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Effect of Superplasticizer on Workability and Mechanical Properties of Self-Compacting Concrete

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Abstract : *Superplasticizer which is also known as high range water reducers are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation, and to improve the flow characteristics of concrete. Flocculation of cement particles occur in a concrete mix without superplasticizer which reduces the workability of concrete, however for the same water-cement ratio there is a uniform distribution of cement particles for a concrete mix with superplasticizer. This paper is a study of the effect of three different types of superplasticizer namely: Sulphonated Naphthalene Formaldehyde (SNF), Poly Carboxylate Ether (PCE) and Modified Poly Carboxylate Ether (MPCE) on the workability and mechanical properties of self-compacting concrete (SCC) mixtures.*

Keywords *- Admixture, Modified Poly Carboxylate Ether, Plasticizer, Polycarboxylate Ether, Retention, Self-compacting concrete, Sulphonated Naphthalene Formaldehyde, Superplasticizer.*

I. INTRODUCTION

Superplasticizers constitute of a relatively new category and improved version of plasticizer, the use of which was developed in Japan and Germany during 1960 and 1970, respectively. They are chemically different from normal plasticizers. The use of plasticizers permits reduction of water to an extent up to 30% without reducing the workability in contrast to the possible reduction up to 15% in case of plasticizers. There are a number of superplasticizers available in the market, out of which three superplasticizers will be used in this research to study their effect on workability and mechanical properties of concrete mixture in both fresh and hardened state. Superplasticizers produce a homogeneous, cohesive concrete generally without any tendency for segregation and bleeding.

Sulphonated Naphthalene Formaldehyde (SNF) is a polymer produced by condensed polymerisation of naphthalene, sulphonic acid and formaldehyde. The dispersion of cement particles caused as a result of negative charge left on the admixture adsorbed cement particle, which will repel the other cement particles. This phenomenon is called *electrostatic repulsion*.

Poly Carboxylate Ether (PCE) is composed of a methoxy-polyethylene glycol copolymer (side chain) grafted with methacrylic acid copolymer. The dispersion of cement particles occur due to *steric hindrance*. Steric hindrance depends on the length of main chain, length and number of side chain. However, they are more sensitive to overdosing, and can lead to problems such as retardation and excessive air entrainment. Modified Carboxylate ether (MPCE) is the modified version of PCE with better water retaining properties.

Viscosity modifying agent or viscosity enhancing agent are often used to improve the cohesiveness and stability of Self-Compacting Concrete (SCC). However, in the superplasticizers used in this research the viscosity modifying agents are added along with the chemical admixture by the chemical manufacturers.

II. SIGNIFICANCE OF RESEARCH

A study on the behaviour of a specific concrete mix with different superplasticizer can show the comparative view on the behaviour of the different superplasticizer used. Table 1 gives the properties of the superplasticizers used in this research.

TABLE 1 PROPERTIES OF SUPERPLASTICIZERS USED

Sl.No	Name of the admixture	Relative density	Colour	Dosage*
1.	SNF	1.24 at 25ºC	Dark Brown	0.5-2%
2.	PCE	1.08 at 25ºC	Honey Brown	0.4-1.2%
3.	MPCE	1.08 at 25ºC	Golden Brown	0.6-1.2%

* as recommended by the manufacturer

The tests and comparative study done on the SCC mixture are for the following:

- Slump flow test
- Slump flow test at T_{500mm}
- V-funnel test
- V-funnel test at T_{5mins}
- L-box test
- U-box test
- Workability retention test
- Compressive strength of concrete
- Rapid chloride penetration test (RCPT)
- Dosage used
- Cost

A concrete mix can be only classified as SCC if it satisfies the following characteristics:

- Filling ability
- Passing ability
- Segregation resistance

TABLE 2 TEST METHODS TO FIND OUT THE FILLING ABILITY, PASSING ABILITY AND SEGREGATION RESISTANCE OF SELF-COMPACTING CONCRETE

Method	**Property**
Slump flow test	Filling ability
T_{50cm} slump flow test	Filling ability
V – funnel	Filling ability
V – funnel at T_5minutes	Segregation resistance
L – Box test	Passing ability
U – Box test	Passing ability

III. TEST PROCEDURES

3.1 Slump flow test

The slump flow test is done to access the horizontal flow of concrete in the absence of obstruction. It is most commonly used test and gives good assessment of filling ability. The test also indicates resistance of self-compacting concrete mixture to segregation.

About 15 kilograms of concrete mix is needed for this test. Place the base plate on level ground. Keep the slump cone centrally on the base plate. Fill the cone with the scoop. Do not tamp. Simply strike off the concrete level with the trowel. Remove the surplus concrete lying on the base plate. Raise the cone vertically and allow the concrete to flow freely. Measure the final diameter of the concrete in two perpendicular directions and calculate the average of the two. Test values for slump flow with different superplasticizers are given in Table 3 and Fig.1.

TABLE 3 TEST VALUES FOR SLUMP FLOW TEST

Sl.No	**Types of admixture used**	**Slump flow value**
1.	SNF	560mm
2.	PCE	650mm
3.	MPCE	800mm

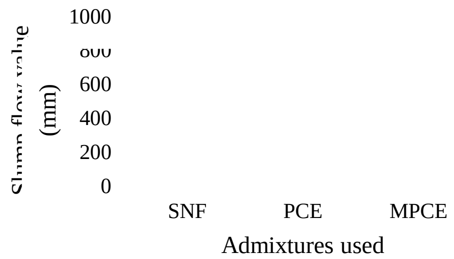

Fig. 1. Variation in slump flow test value for different type of superplasticizer

The higher the flow value, the greater will be the ability to fill the formwork under its own weight. A value of at least 650mm is required for SCC. In case of severe segregation, most coarse aggregate will remain in the centre of the pool of concrete and mortar and paste at the periphery of concrete.

3.2 T_{500mm} slump flow test

Flow table test at T_{500mm} indicates the rate of flow within a defined flow distance. This test shows the filling ability of the SCC.

The procedure for this test is same as for slump flow test. When the slump cone is lifted, start the stop watch and find the time taken for the concrete to reach 500mm mark. This time is called T_{500mm} time. This is an indication of rate of flow of concrete. A lower time indicates greater flowability of concrete mixture. It is suggested that T_{50cm} time may be 2 to 5 seconds. Table 4 and Fig. 2 give the time taken to spread 500mm for the three types of superplasticizer mixed SCC.

TABLE 4 TEST VALUES FOR T_{500mm} SLUMP FLOW TEST

Sl.No	Types of admixture used	T_{500mm} Slump flow value
1.	SNF	4.5 seconds
2.	PCE	3.8 seconds
3.	MPCE	3.2 seconds

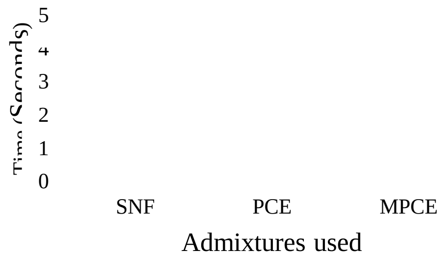

Fig. 2. Variation in slump flow at T_{500mm} for different type of superplasticizer

The less time the concrete mix takes to reach 500mm on the base plate more is the filling ability of self – compacting concrete. Similarly, the more time the concrete mix takes to reach 500mm on the base plate less is the filling ability of SCC. Hence, SNF gives less filling ability compared to PCE, and PCE gives less filling ability compared to MPCE.

3.3 V – funnel test

The equipment consists of a V – shaped funnel. This test was developed in Japan. The V – funnel test is used to determine the filling ability (flowability) of the concrete with a maximum size of aggregate 20mm size. The funnel is filled with concrete (about 12 litres). We find out the time taken for flow. Table 5 gives the time taken to flow the entire concrete through the V-funnel with different superplasticizer addition.

TABLE 5 TEST VALUES FOR V–FUNNEL TEST

Sl.No	**Types of admixture used**	**V-Funnel test value**
1.	SNF	52 seconds
2.	PCE	13.7 seconds
3.	MPCE	14 seconds

V-funnel test is a test to find out the filling ability of concrete. The lesser time the concrete takes to empty the V–funnel as soon as the trap door is opened, better is the filling ability of concrete. Looking at the behaviour of all three superplasticizers in the same mix design of concrete, SNF takes more time than a SCC should take, and hence it fails the test. Whereas, PCE and MPCE pass the test and PCE gives a better performance than MPCE (Fig. 3)

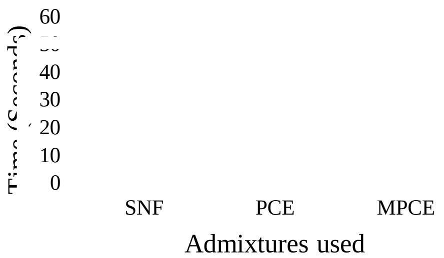

Fig. 3. Variation in V-funnel test value for different type of superplasticizer

3.4 V – Funnel test at $T_{5minutes}$

V – Funnel test at $T_{5\ minutes}$ is similar to V – funnel test and has to be done after the V – funnel test only. The concrete should be left in the V – funnel for 5 minutes and the trap door is opened after 5 minutes. This test helps us to observe the segregation resistance of concrete. Do not clean or moisten the inside surface of the funnel and refill the V-funnel immediately after measuring the flow time. Place the bucket underneath and fill the apparatus completely with concrete without tamping or tapping. Strike off the concrete level with a trowel. Open the trapped door after 5 minutes after the second fill of the funnel and allow the concrete to flow. Calculate the time taken for complete discharge. It is called the flow time at $T_{5minutes}$. For V-funnel test at $T_{5minutes}$ +3 seconds is allowed. Table 6 and Fig. 4 give the time taken for the SCC to flow after 5 minutes in the V-funnel apparatus.

TABLE 6 TEST VALUES FOR V-FUNNEL TEST AT T_{5mins}

Sl.No	**Types of admixture used**	**V-Funnel test value for T_{5mins}**
1.	SNF	90 seconds
2.	PCE	16 seconds
3.	MPCE	18 seconds

If the concrete flows as freely as water, then the range of values of V - funnel at $T_{5minutes}$ should range between 8 – 12 seconds. The lesser the time taken, better is the filling ability of concrete. Whereas, for V funnel test at T_5 minutes about 3 second variation is allowed. MPCE shows better results compared to SNF and PCE for V-funnel test at $T_{5minutes}$

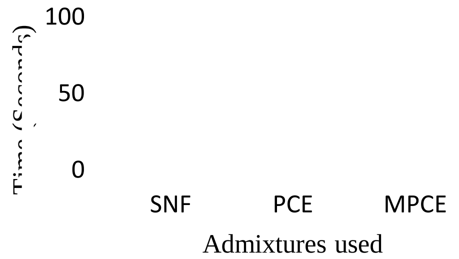

Fig. 4. Variations in V-funnel test at $T_{5minutes}$ for different type of superplasticizer

3.5 L – Box test

L-box test was developed in Japan. The test assesses the flow of concrete, and also the extent to which the concrete is subjected to blocking by reinforcement. About 14 Kilograms of concrete is required for this test. Ensure that the sliding gate can open freely and then close it. Moisten the inside surface, remove all surplus water. Fill the vertical section of the apparatus with concrete. Leave it standing for one minute. Lift the sliding gate watch and record the time taken for the concrete to reach 200mm and 400mm marks. When the concrete stops flowing, the height H_1 and H_2 are measured. Calculate H_2/H_1, the blocking ratio. The whole test has to be performed within 5 minutes. Table 7 and Fig.5 represents the test results for L-box test.

TABLE 7 TEST VALUES FOR L-BOX TEST

Sl.NO	**Admixture**	**H_1 (mm)**	**H_2 (mm)**	**H_2/ H_1**
1.	SNF	65	51.25	0.82
2.	PCE	77	73.15	0.95
3.	MPCE	75	70	0.93

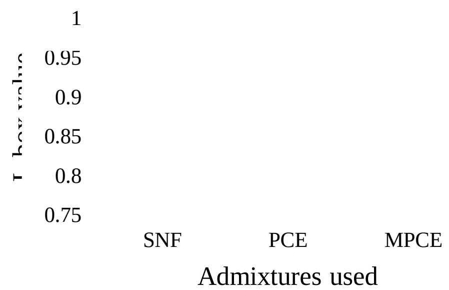

Fig. 5. Variations in L-box test for different type of superplasticizers

If the concrete flows as freely as water, at rest it will be horizontal. Therefore, H_2/H_1 will be equal to 1. Therefore, nearer the test values, the blocking ratio is to unity, the better will be the flow of concrete. The European Union research team suggested a minimum acceptable value of 0.8 T_{20} and T_{40} time can give some indication of ease of flow, but no suitable values have been suggested.

3.6 U – Box Test

U-box test was developed in Japan. The test is used to measure the filling ability of SCC. The apparatus consists of a vessel which is divided by a middle wall into two compartments shown by R1 and R2. An opening with a sliding gate is fitted between the two compartments. Reinforcement bars with a nominal diameter of 15 mm are installed at the gate with centre to centre distance of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 kilograms of concrete. The gate is then lifted and the concrete flows to the other section. The height of concrete in both the sections is measured. Table 8 and Fig.6 gives the test results of U-box test for SCC with different types of superplasticizers.

TABLE 8 TEST VALUES FOR U-BOX TEST

Sl. NO.	**Admixture**	**U_1 (mm)**	**U_2 (mm)**	**$U_1 – U_2$ (mm)**
1.	SNF	140	90	50
2.	PCE	128.5	100.5	28
3.	MPCE	130	105	25

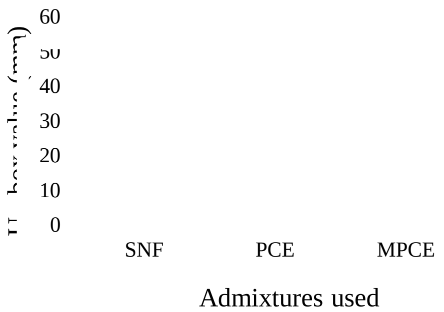

Fig. 6. Variations in U-box test for different type of superplasticizer

If the concrete flows as freely as water, at rest it will be horizontal. Thus, U1 – U2 = 0. Therefore, the nearer the filling value is to zero better is the passing ability of concrete. The acceptable value of the filling height is 30 mm maximum.

3.7 Workability Retention Test

Workability of concrete is one of the most important criteria that should be always be kept in check for long duration depending upon the retention time which is calculated keeping the distance between the site and the Ready Mixed Concrete (RMC) plant. When concrete is to be designed for more than M40, naturally, admixture(s) of preferred choice is to be used. The main types of admixtures that must be used are water reducing agents and superplasticizer. When water reducing agents are used, the total quantity free water used will be kept under control as increasing free water affects the strength of concrete. For a retention time of about 2 hours, either a PCE or an MPCE is can be used. Any admixture which is a superplasticizer cum- water reducing agent if chosen will reduce the cost of the concrete. Theoretically, initially at the RMC plant, immediately after the mixing of concrete, a certain amount of bleeding is allowed such that the bleeding is arrested within 20 – 25 minutes from the mixing time of concrete. Thus, with regard to the bleeding of concrete which increases the stickiness of the rest of the material (cementitious material and aggregates, the workability of concrete is less) within 20 – 25 minutes, the workability of concrete must increase when compared to the initial workability and by the end of 2 hours of retention period; the desired flow should be attained. Thus, for this reason, initial flow value for SCC is kept higher. Table 9, Table 10, Table 11 and Fig.7 show the workability retention over time of different types of superplasticizer mixed SCC.

TABLE 9 SLUMP FLOW VALUE OVER A PERIOD OF TIME FOR SNF

Sl.NO	**Time (Minutes)**	**Slump (mm)**		**Average slump (mm)**
1.	15	640	640	640
2.	30	547	548	547.5
3.	45	454	456	455
4.	60	375	375	375
5.	75	324	326	325
6.	90	275	275	275
7.	105	250	250	250
8.	120	250	250	250

TABLE 10 SLUMP FLOW VALUE OVER A PERIOD OF TIME FOR PCE

Sl.NO	**Time (Minutes)**	**Slump (mm)**		**Average slump (mm)**
1.	15	730	730	730
2.	30	690	690	690
3.	45	660	660	660
4.	60	650	650	650
5.	75	600	600	600
6.	90	570	570	570
7.	105	550	550	550
8.	120	500	500	500

TABLE 11 SLUMP FLOW VALUE OVER A PERIOD OF TIME FOR MPCE

S.No	**Time (minutes)**	**Slump (mm)**		**Average slump (mm)**
1.	15	700	700	700
2.	30	680	680	680
3.	45	670	670	670
4.	60	660	660	660
5.	75	650	650	650
6.	90	630	630	630
7.	105	610	610	610
8.	120	600	600	600

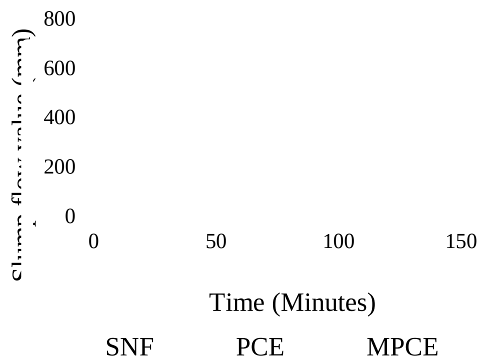

Fig. 7. Variation in slump flow value of SCC mixture versus time period using different superplasticizer

The change in slump flow over time is drastically decreasing for SNF, whereas for PCE the flow is as steep as that of MPCE. The variation for PCE and MPCE is not that drastic as in comparison with PCE and MPCE, but it is impossible to miss the fact that the slump flow is more constant for MPCE than for SNF. Hence, when loaded in a truck, the concrete that will lose its workability over time is SNF followed by PCE, which will then be followed by MPCE.

3.8 Compressive Strength Test

The concrete develops strength with continued hydration. The rate of gain of strength is faster to start with and the rate gets reduced with age. It is customary to assume the 28th day strength as the full strength of concrete. Although concrete develops strength beyond 28 days. Earlier codes have not been permitting to consider that this strength in the design. The increase in strength beyond 28 days is used to get immersed with the factor of safety and make the structure more economical. The first step to mix design calculation is the target strength, which according to IS 10262:2009 is given by:

$$f'_{ck} = f_{ck} + 1.65s \qquad (1)$$

The design is then carried out using the value of f'_{ck}, which in this case gives a value of 48.25 MPa.

TABLE 12 COMPRESSIVE STRENGTH VALUE FOR SNF

Sl.No	**Days**	**Weight (kg)**	**Ultimate Load (kN)**	**Strength (MPa)**	**Average strength (MPa)**
1.	3	8.360	641.7	28.52	28.2
		8.320	649.1	28.85	
		8.396	610.2	27.12	
2.	7	8.360	815.0	36.22	36.2
		8.325	825.8	36.70	
		8.412	805.5	35.80	
3.	28	8.385	1189.4	52.86	53.5
		8.405	1206.9	53.64	
		8.365	1217.7	54.12	

TABLE 13 COMPRESSIVE STRENGTH OF PCE

Sl.No	**Days**	**Weight (kg)**	**Ultimate Load (kN)**	**Strength (MPa)**	**Average strength (MPa)**
1.	3	8.455	700.7	31.14	31.8
		8.540	740.0	32.89	
		8.460	705.6	31.36	
2.	7	8.575	868.5	38.60	38.1
		8.560	844.7	37.54	
		8.495	857.9	38.13	
3.	28	8.455	1241.1	55.16	55.7
		8.500	1258.2	55.92	
		8.545	1262.7	56.12	

TABLE 14 COMPRESSIVE STRENGTH OF MPCE

S.No	**Days**	**Weight (kg)**	**Ultimate Load (kN)**	**Strength (MPa)**	**Average strength (MPa)**
1.	3	8.590	840.9	37.50	37.9
		8.490	857.4	38.50	
		8.450	849.2	37.70	
2.	7	8.640	951.0	42.50	43.0
		8.590	979.8	43.50	
		8.600	965.0	42.90	
3.	28	8.595	1328.0	59.02	59.2
		8.685	1139.8	59.50	
		8.650	1330.0	59.11	

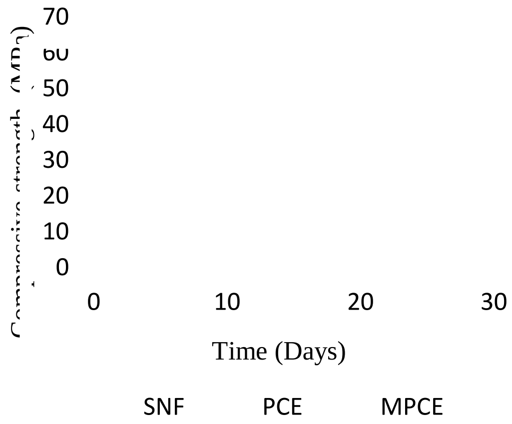

Fig. 8. Compressive strength test value results for SCC for different superplasticizers

The 28th day compressive strength values for SNF, PCE and MPCE as obtained after testing the respective concrete samples are more than the target strength for which they were designed. Table 12, Table 13, Table 14 and Fig.8 represents the compressive strength development over time of SNF, PCE and MPCE based self-compacting concrete mixtures.

3.9 Rapid Chloride Penetration Test

Reinforced concrete structures are exposed to harsh environments, yet are often expected to last with little or no repair or maintenance for long periods of time (often 100 years or more). To do this, a durable structure has to be produced. One of the major forms of environmental attack is chloride ingress, which leads to corrosion of the reinforcing steel and a subsequent reduction on the strength, serviceability, and aesthetics of the structure. This may lead to early repair or premature replacement of the structure. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of the reinforcing steel bars by using relatively impenetrable concrete (concrete containing fly ash is used in this case). The ability of chloride ions to penetrate the concrete must then be known for design as well as quality control purposes. The penetration of the concrete by chloride ions, however, is a slow process. It cannot be determined directly in a time frame that would be useful as a quality control measure. Therefore, in order to assess chloride penetration, a test method that accelerates the process is needed, to allow the determination of diffusion values in a reasonable time, for which rapid chloride test helps us to assess the concrete made.

The concrete sample (a 100mm diameter, 200mm high cylindrical sample) after 56days of curing was taken out of the water bath and was cut into three equal portions. One of the cut concrete cylinder sample is in indirect contact with Sodium Chloride (NaCl) solution while the other face is in indirect contact with Sodium Hydroxide (NaOH) solution. A DC supply of 60 Volts is supplied to the concrete for 6 hours. The DC supply is connected to the stainless steel cathode and anode on either side of the concrete which come in direct contact with the concrete and the NaOH solution on the other side. The charge passed is determined using the following formula:

$$Q = 0.9\,(I_1+2(I_2+I_3+\ldots+I_{12})+I_{13}) \qquad (2)$$

Where, $I_1, I_2, \ldots, I_{13}$ are current passing through the cell at 30 minutes interval
Q – charge passed in Coulombs

Table 15 shows the range of charge passing through the concrete sample and their interpretation according to the American Society for Testing and Materials (ASTM) C 1202 .Table 16, Table 17, Table 18 and Fig. 9 illustrate the test results of Rapid Chloride Penetration test of SCC with SNF, PCE and MPCE superplasticizers.

TABLE 15 RANGE OF CHARGE PASSING THROUGH THE CONCRETE SAMPLE AND THEIR INTERPRETATION ACCORDING TO ASTM C 1202 CODE

Charge passed (Coulombs)	**Chloride ion penetrability**
>4000	High
2000 - 4000	Moderate
1000 - 2000	Low
100 - 1000	Very low
<100	Negligible

TABLE 16 RAPID CHLORIDE PENETRATION TEST VALUES FOR SNF

Sl.No	**Time**	**Sample 1**	**Sample 2**	**Sample 3**
1.	11:30	50	60	65
2.	12:00	52	60	66
3.	12:30	55	60	66
4.	13:00	55	60	67
5.	13:30	55	60	68
6.	14:00	55	60	68
7.	14:30	59	63	68
8.	15:00	59	63	68
9.	15:30	59	63	68
10.	16:00	59	63	68
11.	16:30	59	63	68
12.	17:00	59	63	68
13.	17:30	59	63	68
Charge passed		1224.9	1331.1	1457.1
Average		1337.7 Coulombs		

TABLE 17 RAPID CHLORIDE PENETRATION TEST VALUES FOR PCE

Sl.No	**Time**	**Sample 1**	**Sample 2**	**Sample 3**
1.	11:30	64	82	96
2.	12:00	67	82	100
3.	12:30	68	84	100
4.	13:00	73	85	102
5.	13:30	75	87	104
6.	14:00	76	88	108
7.	14:30	79	91	111
8.	15:00	82	91	111
9.	15:30	83	95	111
10.	16:00	83	95	111
11.	16:30	83	95	111
12.	17:00	84	95	120
13.	17:30	84	95	123
Charge paassed		1668.6	1937.7	2337.3
	Average	1981.2 Coulombs		

TABLE 18 RAPID CHLORIDE PENETRATION TEST VALUES FOR MPCE

Sl.No	Time	Sample 1	Sample 2	Sample 3
1.	11:30	59	57	76
2.	12:00	59	63	80
3.	12:30	59	68	83
4.	13:00	59	72	84
5.	13:30	59	75	87
6.	14:00	59	75	88
7.	14:30	60	76	91
8.	15:00	60	76	91
9.	15:30	60	79	92
10.	16:00	60	79	92
11.	16:30	60	79	92
12.	17:00	62	80	93
13.	17:30	63	82	96
Charge passed		1292.4	1604.7	1906.2
Average		1601.1 Coulombs		

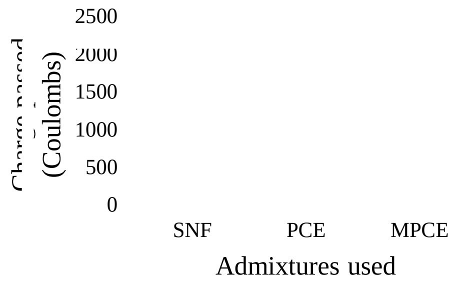

Fig. 9. Rapid Chloride Penetration Test (RCPT) values for different superplasticizers

Lesser the charge passed across the concrete sample, more is the resistivity offered by the concrete mix. Likewise, when more charge is passed across the concrete sample then the concrete mix offers less resistance to chloride ion ingress. From the test results shown above, it is evident that SNF has better resistance to chloride ion ingress compared to the other two SCC mixtures.

IV. CONCLUSION

The characteristic behaviour of concrete was studied using different superplasticizers Sulphonated Naphthalene Formaldehyde (SNF), Polycarboxylate Ether (PCE) and Modified Polycarboxylate Ether (MPCE), respectively were studied. And this chapter will compile all the studies done in the previous chapters together. The Table 19 shows the comparison in the properties of fresh concrete after mixing the concrete with different superplasticizers. From this comparative study we have found that SNF does not pass some tests like V – funnel test, V – funnel at $T_{5\ minutes}$ test and U – box test, which are essential for confirming the fresh concrete to be a SCC. And that concrete when mixed with this admixture the fresh concrete performs considerably less when compared to the other two admixtures used. However, the cost of SNF is lesser than the other two admixtures (about Rs60 per litre). The cost comes up to be Rs5216 for mixing one metre cube of concrete using SNF. More over the retention in workability of SNF changes drastically over time.

PCE when mixed with concrete gives good results. It passes every test listed to be classified as a SCC. However, the cost of PCE is highest among all the three chemical admixtures (About Rs180 per litre). The cost comes up to be Rs5846 for mixing one metre cube of concrete using PCE. The retention in workability of concrete mixed with PCE does not vary much with time, giving a better workability of concrete for a longer time.

MPCE when mixed with concrete gives good results compared to PCE. It passes every test listed for satisfying to be classified as a SCC. However, the cost of MPCE is lower than PCE and higher than a SNF (About Rs140 per litre). The cost comes up to be Rs5416 for mixing one metre cube of concrete using MPCE. The workability versus time graph for concrete mixed with MPCE is near to constant, hence giving a better workability for a longer time.

Hence, MPCE is a better superplasticizer than the three selected superplasticizers, considering characteristic behaviour of fresh and hardened concrete and economy point of view.

TABLE 19 COMPARISON OF THE TEST RESULTS CONDUCTED ON THE SELF-COMPACTING CONCRETE MIXTURE USING THREE DIFFERENT SUPERPLASTICIZERS

Sl.No	Properties	SNF	PCE	MPCE
1.	Slump flow test	560mm	650mm	800mm
2.	Slump flow at $T_{500\ mm}$	4.5sec	3.8sec	3.2sec
3.	V- funnel test	52sec	13.7sec	14sec
4.	V- funnel at $T_{5\ minutes}$	90sec	16sec	18sec
5.	L – box test	0.82	0.95	0.93
6.	U – box test	50mm	28mm	25mm
7.	Compressive strength on 3rd day	28.2MPa	31.8MPa	37.9MPa
8.	Compressive strength on 7th day	36.2MPa	38.1MPa	43MPa
9.	Compressive strength on 28th day	53.5MPa	55.7MPa	59.2MPa
10.	RCPT	1337.7 C	1981.2 C	1601.1 C
11.	Dosage used	1.4%	1.0%	0.8%
12.	Cost per m^3 concrete	Rs 5216	Rs 5846	Rs 5416

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