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Experimental Study on Portland Pozzolana Cement-Superplasticiser Compatibility in Mortar

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Abstract: Chemical admixtures like Superplasticisers (SPs) have become a necessary component of high performance concrete in the present era. The selection of an appropriate type of admixture at an optimum dosage is very important. Most users apply a trial-and-error approach with these chemicals. This often results in an adverse experience and low cost-effectiveness, many times producing a bias against admixtures in general. The compatibility between the cement and admixture, which is influenced by the characteristics of cement paste and mortar, their type and dosage of admixtures, needs to be understood. The objective of this study is to understand the effect of SPs on the flowability of Portland Pozzolana cement mortar, with the aim of optimising the dosage through simple test methods. In order to evaluate the influence of SPs and cement characteristics, studies were conducted with different families of SPs and commercially available Portland Pozzolana Cement (PPC) on the aspects of fluidity and loss of fluidity. In construction industry, PPC is preferred to Ordinary Portland Cement (OPC) since it is more eco-friendly and durable. The standard mortar workability tests like marsh cone, flow table have been used to evaluate the flow behaviour of cement mortar. Based on the test results combined with the cost evaluation, compatible combinations of cement and SPs are recommended.

Keywords: *Superplasticizers, Portland pozzolana cement, Compatibility, Optimum dosage, workability, Loss of fluidity*

1. Introduction

The use of admixtures has become common practice in the production of concrete. Concrete without admixture is rare in current infrastructure projects. Admixtures are used to impart some beneficial influence onto concrete whether it is to be in its fresh or hardened state [1]. These admixtures are synthetic high molecular weight water soluble polymers and solubility is mainly achieved by the presence of adequate hydroxyl, sulphonate or carboxylate groups attached to the main organic unit which is usually anionic [2][3]. The admixture interacts with the various constituents of cements and influences the hydration reaction in different ways namely, retardation in initial cement hydration, alterations in the structure and composition of the C–S–H gel and reduction in the porosity [4]. There is a need for the characterization of Indian cement and admixture properties, so as to understand the nature of their interactions. Most of the investigations on cement-superplasticizer interactions in India have been limited to the evaluation of concretes workability as well as loss in slump with time.

There have been studies to understand the physico-chemical nature of this interaction [5][6], normally done on cement paste or cement mortars. These studies conducted on the cement-superplasticizer compatibility mainly focuses on OPC. Similar studies with respect to PPC are limited in number [6] in India. The wide range of cements and plasticizers utilized as well as the varying field conditions necessitate a study to explains the interaction.

In the present investigation, PPC was used and experimental procedure for evaluating the flow behaviour of the cement with different types of superplasticizers at different dosage was studied. Such a study is significant because over the last decade there has been increase in the production and consumption of PPC. PPC is preferred to Ordinary Portland Cement since it is economical, has reduced heat of hydration and higher long term strength and also reduction in the emission of CO_2 which is the main cause of global warming.

2. Objectives of the Study

Most users apply a trial-and-error approach to the dosage of SPs. This often results in an adverse experience and low cost-effectiveness. Hence the study of the cement- SP interaction was planned with the materials available in Indian market. Four brands of PPC are taken namely C1, C2, C3 and C4. Four families of SPs are chosen namely Polycarboxylate Ether (PCE), Lignosulphate (LS), Sulfonated Naphthalene Formaldehyde (SNF) and Sulfonated Melamine Formaldehyde (SMF). Two different brands of SPs are taken from each family. Workability study was done with Flow Table and Marsh Cone test by varying the superplasticizer/cement ratio (SP/C). The study was done on 1:1.5 ratio mortars, at a water-cement ratio of 0.40.

3. Experimental Details

A. Tests on Cement

Physical properties of the cement tested according to the IS 4031 [13] specifications are listed in Table1.

Table 1. *Physical properties of the Cement*

Tests	C1	C2	C3	C4
Fineness (%)	4.37	5.33	10	6
Specific gravity	2.80	2.80	2.72	2.81
Consistency (%)	35	35	34	42
Initial Setting Time (min)	150	110	142	75
Final Setting Time (min)	200	185	194	155
Compressive Strength (MPa)	33.52	30.50	29.40	28.49

B.Tests on fine aggregate

Properties of the fine aggregate tested according to the IS 2386 [15] is tabulated in the Table 2. The properties are in compliance with the specifications of IS 383 [14].

Table 2. *Properties of fine aggregates*

Tests	Results
Fineness Modulus (%)	2.87
Grading Zone	2
Specific Gravity	2.52
Bulk Density(kg/m^3)	1678
Percentage Voids (%)	42.91
Maximum Percentage of Bulking (%)	19.047
Corresponding Moisture Content (%)	2
Water Absorption (%)	1.7

C. Test on Superplasticisers

Solid content of SPs was determined according to IS 9103 Annex E (2004) [16]. The density of SPs obtained from the data sheet provided by the corresponding supplier is also tabulated along with the solid content in Table 3. Recommended dosage of SP specified by the manufacturer (L/100 kg) after convertion as SP/C ratio is also included in the table. These values are utilized in Section 6 to check the Cement-Superplasticizer compatibility.

Table 3. *Properties of the Superplasticisers*

Designation	Density (kg/L)	Solid Content (%)	Recommended dosage (SP/C)	Cost per L of SP (Rs)
PCE-1	1.09	35.56	0.44-1	100
PCE-2	1.09	34.93	0.55-1.1	262
SNF-1	1.2	40.55	0.6-2.4	150
SNF-2	1.24	40.09	0.37-1.24	35
SMF-1	1.15	13.83	0.5-1	75
SMF-2	1.2	35.69	0.2-1.5	55
LS-1	1.18	33.50	0.18-0.3	150
LS-2	1.19	35.03	0.18-0.3	150

4. Workability Study

In this study, Flow Table and Marsh Cone tests were used to study the flow behaviour of cement mortar. The mixing sequence for the test was done as per the observations and analysis of various mixing methods [7].

A. Flow Table Test

Flow Table test was used to find the fluidity of the mortar (by finding the spread diameter) and the saturation SP dosage in the cement mortar.

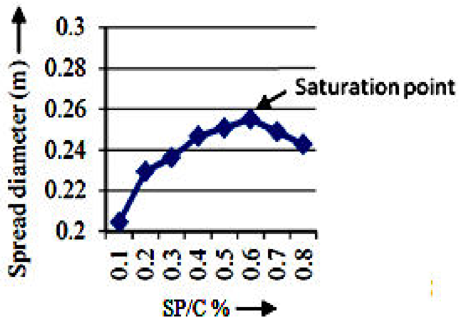

Fig 1. *Flow curve of Superplasticised mortar*

In this study, a Flow Table of diameter 350 mm with a conical mould of 70 mm internal diameter on the top end, 100 mm internal diameter on lower end and 50 mm height was used. The oiled mould was placed on the table and filled with mortar. After vertically withdrawing the mould, the flow table with mortar was jolted 25 times, and the spread diameter measured in four directions and average is noted. The test gives the fluidity of mortar in terms of the spread diameter.

The saturation point is the dosage beyond which further addition of SP does not increase spread diameter but result in segregation.

B. Marsh Cone Test

The Marsh Cone test is also used to evaluate the fluidity and the saturation SP dosage in the cement mortar. In this study, a metal cone (as per European standards EN 445, ASTM C 939) with a bottom nozzle of diameter 13 mm was employed. An initial volume of 1000 ml of mortar was poured into the cone and the time (in seconds) required for 500 ml of mortar to flow down through the nozzle (collected in a beaker) was observed. In all cases, there is increase in fluidity with increase in the dosage of SP up to certain dosage, which is taken as the saturation dosage [3]. The test gives the fluidity of mortar in terms of the flow time; higher the flow time, lower is the fluidity of the mortar. In this method, the super plasticizer dosage corresponding to an internal angle of $140^0 \pm 10^0$ is taken as the saturation dosage (Fig.2). This criterion has been proposed on the basis of a study [8], of about 200 tests on superplasticised cement pastes.

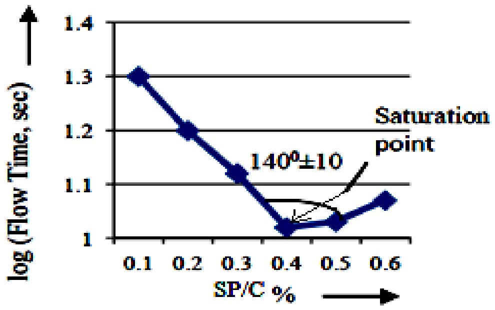

Fig 2. Marsh cone flow time curve for superplasticised cement mortar

Results

The results of workability test performed immediately after mixing (0 minute) are graphically represented (Fig.3 to Fig.5). For brevity only typical sample results are shown. The saturation dosage of all cement - super plasticizer combinations are given in Table 4.

A general agreement is found in saturation dosages calculated using flow table data and the flow time curve of marsh cone test. Similar observation has been reported in an earlier study [9].

Flow Table

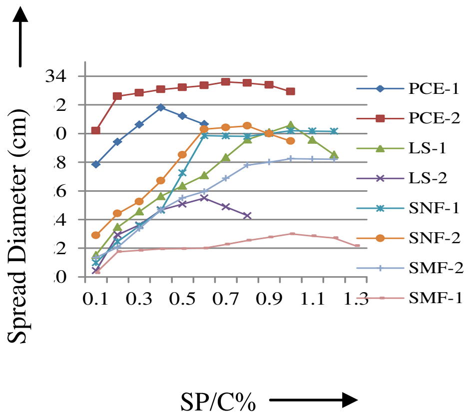

Fig 3. Spread Diameter for C1 with different SP at 0 min

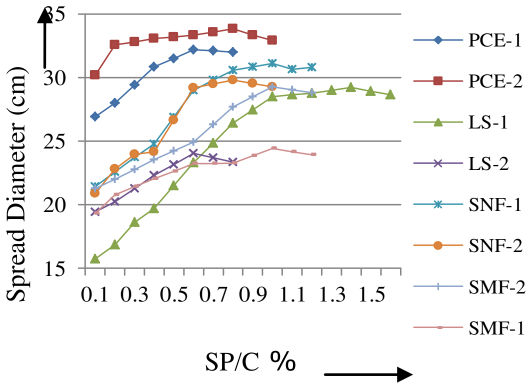

Fig 4.Spread Diameter for C2 with different SP at 0 min

B.**Marsh Cone**

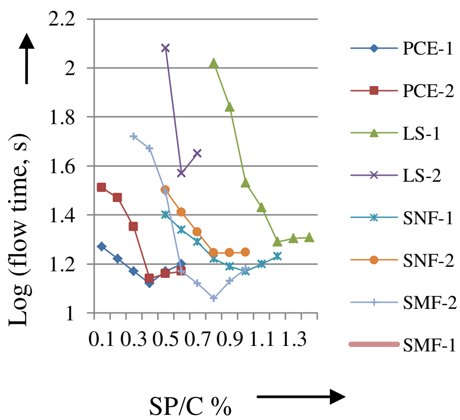

Fig 5. Flow Time for C3 with different SP at 0 min

From figures 3-5 it is found that, the performance of the PCE based superplasticizer are better than other families of SPs. This is mainly due to the steric hindrance between the cement particles in addition to electrostatic repulsive force [12]. It is observed that not only SPs of different basic groups behave differently, but even the SPs within the same basic group also behave differently. This is attributed to the difference in their synthesis, which influences upon their molecular weight and chemical configuration [10].

5. Loss of Fluidity

To evaluate the change in flow behavior of mortar with time, marsh cone flow time and flow table spread were measured after 30 and 60 minutes of mixing, typical results of which are indicated from Fig.6 to Fig.9. The loss of fluidity with time is measured through (i) the reduction in spread diameter in the flow table test and (ii) by increase in flow time in marsh cone test.

A. Flow Table

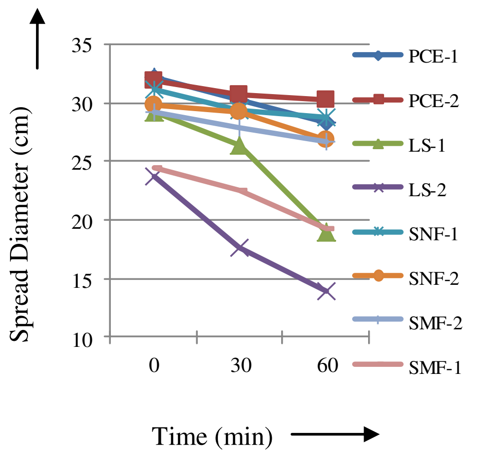

***Fig 6**. Loss of Fluidity for C2 of Flow Table*

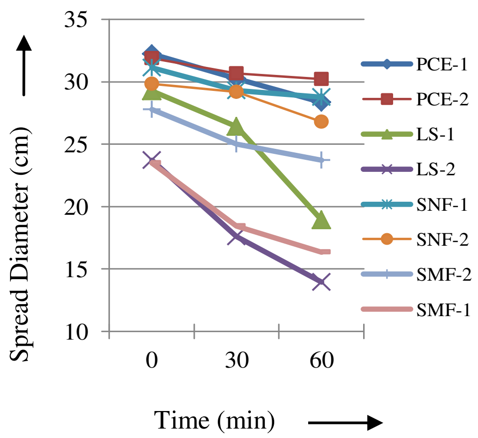

***Fig 7**. Loss of Fluidity for C4 of Flow Table*

B. Marsh Cone

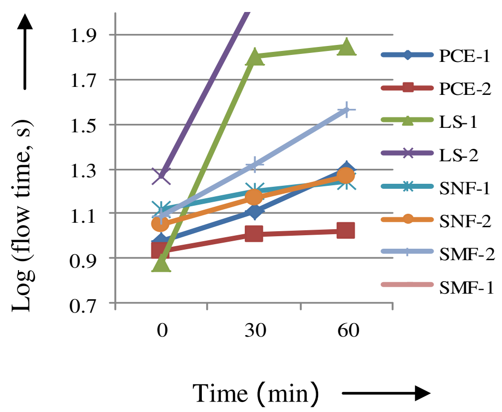

***Fig 8**. Loss of Fluidity for C1 of Marsh Cone*

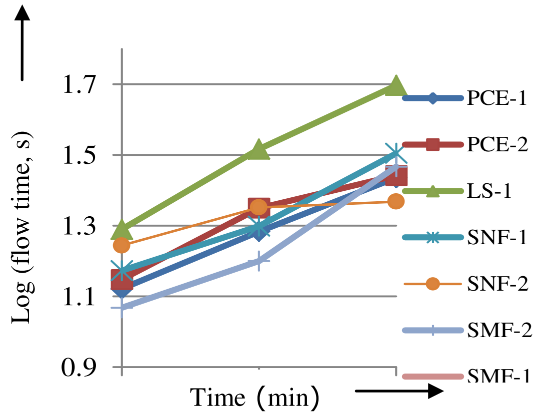

***Fig 9**. Loss of Fluidity for C3 of Marsh Cone*

From the above graphs (Fig 6 to Fig 9), it is observed that the flow table spread decreases and marsh cone flow time increases as time elapses for all the SPs. It can also be observed that PCE based SPs are good in retaining the fluidity. In contrast to this, in LS based SPs the loss of fluidity is more. In the case of LS based SPs, low dosages are not sufficient to initiate flow after 30 minutes.

6. Identifying Compatible Cement – SP Combinations

The methodology for the selection of an appropriate cement-SP combination involves two steps.

Step1: Determining the saturation dosage of super plasticizer at zero and 30 minutes through flow table and marsh cone test.

Step 2: If there are well defined saturation dosages at zero and 30 minutes, check is done to verify whether these dosages are falling within the recommended dosages given by the manufacturer (indicated in table 3). If all the saturation dosage values fall within the recommended dosage, the mix is considered as compatible. Based on such comparison, the compatible cement-superplastciser combinations have been identified and are listed in table 5.

***Table 4.** Saturation dosage of Superplasticiser at 0 minute and 30 minute*

		Zero minute		**30 minute**	
Cement	**SP**	**Flow Table**	**Marsh Cone**	**Flow Table**	**Marsh Cone**
C1	PCE 1	0.4	0.4	0.4	0.5
	PCE 2	0.7	0.7	**0.6**	0.6
	LS 1	1	0.6	1	0.8
	LS 2	0.6	0.6	0.6	NF
	SNF 1	1	0.6	1	0.6
	SNF 2	0.6	0.6	0.6	0.6
	SMF 1	1	NF	0.2	NF
	SMF 2	1	1	1	1

		Zero minute		30 minute	
Cement	SP	Flow Table	Marsh Cone	Flow Table	Marsh Cone
C2	PCE 1	0.6	0.6	0.5	0.4
	PCE 2	0.4	0.4	0.4	0.4
	LS 1	1	1	1.4	NF
	LS 2	0.6	ND	0.4	NF
	SNF 1	0.8	0.8	0.8	0.8
	SNF 2	0.6	0.6	0.8	0.8
	SMF 1	1	NF	1	NF
	SMF 2	1	1	0.8	0.8
C3	PCE 1	0.4	0.4	0.4	0.4
	PCE 2	0.4	0.4	0.5	0.4
	LS 1	1.2	1.2	1.2	1.3
	LS 2	0.6	ND	0.6	NF
	SNF 1	0.8	0.8	1	0.9
	SNF 2	0.8	0.8	0.8	0.8
	SMF 1	1	NF	0.9	NF
	SMF 2	0.8	0.6	0.8	0.7
C4	PCE 1	0.4	0.4	0.4	0.4
	PCE 2	1	1	0.8	1
	LS 1	0.8	0.8	0.8	NF
	LS 2	0.6	ND	0.6	NF
	SNF 1	0.8	1	0.8	1
	SNF 2	0.6	0.6	0.8	0.8
	SMF 1	1.2	NF	1.1	NF
	SMF 2	1	1	1	1

**ND Not Defined *NF No Flow*

Table 5. *Compatible Cement –SP Combinations*

Cement	Compatible SP
C1	PCE2
	SNF1
	SNF2
	SMF2
C2	SNF1
	SNF2
	SMF2
C3	SNF1
	SNF2
	SMF2
C4	PCE2
	SNF1
	SNF2
	SMF2

7. Relative Cost Estimation

Cost of superplasticizer at the saturation dosage for the compatible cement –superplasticizer combinations were calculated. Cost estimate has been made on the basis of the market cost of the different plasticizers as listed earlier in table 3. These estimates are based on the saturation dosage obtained through marsh cone test only. Relative cost of compatible combinations is given in table 6.

Table 6. *Cost analysis of compatible Cement –SP combinations*

Mix coimbination	Relative cost
C1 – PCE2	10
C1 – SNF1	4.4
C1 – SNF2	1
C1 – SMF2	2.70
C2 – SNF1	5.90
C2 – SNF2	1
C2 – SMF2	2.70
C3 – SNF1	5.90
C3 – SNF2	1.33
C3 – SMF2	1.6
C4 – PCE2	12.76
C4 – SNF1	6.64
C4 – SNF2	1
C4 – SMF2	2.70

8. Conclusions

The following conclusions can be made on the flow behavior of superplasticised cement mortar and are applicable for the range of parameters investigated.

- The flow time determined from Marsh cone test is a good indication of relative fluidity of superplasticised mortar and can also be used for selection of SP. With flow curves it is possible to determine precisely the influence of SP dosage on fluidity of cement mortar.
- Maximum spread observed at the optimum dosage of SP and hence called saturation point of SP dosage. After the saturation point, the increase of SP dosage doesn't show any improvement of the workability of mortar rather it decreased the spread and increased the flow time. Even adding more SP causes segregation of the mortar.
- Similarities can be found when comparing flow table data with the flow time curve of marsh cone test. With both the test methods, the superior properties with regard to flow and flow retention were observed for PCE based SPs at relatively

low dosage levels even then many PCE SP combinations are classified as incompatible because, the saturation dosage of these are lesser than the recommended dosages of manufactures.

- Interactions of different families of SPs on the tested brands of PPC, is clearly exhibited through variations observed in mortar fluidity.
- Out of 32 cement - superplasticiser combinations investigated, only14 combinations are satisfying the proposed compatibility criteria. The results reveal that not only SPs of different basic groups behave differently, but even the SP within the same basic group also behaves differently.
- Superplasticiser belonging to lignosulphate family is not compatible with any of the cement.

9. Acknowledgments

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