

Influence of GGBS on Rheology of Cement Paste and Concrete with SNF and PCE based Superplasticizers

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Abstract

Limestone and clay which are the major ingredients of the cement production are non-renewable resources. Therefore, it is essential to identify a sustainable material to replace cement. The by-product from the steel plant is subsequently granulated to desired fineness and is termed as Ground Granulated Blast furnace Slag (GGBS). Superplasticizers (SP) are used to improve the workability of concrete at low water-cement ratios and increase the compressive strength by reducing it. But, this workability is sometimes lost rapidly as time progresses after contact between the cement and water. Therefore, it is necessary to understand the mechanisms that influence the cement-super plasticizer interaction for selecting an appropriate type of admixture at an optimum dosage. In this present research the compatibility study, between six combinations of cement using different percentages of GGBS with two different SPs were investigated. The optimum dosage was found using marsh cone test. The cement mortar flow test was conducted to find out the setting time and compressive strength of the mortar. It is found that the increase in addition of GGBS decreases the dosage of Superplasticizers to achieve the desired workability. The target mean strength of the M40 concrete was achieved with replacement of 50% GGBS using PCE based SP.

Keywords: GGBS, Saturation Dosage of SPs, Slump Retention

1. Introduction

Concrete has been recognized as the most essential building material for sustainable infrastructure development in India. Concrete and construction technology has made lot of advances and has introduced lot of innovations in bringing out new materials, new concrete construction equipments for transportation, placement, compaction and finishing. For meeting the requirements of present day construction projects various special concretes have been introduced like high strength and high-performance concrete. Strength, durability, economy and workability are the characteristics required for the new generation concretes. These high strength and high performance concretes are achieved mainly by reducing the water cement ratio.

This reduction in water cement ratio will have a direct impact in the workability and compaction of concrete. The desired workability of concrete at very low water cement ratio is achieved by using SP. SPs are mainly used to produce concretes with the following characteristics. The

concrete construction community is increasingly facing compatibility issues mainly due to the increasing transportation distance of concrete from the batching plants and time delay in transportation due to traffic congestion etc. The concrete at site often gets rejected, if not accepted by compromising the quality.

There is a distinct need for the characterization of Indian cement and admixture properties, in order to understand the nature of their interactions. Moreover, the wide range of cements used, varying transportation durations and climatic conditions necessitate a fundamental study that explains the mechanisms of interaction and helps establish methods for identifying incompatibility in practical situations. Today concrete has gone beyond the stage of a mere four component system and can be the combination of far more number of ingredients such as mineral admixtures (fly ash, Ground Granulated Blast furnace Slag, silica fume, rice husk ash, metakaoline) and chemical admixtures (SP). When concrete contains mineral admixtures, the following issue arises: Does the SP

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main action of dispersion and deflocculation act only on cement particles or does it also affect mineral admixture particles. To understand this, an experiment with various percentage of addition of mineral admixture (GGBS) up to the permissible limit given in IS 455:1989 with different types of SP needs to be studied. In this study, Marsh cone test will be performed in various pastes made with different SP dosages for a given water cement ratio. OPC cement with two varying fineness, cement with various percentages of replacement by GGBS will be studied for the fresh and hardened properties of concrete using two types of SP Sulphonated Naphthalene Formaldehyde (SNF) and Polycarboxylate Ether (PCE).

The interaction of SP with different cement types, its effects on the flow loss and the chemistry of the pore solution at early time of hydration from mixing to presetting were studied. The study revealed that most of the SP is removed from the pore solution immediately after mixing. The adsorption capacity of the paste is mainly determined by the molecular weight, cement fineness and type of cement¹.

It is confirmed that the SP adsorption depends both on the amount of C_3A and the presence of soluble alkali sulphates in the cement. The study reveals that the incorporation of fly ash in concrete reduces the need of SP necessary to obtain a similar slump flow compared with the concrete containing only cement as binder. On the other hand, it is observed a total loss of fluidity when Portland cement was replaced by blended cement, where SP dosage had to be increased from 0.5% to 1.5% to maintain the same workability². It is also found³ that the fluidity of the cement paste decreases with the introduction of the fillers, this reduction is proportional to their replacement level and type of fillers used.

Researchers⁴⁻⁷ described the method for determining the saturation dosage of SP using Marsh cone test. The fluidity of the mortar was studied using Marsh cone and flow table spread. An attempt was made to correlate the flow and setting behavior of cement paste with the slump and setting of concrete. The saturation dosage obtained for paste and mortars were comparable. However slightly higher dosage may be required in concrete for adequate workability due to SP adsorption by the fines present in the aggregate. The test on the paste can be used as a guide in selecting SP for concrete. Factors affecting compatibility between cement and SP as follows:

- Tricalcium Aluminate.
- Calcium Sulphates.

- Alkalies.
- Fineness of Cement.
- Dosage of Superplasticizer.

The objectives of this study is to assess the optimum dosage of SP for different types of cement such as OPC and PSC with 30% to 70% addition of GGBS with different types of SP (SNF and PCE), to identify the slump retention at different time intervals for these cement - SP combinations and compressive strength of concrete at optimum SP dosage and finally, to study and arrive ideal combination of cement and SP.

2. Materials

The cement type used for this study is OPC and PSC which constitutes 99% of the cement manufactured in India. The incorporation of Ground Granulated Blast furnace Slag (GGBS) can make the compatibility relation between cementitious material and SP more complex. Therefore, it becomes a very essential consideration for selection of the compatible interacting couple. Hence, due importance has been given to select that compatible cement- SP combination with SNF and PCE based SP.

2.1 Cement and GGBS

Cement is a binder, a substance that sets and hardens and can bind other materials together. The physical properties of ordinary Portland cement (OPC 53) are mentioned in Table 1 and the chemical Properties of Cement and GGBS with fineness of 360.2 m²/kg is given in Table 2.

2.2 Super Plasticizers

In this study, the following two types of SPs are used say Sulphonated Naphthalene Formaldehyde (SNF) and

Table 1. Physical properties of cement

Cement Sample		OPC 53
IST (min)		280
FST (min)		345
Fineness (m ² /Kg)		254
Compressive Strength in "Mpa"	3days	44.9
	7days	66.5
	28days	76.8
Standard Consistency (%)		24.5

Table 2. Chemical properties of cement and GGBS

Sample	OPC 53G	GGBS
LOI (%)	1.47	0.32
IR (%)	0.46	0.69
SO ₃ (%)	3.12	1.47
MgO (%)	1.1	1.72
SiO ₂ (%)	20.58	39.7
Al ₂ O ₃ (%)	5	13.59
Fe ₂ O ₃ (%)	3.82	1.36
CaO (%)	62.17	38.3

Table 3. Properties of Superplasticizer

Type of Superplasticizer	PCE	SNF
Relative Density at 25°C	1.08	1.233
pH Value	7.2	8.48
Dry Material Content (%)	33.72	43.81
Chloride Ion Content (%)	0.0079	0.0071

Polycarboxylate Ether (PCE). The properties of SPs are tested as per IS codal⁸ provisions are reported in Table 3.

3. Experimental Test Results

Marsh cone test is being conducted for all combinations of cements at various dosages to find the optimum dosage with SNF and PCE based SP with water-cement ratio of 0.35. Initial Setting Time (IST) and Final Setting Time (FST) of cement paste were tested with optimum dosage of SP and without SP at 27°C ± 2°. Concrete slump test at various time intervals and compressive strength were determined using optimum dosage of SNF and PCE based SP to arrive the ideal combination of cement and SP.

3.1 Marsh Cone Test

The Marsh funnel is a simple device for measuring viscosity⁹ from the time it takes a known volume of liquid to flow from the base of a cone through a short tube. It consists of a 152 mm across and 305 mm in height to the apex of which is fixed a tube of 8 mm internal diameter and of length 60 mm. A mesh is fixed near the top across half the cone. In use, it is held vertically and end of the orifice is closed with a finger. Measure the 1000 ml volume of cement paste prepared as per ASTM¹⁰ procedure and poured through the mesh. (This removes any particles which might block

the orifice). To take the measurement, once the finger is released as a stop clock is started and the paste is allowed to run into a measuring container and the time taken to discharge 500 ml of paste measured in seconds and recorded. The flow time measured enables to evaluate the fluidity of the cement grout; the longer the flow time will be, the more the grout is viscous and the shorter the flow time, the more the grout is fluid. All the factors other than the dosage of SP were kept as constant and the rate of change of flow time defines the optimum dosage, the logarithm of flow time allows the use of criterion that depends only on the intrinsic characteristics of the paste. The objective method proposed by Gomes et al. was used for calculating the optimum dosage that the internal angle corresponding to each data point is calculated and the SP dosage corresponding to an internal angle of 140° ± 10° is determined as optimum dosage. Interpolation is used in determining the same when no data points are in the range of angles.

3.2 Types of Cement Selected for the Study

The cement chosen are two types is to be mixed with GGBS, seven variation of mixes are used which includes two from OPC 53G only with variation of fineness. The Portland Slag Cement (PSC) is obtained by mixing of various percentages of GGBS which satisfies the IS code¹¹ provisions and cement. The details of GGBS replaced with various percentages along with cement grinded to obtain the fineness of around 320 m²/kg. The details of cement (OPC 53G) and the mixture of PSC with its fineness along with designation are given in Table 4.

3.2.1 Chemical Composition of Cement Mixture

The chemical compositions of the selected cements were tested¹² and the parameters are reported in Table 5. Increasing the percentage of GGBS in the cement mixture is reducing calcium oxide and thereby it may help in reducing the optimum dosage required to achieve the desired workability in concrete.

Table 4. Types of cement mixture used for study

Code	C1	C2	C3	C4	C5	C6	C7
Type of Cement	OPC 53	OPC 53	PSC	PSC	PSC	PSC	PSC
Fineness (m ² /kg)	254	320	320	321	326	323	321
GGBS (%)	NA	NA	30	40	50	60	70

Table 5. Chemical composition of cement mixture

Properties	C1	C2	C3	C4	C5	C6	C7
CaO (%)	62.2	62.1	54.3	51.5	51.1	50.6	50.2
LOI (%)	1.47	0.91	0.55	0.63	0.66	0.67	0.69
IR (%)	0.46	0.66	0.43	0.44	0.45	0.45	0.48
SO ₃ (%)	3.12	2.94	2.2	2.52	2.6	2.61	2.65
MgO (%)	1.1	1.07	1.57	1.56	1.55	1.55	1.54
SiO ₂ (%)	20.6	21.2	26.8	27.9	28.4	28.9	29.3
Al ₂ O ₃ (%)	5	5.07	8.31	9.16	9.28	9.36	9.41
Fe ₂ O ₃ (%)	3.82	4.22	3.05	2.95	2.9	2.88	2.81

Table 6. Physical properties of cement mixture

Sample Code	C1	C2	C3	C4	C5	C6	C7
NC (%)	24.5	26.5	29.5	29.0	28.0	27.5	27.5
IST (min)	280	140	225	310	325	340	350
FST (min)	345	215	315	354	370	385	390
Fineness (m ² /Kg)	254	320	320	321	326	323	321
Compressive Strength in "Mpa"							
3days	44.9	45.6	30.8	26	23.6	22.7	19.8
7days	66.5	71.9	51.0	40	35.1	31.7	26.5
28days	76.8	81.4	76.2	66	61.3	58.6	54.9

3.2.2 Physical Properties of Cement Mixture

The physical properties of the selected cements of OPC and PSC were tested¹³ and the parameters are given in Table 6. It is observed that the physical property of OPC with increased fineness and addition of mineral admixtures (such as GGBS) are playing a vital role in increasing water demand (increasing the standard consistency).

3.3 Mix Proportioning

M40 grade concrete mix proportioning¹⁴ for the study arrived based on the properties^{15,16} of ingredients with the water-cement ratio¹⁷ of 0.35 using optimum dosage of PCE and SNF based SP. The cement content had been replaced with different cement mixture prepared for the study.

4. Results and Discussions

We selected the replacement of ordinary Portland cement with various percentage of addition of GGBS and determined the optimum dosage SNF and PCE based SPs. Also studied, the performance of concrete slump and retention up to 3 hrs

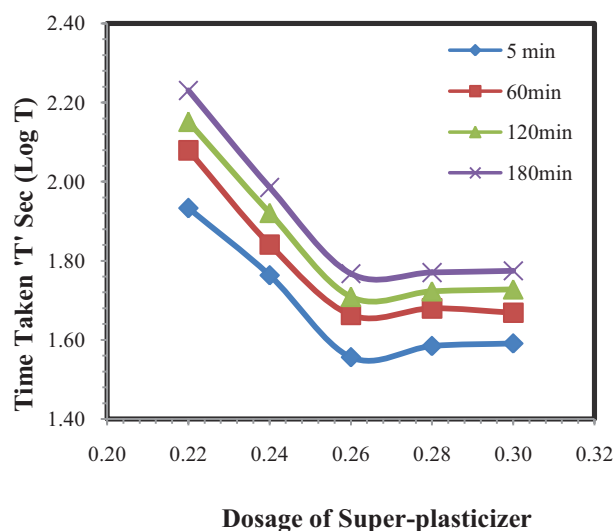
at optimum dosage, which was found through Marsh cone test and all dosages are expressed by considering dry polymer percentage on cement mass. In this study, the trials were conducted using different combinations of cement mixture as mentioned in Table 4 along with SNF/PCE based SPs at various dosages to determine the optimum dosage and slump retention at various intervals at initial, 60 mins, 120 mins, 180 mins and also observed slump and slump retention of concrete with optimum dosage of SP at the same intervals.

4.1 Optimum Dosage of PCE based Superplasticizer

The marsh cone test conducted using various combinations of cement with PCE based SP to determine the optimum dosage of each combination of cement by graphical representation of dosage of SP with logarithmic time taken to discharge the cement paste as mentioned in Table 7 and showed in Figure 1.

Table 7. Effect of dosage of PCE Superplasticizer

Dosage of SP (%)	Marsh cone value T in sec (Time taken to travel 500 ml)			
	5 min	60 min	120min	180 min
0.22	1.93	2.08	2.15	2.23
0.24	1.76	1.84	1.92	1.99
0.26	1.56	1.66	1.71	1.77
0.28	1.58	1.68	1.72	1.77
0.3	1.59	1.67	1.73	1.77

**Figure 1.** Marsh cone flow curve for PCE SP.

The optimum dosage vs. cement combination has been plot and the minimum PCE based SP dosage required to achieve better slump retention is possible with replacing the OPC by 70% GGBS at same fineness. Hence, increasing the addition of GGBS will improve one of the important behaviour of fresh concrete i.e., slump and slump retention at lesser dosage of PCE based SP.

4.2 Optimum Dosage of SNF based Superplasticizer

The marsh cone test conducted using various combinations of cement with PCE based SP, to determine the optimum dosage of each combination of cement by graphical representation of dosage of SP with logarithmic time taken to discharge the cement paste as given in Table 8.

The graphical representation of dosage of SP vs. logarithm time taken to discharge the desired cement paste with SNF based SP plot to in Figure 2.

It shows that the minimum SNF SP dosage required to achieve better slump retention is possible with replac-

ing the cement by 70% GGBS at same fineness. Hence, increasing the addition of GGBS will improve one of the important behaviour of fresh concrete i.e. slump and slump retention.

4.3 Comparison of Test Results between PCE and SNF SP with various Cement Combinations

Optimum dosage of all cement combinations with PCE and SNF based SP, setting time of the cement paste, without SP and with PCE/SNF based SP for all combinations of cement paste at optimum dosage (as per IS 4031:1988 Part 5), slump test at various time intervals (as per IS 1199:1959) and compressive strength of concrete (as per IS 516:1959) test were performed and compared in Table 9.

An addition of PCE based SP is increasing the Initial Setting Time (IST) and Final Setting Time (FST) of the

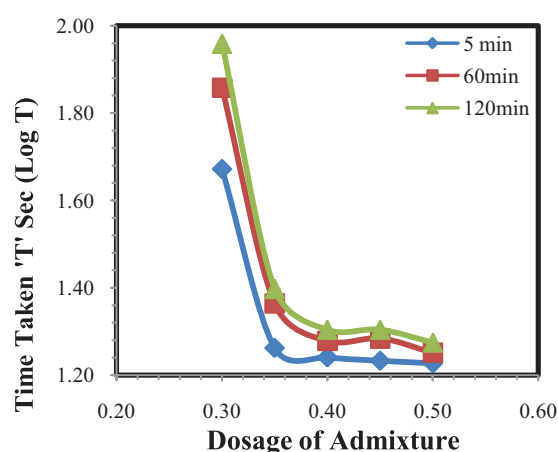


Figure 2. Marsh cone flow curve for SNF SP.

Table 8. Effect of dosage of SNF Superplasticizer

Dosage of SP (%)	Marsh cone value T in sec (Time taken to travel 500 ml)		
	5 min	60min	120min
0.3	1.67	1.86	1.96
0.35	1.26	1.36	1.4
0.4	1.24	1.28	1.3
0.45	1.23	1.28	1.3
0.5	1.23	1.25	1.28

Table 9. Comparison of test results between PCE and SNF based SP with various combinations of cement

Sample Code	Without SP		PCE based SP						SNF based SP					
	IST (min)	FST (min)	Optimum Dosage (%)	IST (min)	FST (min)	Compressive Strength (MPa)		Slump Retention (hrs)	Optimum Dosage (%)	IST (min)	FST (min)	Compressive Strength (MPa)		Slump Retention (hrs)
						7 days	28 days					7 days	28 days	
C1	280	345	0.18	560	670	46.85	62.6	3	0.35	425	530	44.03	61.71	1.5
C2	140	215	0.27	385	615	50.74	66.8	3	0.50	290	425	47.65	64.15	1.5
C3	225	315	0.24	745	995	47.03	62.15	3	0.50	610	820	45.2	60.61	1.5
C4	310	354	0.22	820	980	41.6	57.73	3	0.48	665	910	37.4	55.9	1.5
C5	325	370	0.18	890	1065	35.8	53.8	3	0.48	730	945	31.1	42.75	1.5
C6	340	385	0.17	955	1120	31.3	41.1	3	0.43	810	1025	28.07	39.4	2
C7	350	390	0.16	1215	1305	27.5	35.8	3	0.40	895	1110	22.1	28.7	2

cement paste at optimum dosage from 100–235%. Similarly, an addition of SNF based SP is increasing the Initial Setting Time (IST) and Final Setting Time (FST) of the cement paste at optimum dosage from 50–185%. It shows that the influence of SP in the rheology of cement paste, hence the slump retention performance is satisfactory.

Concrete trial mixes were conducted using various combinations of cement with PCE and SNF based SP at optimum dosage to observe the slump and retention performance. It has been noticed that there is no significant changes observed in slump and slump retention using PCE based SP 100 mm slump can be maintained at 3 hours and with SNF based SP can be maintained upto one and half hours.

The compressive strength of hardened concrete is determined using 150 mm cube specimen for various cement combinations with optimum dosage of PCE and SNF based SP. It is observed that the target compressive strength of 48 Mpa can be achieved with the addition of 50% addition of GGBS using PCE based SP at optimum dosage. Similarly, the compressive strength of concrete with addition of GGBS from 50% to 70% using SNF based SP is not satisfactorily.

5. Conclusions

- From the experimental study it was observed that an increase in 30% fineness of OPC results in an increase in the optimum dosage of PCE and SNF based SP by 50 and 43%, respectively. Therefore, it is concluded that the increase in fineness of cement can lead to increased SP consumption, provided the other factors remains constant.
- It was found that an increase in GGBS content from 30 to 70% resulted in a decrease in the optimum dosage of PCE based SP by 40%. This reduction was 20% for SNF based SP. Therefore, it is concluded that GGBS can be used to reduce the dosage of SP for the desired workability requirement of concrete.
- Increasing the dosage SNF and PCE based SP with various percentage of addition of GGBS increasing the setting time of cement paste with by 100 to 250%.
- For M40 grade concrete, cement replaced with GGBS dosage of 60% to 70% and 50% to 70% failed to achieve the target compressive strength of 48 Mpa at optimum dosage of PCE and SNF based SP's respectively.
- M40 grade concrete made with SNF based SP retains a slump 100 mm up to one and a half hours when compared to three hours retention by PCE based SP.

6. Acknowledgement

The authors wish to acknowledge the Ultratech Cement Ltd. for the greatest support extended in providing clinker, gypsum and laboratory facilities. Also wish to acknowledge JSW and BASF construction chemicals for giving the product information and supplying of GGBS and SPs for the entire study.

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