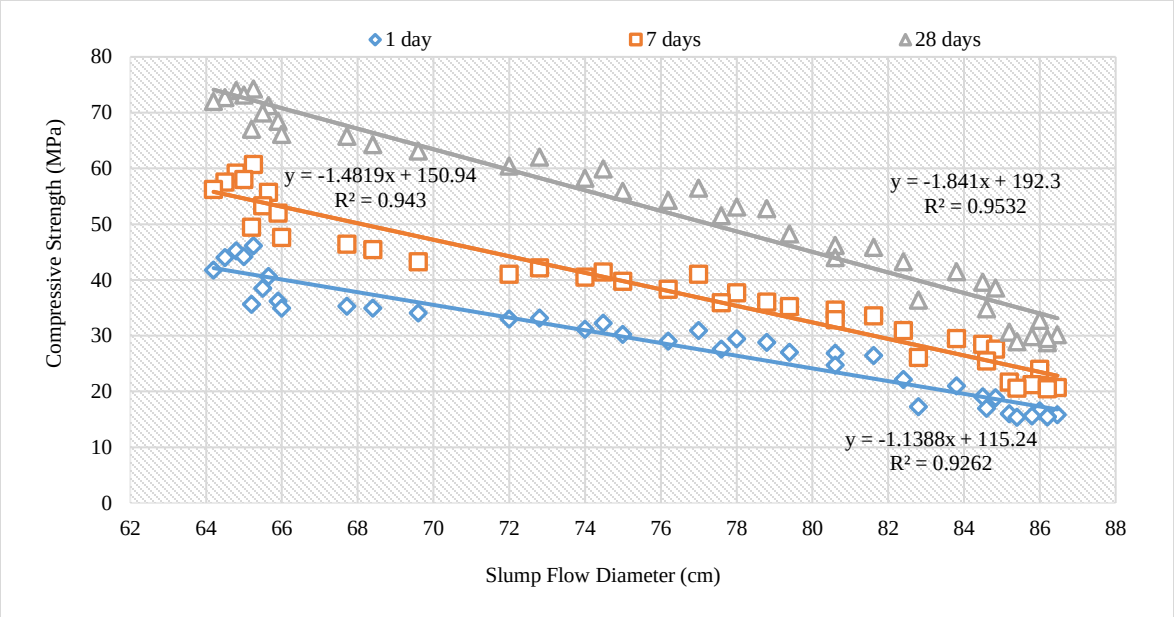

Figure 8. Correlation between slump flow and compressive strength

2. Correlation between V-Funnel time and compressive strength

Results obtained from Figure 9. shows that the V-funnel test and compressive strength was correlated high level: $R^2 = 0.847$ at 1 day, $R^2 = 0.895$ at 7 days and $R^2 = 0.805$ at 28 days.

At 1 day, the best fit-curve representing the relationship is given by:

Compressive strength value (MPa) = [2.0389 × V-Funnel value] + 7.239

At 7 days, the best fit-curve representing the relationship is given by:

Compressive strength value (MPa) = [2.7017 × V-Funnel value] + 9.888

At 28 days, the best fit-curve representing the relationship is given by:

Compressive strength value (MPa) = [3.1672 × V-Funnel value] + 19.067

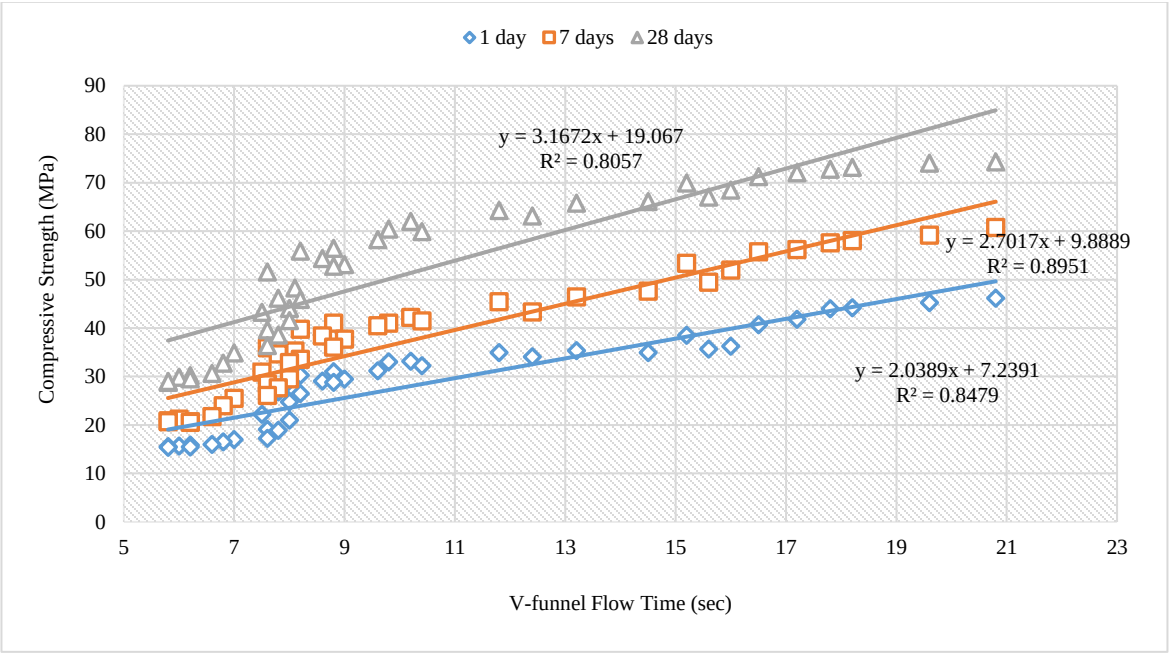

Figure 9. Correlation between V-funnel flow time and compressive strength

3. Correlation between L-box ratio and compressive strength

Results obtained from Figure 10. shows that the L-box ratio and compressive strength was correlated high level:
$R^2 = 0.970$ at 1 day, $R^2 = 0.960$ at 7 days and $R^2 = 0.950$ at 28 days
At 1 day, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [-159.41 × L-box ratio] + 177.1
At 7 days, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [-204.52 × L-box ratio] + 228.73
At 28 days, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [-251.4 × L-box ratio] + 286.45

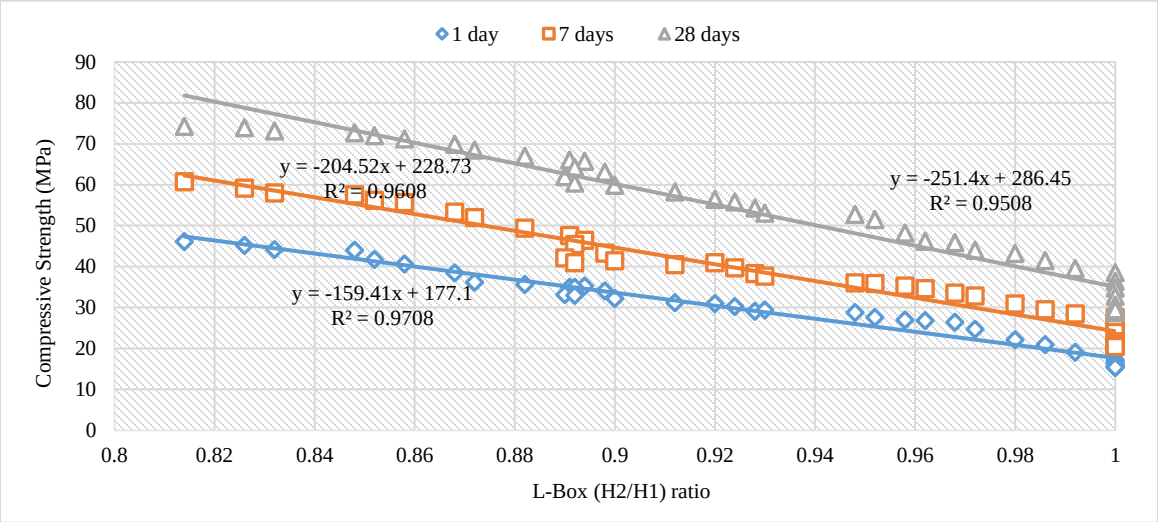

Figure 10. Correlation between L-box ratio and compressive strength

4. Correlation between plastic viscosity and compressive strength

Results obtained from Figure 11. shows that the plastic viscosity and compressive strength was correlated high level:
$R^2 = 0.859$ at 1 day, $R^2 = 0.902$ at 7 days and $R^2 = 0.824$ at 28 days
At 1 day, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [0.206 × Plastic viscosity] +16.951
At 7 days, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [0.2721 × Plastic viscosity] +22.8
At 28 days, the best fit-curve representing the relationship is given by:
Compressive strength value (MPa) = [0.321 × Plastic viscosity] +34.066

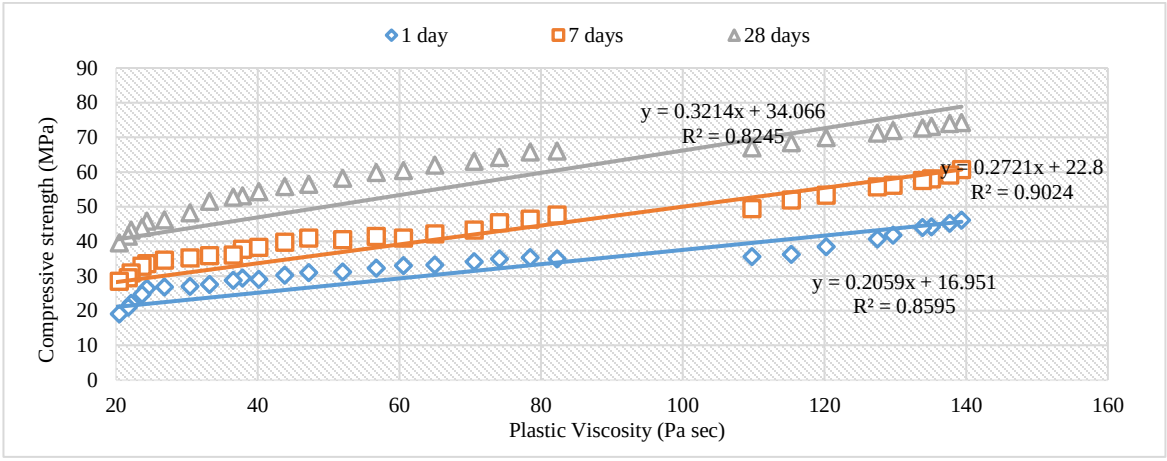

Figure 11. Correlation between Plastic viscosity and compressive strength

5. Correlation between yield stress and compressive strength

Results obtained from Figure 12. shows that the yield stress and compressive strength was correlated high level: $R^2 = 0.931$ at 1 day, $R^2 = 0.949$ at 7 days and $R^2 = 0.922$ at 28 days.

At 1 day, the best fit-curve representing the relationship is given by:

Compressive strength value (MPa) = [0.7304 ×Yield stress] + 16.839

At 7 days, the best fit-curve representing the relationship is given by:

Compressive strength value (MPa) = [0.951 ×Yield stress] + 22.882

At 28 days, the best fit-curve representing the relationship is given by:

Compressive strength value (MPa) = [1.158 ×Yield stress] + 33.593

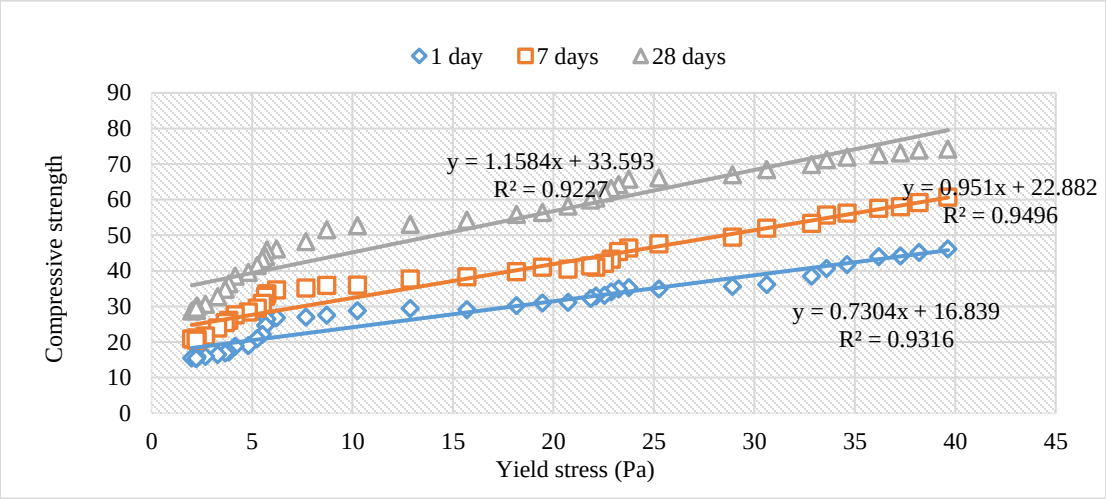

Figure 12. Correlation between Yield stress and compressive strength

It is found from the results obtained that, compressive strength values can be predicted based on the rheological properties of SCC.

IV. Conclusion

Based on experimental results obtained, it can be noted that with increase in superplasticizer dosage the compressive strength decreases. In addition, with increase in dosage of superplasticizer, the slump flow diameter value and Hf/Hi ratio increases. On the other, V-funnel flow time, the plastic viscosity and the yield stress values decreases with increase in superplasticizer amount. It can be concluded from the results that the rheological properties (slump-flow diameter, L-box ratio, V-Funnel time) and hardened properties (compressive strength) were correlated at a high level.

V. References

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