High Performance, Cost Effective and Sustainable Concretes with Blended Cements and PC Admixtures

G.A.B. SURESH, AGM-R&D

Ramco Research and Development Centre, (RRDC), A Division of The Ramco Cements Limited Chennai-India

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Abstract - *Chemical and Mineral admixtures have become common ingredients of concrete for develop high performance concrete. Chemical admixtures are materials in the form of powder or fluids that are added to the concrete to improve the rheological, strength and durability properties. Sulphonated Naphthalene Formaldehyde(SNF) and Mid & High range PolyCarboxylate (PC) based admixtures are generally been using in Ready Mix Concrete units and Infra Projects. In this paper mainly focused on performance of SNF and different range PC admixtures in Blended Cement Concretes. The dormant period and peak temperatures of OPC at different percentage of PC admixture and Fly Ash determined by using Temperature scanner. In this paper also discusses the role and mechanism of chemical admixtures in concrete. Appropriate admixtures had selected for concrete trials based on Kantro miniature Slump cone test results. By using PC based admixtures in blended Cement concretes can develop high performance, cost effective and sustainable concretes*.

Key words – Super-Plasticizers, Repulsion, Steric Hindrance, Miniature Slump Cone, Flow, Slump

I. INTRODUCTION

In the construction industry, the common using admixtures are accelerators, retarders, plasticizers, super-plasticizers, air-entraining, water proofing, corrosion inhibitors etc. The chemical admixtures classification as per ASTM, BIS and BS are given in Table-1

1.1 The Super-plasticizers are Classified as under Material Formulations (1):

- Modified & Refined ***Lignosulphonates*** :- Derived from neutralization, precipitation, and fermentation processes of the waste liquor obtained during production of paper-making pulp from wood
- Sulphonated ***Naphthalene*** formaldehyde (SNF) condensates (1960-Japan):- Produced from Naphthalene by oleum or SO_3 sulphonation; subsequent reaction with formaldehyde leads to polymerization and the sulphonic acid is neutralized with sodium hydroxide or lime
- Sulphonated ***Melamine*** formaldehyde (SMF) condensates (1970-Germany):- Manufactured by normal resinification of Melamine formaldehyde
- ***Polycarboxylate*** (PC):- Free radical mechanism using peroxide initiators is used for polymerization process in these systems

Gambhir M L (2010)[2] describes that the sulphonated Melamine formaldehyde condensates tend to reduce air entrainment , resulting in a mix which may be more prone to bleeding and segregation. The sulphonated Naphthalene formaldehyde condensates gives greater level of set retardation and air entrainment, thus significantly improves the workability. The increase in the level of air entrainment is too low to affect the cohesiveness of the mix, so a high sand content is desirable with the high workability mixes to prevent bleeding and segregation. The lignosulphonates give the greatest workability retention but conversely, they give the most set retardation and, therefore, generally give the lowest 1-day strength. The polycarboxylates are used to produce concrete with very high workability and low slump loss. However, they are not preferred to use in Concrete because of the greater cost.

1.2 Major Factors, which Contribute to the Incompatibility of Chemical Admixtures in the Concrete:

1. Generic type of the admixture
2. Admixture specifications and its properties
3. Quality of the admixtures and consistency of its quality from batch to batch
4. Incompatibility of one admixture with another if more than one in use at a time
5. Dosage of admixtures and its sensitivity in overdosing and mode & time of dosing
6. Failure to modify the dosage of admixture if the site conditions demand due to changes in the ambient conditions of temperature, %RH, Wind velocity etc.
7. Contamination through water or aggregates
8. Physical and Chemical Properties of cements or Cementitious materials
9. Water to cement ratio
10. Type and characteristics of aggregate and its grading
11. Concrete mix design w.r.t. ingredient contents

12. Ambient temperature
13. Incomplete or non-uniform mixing
14. Lack of adequate curing of concrete
15. Change of source materials
16. Inadequate wetting of the concrete mix ingredients prior to admixture addition

2. MECHANISM OF ACTION OF SUPER-PLASTICIZERS

Super-plasticizers improve workability and reduce water requirement in concrete mixes by mainly two methods, (1) Electrostatic Repulsion and (2) Steric Hindrance. The mechanism of action of superplasticizers on cement particles is shown in Fig.1. First method is the formation of repulsive electrostatic forces on cement particles, which will move away from each other and disperse in the aqueous medium. The grinding of cement results in the ground particles having a surface charge (zeta potential). The adsorption of the admixture leads to a decrease of the zeta potential, and eventually causes like charges (negative) on the cement particles. The second is the formation of admixture molecules on solid particles, which create a steric hindrance causing spatial distance between particles and hence decreases probability to their adhesion in the aqueous medium. These two actions prevent the agglomeration of particles and create a dispersing effect which facilitates the availability of more surface area for cement particle interaction. Naphthalene, Melamine and modified lignosulphonates are known to cause effect by electrostatic repulsion whereas the PC based admixtures by steric or spatial hindrance.

Steric hindrance is a more effective mechanism than electrostatic repulsion. The side chains, primarily of polyethylene oxide extending on the surface of cement particles, migrate in water and the cement particles are dispersed by the steric hindrance of the side chains. Electrostatic repulsion depends on the composition of the solution phase and the adsorbed amount of the superplasticizer (greater the adsorption, better the repulsion). On the other hand, steric repulsion depends on the length of main chain, length and number of side chains. In the case of PC based admixtures, initial slump is based on main molecule length and slump retention is based on number of side molecules and its length. Because of the steric repulsion mechanism, PC admixtures are generally more effective than the sulphonate based admixtures, and generally do not experience much problems at low water to cement ratios.

Prof. P.K. Metha stated that a retarding admixture impedes the dissolutions of the cement cations (calcium ions) and anions (Aluminate ions) . Aluminate anions has higher dissolve rate than the Silicate anions. In the presence of monovalent cations (K^+ or Na^+) reduces the solubility of Ca^{2+} ions and promotes the solubility of silicate and aluminate ions. In small concentrations, the former effect is dominant; in large concentrations, the latter effect becomes dominant. In the presence of monovalent anions (Cl^-, NO_3^- or SO_4^{2-}) reduces the solubility of Silica and Aluminate ions and promotes the solubility of calcium ions. In small concentrations, the former effect is dominant; in large concentrations, the latter effect becomes dominant.

3. TROUBLE-FREE AND COST-EFFECTIVE CONCRETE WITH PC ADMIXTURES

Technical Literatures are saying that Polycarboxylate (PC) based admixtures are the most effective and suitable for all type cements, all grade concretes and in all climate conditions. PC admixtures can work at lower dosages, low water cement ratio than Naphthalene, Melamine and Lignosulphonate admixtures. PC admixtures can reduce water content in concrete as much as 40%. Thus, they are highly preferred to make high and ultra-high strength concrete, where the w/c may be as low as 0.20. Generally, these admixtures exhibit excellent slump retention characteristics and do not cause any delay in the gain of strength of the concrete.

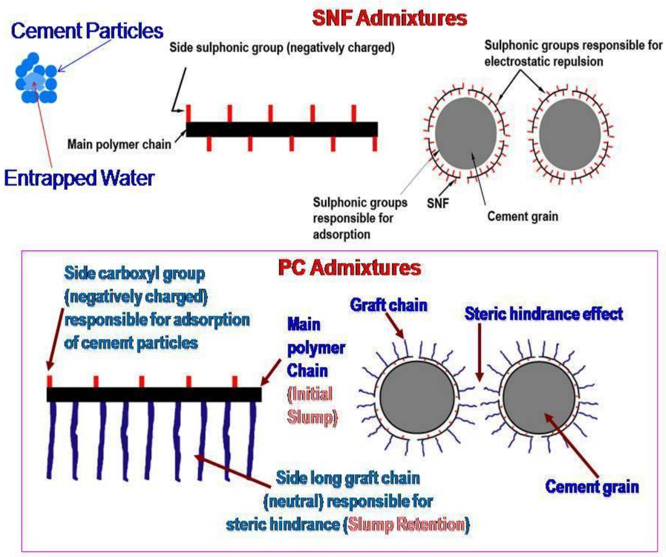

Fig.1 Mechanism of action of super-plasticizers on cement particles

The downside of PC admixtures is their high cost. Since PC works even at low water content, for same grade, concrete can be re-designed up to 5% cement content reduction with slightly increase admixture dosage, thus concrete will attain better workability & strengths and high durability, lower shrinkage, creep and heat of hydration without affect the overall cost of the concrete.

The Schematic diagram of the effect of super-plasticizers on fresh and hardened concrete is shown in Fig.2. From the diagram it is observed that out of five options, II-option i.e. reduced total water and cement content with optimum dosage of super plasticizer is the best option for better rheological, strength and durability properties of the concrete.

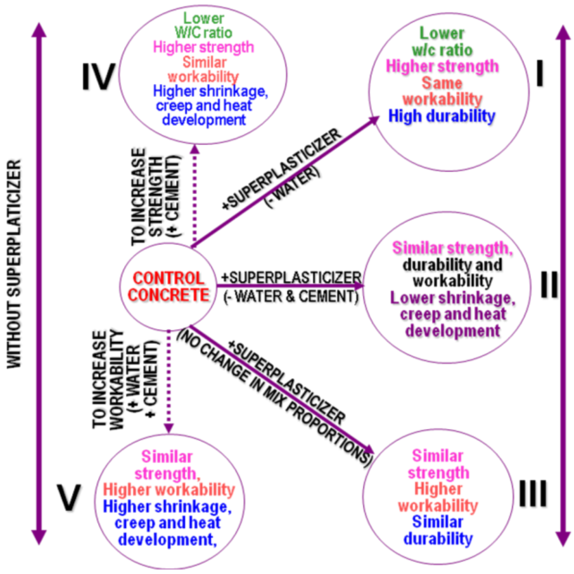

Fig. 2 The effect of super-plasticizers on fresh and hardened concrete(3)

4. EXPERIMETS

4.1 Temperature Gradient with Chemical and Mineral Admixtures

The temperature Scanner study has conducted at Ramco R&D Centre by using OPC 53G cement and Chemical & Mineral Admixtures. The temperature Gradient in OPC cement pastes with Chemical Admixture (PC admixture) and Mineral Admixture (Class F Fly Ash) shown in the Fig 3 . It observed that Dormant Period (workability period), IST and FST increases with increase dosage of PC based admixture and peak temperature more or less same at different dosage of PC admixture. And also observed that Peak Temperature of OPC cement paste decreases with increase percentage of Fly Ash and Dormant Period, IST & FST more or less same.

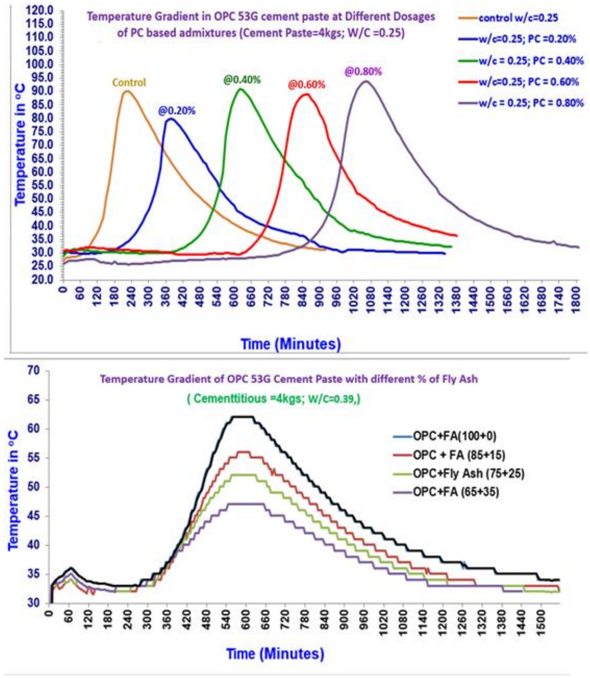

Fig. 3 Temperature Gradient in OPC at different dosage of PC admixture and at % Fly Ash

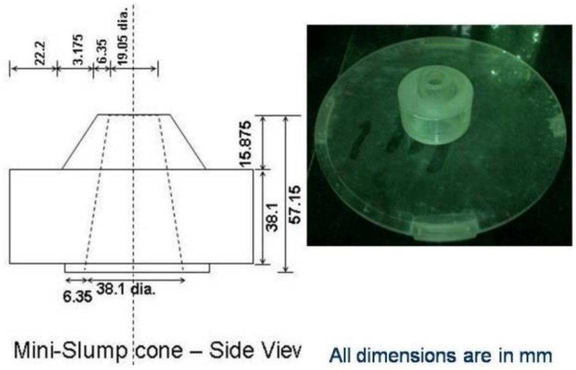

Fig.4 Preliminary Evaluation of Admixtures Compatibility study with Miniature Slump Test (4).

4.2 Admixture Compatibility study (a) Miniature Slump Cone Test and (b) M45 Grade Concrete Trials

The materials' physical properties are shown in Table 2 & 3. To understand the behavior of different types of admixtures with Ramco PPC cement collected Naphthalene, Mid-Range PC and High Range PC admixtures each three numbers which generally uses in the Infra Projects and Ready Mix Concrete Units. To understand the flow properties between Ramco PPC cement and admixtures, initial the Kantro miniature slump studies have carried out by using Ramco PPC cement and different types of admixtures and the test results of the same are given in Table 4. The Kantro

Miniature Slump Cone test shown in Fig. 4. Based on the miniature slump tests' flow and cement paste compressive strength test results, M45 Grade Concrete trials have conducted with identified suitable and most effective admixtures. The test results of the same are given in Table 5 and Table 6.

5. CONCLUSIONS

- ★ M45 Grade Concrete with Ramco PPC has attained 28 days compressive strength about 125 percent when compared to Concrete Grade Target Strength i.e. 53.3 MPa.
- ★ Based on the Miniature flow and strength test results, High Range PC-3, Mid Range PC-1, and Naphthalene SNF-1 admixtures performed better than other similar type of admixtures. But concrete with High Range PC-3 or Mid Range PC-1 admixture shows better performance than concrete with Naphthalene SNF-1 admixture
- ★ Based on M45 grade concrete trials test results, it is observed that the concrete with 0.45% dosage of High Range PC-3 admixture has attained good slump and strength when compared to 0.80% dosage of Mid Range PC-1 admixture mixed concrete and 1.20% dosage of Naphthalene SNF-1 admixture mixed concrete.
- ★ *High Strength, High Slump Retention and High Durability attained by using Ramco OPC 53G cement with Fly Ash and PC based admixtures.*
- ★ Based on the above experimental data and available literature, it is concluded that after compatibility study, better to use PC based admixtures to exhibit fewer compatibility problems when compared to Naphthalene, Melamine and Lignosulphonate admixtures. With effective and efficient optimum mix designs, makes the concrete more cost effective and durable.
- ★ Chemical admixtures alone cannot solve all the strength and durability requirements and it is the complementary understanding between supplementary cementing materials and chemical admixtures that can strike the deal.
- ★ The chemical admixtures are gaining momentum in the context of various new developments such as multi-component cementitious systems, high volume fly ash concrete, Self-Compacting Concrete etc. The heightened awareness for durability of concrete also contributes for the enhanced demand for chemical admixtures.
- ★ ***The need for sustainable development in construction industry demands the use of high volumes of Blended Cements / supplementary cementing materials such as fly ash and slag which need to go with PC based Super- plasticizers.***

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Author

G.A.B. Suresh has completed Master of Technology in Civil Engineering from Indian Institute of Technology, Madras (IITM), INDIA in 1997. He is currently serving as AGM-R&D (Concrete Technologist) in Ramco Research and Development Centre (RRDC), A Division of The Ramco Cements Limited, Chennai, Tamil Nadu, INDIA.

Table 1: Chemical Admixtures Comparative Chart based on ASTM , BIS and BS standards

ASTM C 494:	BIS 9103:	BS 5075 Part-1
• **Type A :** Water reducing • **Type B :** Retarding • **Type C:** Accelerating • **Type D :** Water reducing and retarding • **Type E:** Water reducing and accelerating • **Type F:** water reducing high range • **Type G:** Water reducing high range and retarding **ASTM C 260 :** Air- Entraining	• Accelerators • Retarders • Plasticizers (WR) • Superplasticizers (HRWR) • Air-Entraining	• Accelerating • Retarding • Normal water reducing • Accelerating water reducing • Retarding water reducing **BS 5075 Part – 2** • Air-Entraining **BS 5075 Part – 3** Superplasticizing and retarding

Table 2. Physical Properties of Materials

Description	Crushed Rock Fines	River Sand	12mm Aggregate	20mm Aggregate
Specific Gravity (SSD)	2.67	2.60	2.79	2.72
Water Absorption (%)	1.78	0.97	0.51	0.47
Aggregate Impact value (%)	-	-	22.5	21.7
Bulk Density (Loose) (kg/m^3)	1585	1623	1388	1416
Bulk Density (Compacted) (kg/m^3)	1812	1739	1565	1578
Flakiness Index (%)	-	-	27.3	14.69
Elongation Index (%)	-	-	36.2	23.4

Specific Gravity: OPC 53G =3.14; Ramco PPC = 2.86 ; Fly Ash = 2.26

Table 3. Fine and Coarse Aggregate Sieve Analysis

Coarse Aggregate			Fine Aggregate (Percentage Passing)		
Sieve Size (mm)	Percentage Passing		Sieve Size (mm)	River Sand	Crushed Rock Fines
	12.5mm	20mm			
20	100	92.59	10	100	100
16	100	52.01	4.75	93.11	99.3
12.5	96.88	9.24	2.36	82.69	95.1
10	61.56	0.79	1.18	62.73	68.9
6.3	3.74	0.15	0.6	30.84	50.3
4.75	-	-	0.3	5.31	34.1
- 4.75	-	-	0.15	1.04	13.0

Table 4. Ramco PPC Cement Paste Flow Studies with different types of admixtures by Miniature Slump Test

Admixture Details			w/c	Admixture Dosage (%)	Cement Paste Flow (cm)		Cement Paste Compressive Strength (MPa)	
Admixture	Solid Content (%)	pH			1½ hr.	2.0 hr.	1-Day	3- Days
High Range PC Admixtures (HRPC)								
HRPC - 1	38.82	6.74	0.36	0.60	13.7	13.4	2.8	31.4
HRPC - 2	26.14	7.51	0.36	0.60	4.7	-	5.7	32.9
HRPC - 3	**38.24**	**6.36**	**0.36**	**0.60**	**14.4**	**14.4**	**10.5**	**43.4**

Mid Range PC Admixtures (MRPC)								
MRPC - 1	**26.74**	**6.96**	**0.36**	**0.80**	**14.5**	**14.2**	**2.3**	**42.8**
MRPC - 2	31.32	6.39	0.36	0.80	14.9	14.5	23.7 (2D) 1-D (Wet)	37.1
MRPC - 3	24.75	6.30	0.36	0.80	13.8	12.7	32.4 (2D) 1-D (Wet)	47.3
Naphthalene Admixtures (SNF)								
SNF-1	**36.91**	**8.42**	**0.36**	**1.20**	**10.8**	**10.6**	**23.4 (2D) 1-D (Wet)**	**38.6**
SNF-2	44.68	8.37	0.36	1.20	14.1	14.1	20.1 (2D) 1-D (Wet)	31.3
SNF-3	42.25	8.90	0.36	1.20	10.2	8.0	Upto 2 days wet	20.9

Table 5 M45 Grade Concrete Trials' Mix Proportions and test results with RAMCO PPC and Suitable Admixtures

MIX NO	**Batch weight in SSD condition per cu.m of concrete (kgs)**						**Admixture details**	**Slump (mm)**		**Compressive Strength (MPa)**			
	RAMCO PPC	**River Sand**	**Coarse Aggregate**		**Water (w/c)**	**Admixture (%)**				**1 Day**	**3 Days**	**7 Days**	**28 Days**
			12 - mm	**20 - mm**				**1½ hr.**	**2.0 hr.**				
1	450	783	419	613	162 (0.36)	5.40 (1.20)	Naphthalene (SNF-2)	85	-	10.6	32.0	42.2	**55.9**
2	450	783	419	613	162 (0.36)	5.40 (1.20)	Naphthalene (SNF-1)	140	84	13.6	31.1	43.9	**57.5**
3	450	783	419	613	162 (0.36)	3.60 (0.80)	Mid Range PC (MRPC-1)	195	72	18.7	36.4	39.0	61.2
4.	435	796	426	623	157 (0.36)	4.13 (0.95)		190	155	18.4	38.2	46.4	64.7
5	**450**	783	419	613	**162 (0.36)**	2.03 (0.45)	High Range PC (HRPC-3)	205	**205**	20.2	33.0	48.6	**64.7**
6	**435**	796	426	623	**157 (0.36)**	2.39 (0.55)		205	**185**	21.3	37.0	49.1	**62.1**
7	**425**	810	434	634	**149 (0.35)**	2.76 (0.65)		-	**220**	26.4	46.9	50.1	**69.5**

Table 6. M45 Grade Concretes' Workability, Strength and Durability Properties with Ramco OPC 53G and with different types of Mineral & Chemical Admixtures

Mix Description	Batch weight in SSD condition per cu.m of concrete (kgs)								Admixture Details	Slump after 3.0 hours	Compressive Strength (MPa)				RCPT 28 Days (Coulombs)
	RAMCO OPC 53G	Fly Ash	River Sand	CRF	12 - mm	20 - mm	Water (w/cm)	Admixture (%)			1 Day	3 Days	7 Days	28 Days	
M45 (1)	360	100 (Source-A)	483	261	479	637	156 (0.34)	4.14 (0.90)	HRPC-1	230	28.0	39.2	47.2	54.9	**879**
M45 (2)	360	100 (Source-A)	483	261	479	637	156 (0.34)	4.14 (0.90)	HRPC-3	225	34.9	45.0	50.2	**70.4**	**831**

M45 (3)	360	100 (Source-B)	483	261	479	637	156 (0.34)	4.14 (0.90)	HRPC-1	220	16.4	24.2	33.8	49.4	**486**
M45 (4)	360	100 (Source-B)	483	261	479	637	156 (0.34)	4.14 (0.90)	HRPC-3	240	34.2	48.2	52.2	**71.4**	**477**