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Behaviour of Normal Concrete Using Superplasticizer under Different Curing Regimes

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Abstract

The performance of concrete primarily depends upon the type and ratio of its constituents, compaction, curing conditions and admixtures used during curing process. Part of this research emphasis to calculate the consequences on strength of concrete when water-cement ratio is constant and the increase in slump occurs with the increase in amount of superplasticizer by percentage. The rest of the investigation is carried out to study the effects of superplasticizer with different dosages under different curing regimes at an ambient field temperature ranges between 45°C-50°C. For this purpose, a concrete mix at 20MPa with all parameters constant was prepared by using an ASTM C494 type A, and F, anionic melamine polycondensate non-toxic superplasticizer with no chlorides. Different dosages of superplasticizer were used in different batches of all 95 specimens, and cured under different curing conditions and then tested for compressive and tensile strengths following ASTM standards. In all cases, the water curing up to 28 days testing showed maximum strength. The highest and lowest values of compressive strength were obtained with the addition of 0.5% and 1% superplasticizer respectively. It was found that without increasing the W/C ratio, the addition of superplasticizer exhibits increase in strength.

Key Words: *Curing, superplasticizer, workability, slump increase, strength.*

1. Introduction

1.1 General

In modern days, the need of optimum and rapid construction has given rise to the use of chemical admixtures. Among these admixtures, particularly, superplasticizer has a great market nowadays as workability is one of the major issues of a freshly prepared concrete, which can be enhanced by superplasticizer. These superplasticizers, on one hand, lower the water-cement ratio and on the other hand, they improve the workability of concrete. Advanced concrete technology, therefore, requires the detailed study of effects of superplasticizer upon the workability of concrete. The workability can be enhanced by using exact required amount of superplasticizer. Usually, manufacturers indicate the effects of such admixture; however, their action and performance should be checked before use.

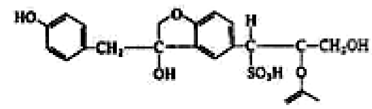
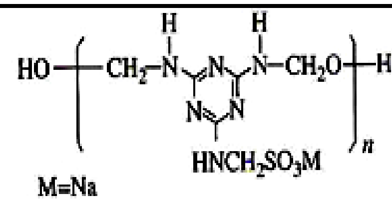
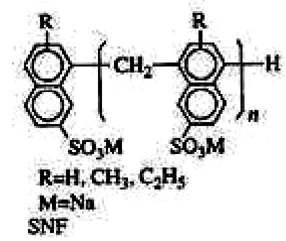
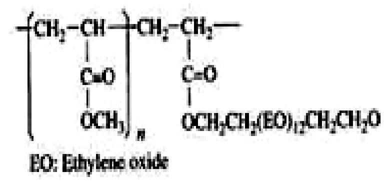
When concrete is fresh, it is desirable to be malleable or workable. But sometimes, due to scorching conditions at site, desirable workability cannot be maintained. Then superplasticizer enhances the workability to sufficient extent by lowering the shear and flow resistance [1]. Even in the case of self-consolidating concrete, superlasticizer greatly enhances the workability of fresh and hardened concrete [2, 3].

Normally, the chemicals used for reducing water quantity are liquids and possess less than 0.5% of cement weight. In these chemicals, solid's contribution ranges from 30% to 40% of total volume. In low range water reducers, high retardation and bleeding may occur but, comparatively, high range water reducing chemicals can be added from 0.7%-2.5% of cement weight [4]. The subjects of interest for this study, superplasticizers, are generally chemicals of the type presented in Table 1 [5].

Superplasticizers are usually classified according to following polymer groups [6]:

- Sulfonated melamine-formaldehyde condensates (SMF)

Table 1 Superplasticizers Classification [5]

Class	Origin	Structure(typical repeat unit)	Relative cost
Lignosulphonates	Derived from neutralization, precipitation, and fermentation processes of the waste liquor obtained during production of paper-making pulp from wood		1
Sulphonated melamine formaldehyde (SMF)	Manufactured by normal resinification of melamine – formaldehyde		4
Sulphonated naphthalene formaldehyde (SNF)	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		2
Polycarboxylic ether (PCE)	Free radical mechanism using peroxide initiators is used for polymerization process in these systems		4

- Sulfonated naphthalene-formaldehyde condensates (SNF)
- Modified lignosulfonates (MLS)
- Polycarboxylate derivatives

It is to be noted that workability increase per increase in superplasticizer dosages is not specified yet, and the effect of increase in dosage of superplasticizers on the strength of concrete is also variable. Therefore, this preliminary study has been undertaken to pave the way to understand the effect of increasing or decreasing the dosages of Super-plasticizer under different curing conditions on the compressive and tensile strength of OPC concrete.

The history of superplasticizers considered to be initiated in Japan and Germany 1960s. Kenichi Hattori of Japan introduced the first superplasticizer in 1964 which was constituted of beta-naphthalene sulfonates. The second superplasticizer, Melment was contained of sulphonated melamine formaldehyde condensate and introduced in Germany in the same year [7]. After a decade, the use of superplasticizers was reached to the American continent in 1970 [6].

Tattersall [8] defined the pros and cons of various tests used to determine concrete strength and workability. He pointed out the major drawbacks in these tests. He also determined that how much slump increases with the percentile increase in superplasticizer keeping water-cement ratio constant and its effect on the strength of concrete.

Guennewig [9] opened the doors of a new research and proved successfully that these materials can be used cost effectively for construction applications such as hot-weather concreting, crane, wall placements, bucked placements, slabs on grade, and pumped concrete. Hanna et al. [10] developed a special apparatus, Rheo pump, in order to study the interaction between either a given superplasticizer with different portland cements or the interaction of different superplasticizers on a given portland cement. Masahiro [11] discussed the effect of superplasticizer on the balance between flow ability and viscosity of mortar in self-compacting concrete. Flatt and Houst [12] produced three different categories to check the chemical effects that can perturb the performance of superplasticizer. They found that at equal dosage of all the three categories, larger cement quantity covered relatively small surface area. Hence, produced poor workability untill superplaster was added. Ravina and Mor [13] studied the sulfonated melamine formaldehyde condensate effect on concrete. They studied the influence of variation in dosage quantity and number of superplasticizer addition. They also emphasized on settlement duration of superplasticizer. They recommended high dosages after an experiment in which lower dosage did not produce any significant effect. They also recommended late mixing and double dosage of superplasticizer. Hsu et al. [14] also studied the effects of different time interval of naphthalene-based superplastizer addition. They concluded that increase in addition time, gradually decreased the saturation of SNF and caused gradual decline in workability of concrete. Khatib and Mangat [15] concluded that the superplasticizers reduce the percentage of openings. These chemicals increase the efficiency of the openings, keeping the size of hole remain same. In recent researches about the superplasticizers, Ramachandran [16] presented a book about the properties and applications of superplasticizers in concrete, mainly focusing on the advantages of superplasticizers. He put forwarded a theory that these chemicals substantially scatter the particles of cement. In his support, he referred to an inspection of cement particles which revealed that after the mixing of water and cement, massive clusters are formed. Superplasticizers break these clusters into tiny particles.

A worthy of note research was performed by Erdogdu [17]. He tried to find out an on-site solution to restore concrete its initial slump. He used water and superplasticizer to retemper concrete and compared the results. The concrete retempered with a superplasticizer yielded significantly higher strength regardless of the mixing duration.

Researches investigating the relationship between cement and superplasticizers are also present in literature. Yamada [18] discussed the errors in analytic methods used for the investigation of interaction mechanism between cement and superplasticizer and provided some chemical equations to overcome the errors appear during applying superplasticizer to cement. Colak [19] investigated the effect of latex concentration on the workability and strength characteristics of Portland cement pastes with and without superplasticizer and produced some analytical methods as a result. The influence of polycondensate and polycarboxylate superplasticizers on the adhesion strength between aged and fresh concrete was investigated by Reese et al. [20]. They measured the imbibition of pore solution released from fresh concrete into aged concrete bars and SEM imaging of minerals formed in the cement transition zone. Polycarboxylate superplasticizer exhibited better performance.

1.2 Effect of temperature on concrete

It is a universal fact that with the rise of curing temperature, the chemical action of hydration accelerates. During placing and setting of concrete under high temperature the strength of concrete increases rapidly at early age, however, after 7 days under high temperature, the strength of concrete starts decreasing. This is due to weak production of rapid early hydration. Such products become porous which remains empty. Also products of rapid hydration may not be uniformly distributed in hardened concrete. Such local weak parts in hardened concrete reduce bond strength of cement paste.

Price [21] studied the hardening of concrete under high temperature have also revealed that during few early days, strength increases rapidly. However, after 1 to 4 weeks the high temperature had adverse effects on strength of concrete. Klieger [22] verified that there is an optimum temperature under which higher strength of concrete is obtained. Optimum temperature to obtain high strength using ordinary Portland cement and modified Portland cement is 18° C. However, for rapid hardening cement, the optimum temperature to get maximum strength is 4° C. A significant study was performed by Shoukry et al. [23]. They investigated the varying temperature and moisture effect on mechanical properties of concrete. The results indicated that concrete strength and modulus of elasticity are inversely related to temperature and moisture content. Modulus of elasticity was found proportional to concrete compressive strength in both temperature and moisture testing. Mirza et al. [24] compared the influence of varied temperature effect on compressive strength of mortars and concrete made up of OPC and blended cements. The later showed good strength at high temperatures.

There is a difference in laboratory and field conditions, so hot weather has different effects on strength of hardened concrete. During hot weather, other factors effecting strength are humidity, sun rays radiation, velocity of air and curing methods. The concrete quality depends on its own temperature more than the surrounding temperature.

2. Research Methodology

2.1 Mixture Detail

In this research, an ASTM C494 type A, and F, anionic melamine polycondensate, non-toxic superplasticizer, with no chlorides having unit specific gravity was used. This chemical assures minor slump losses and increases the workability of concrete, both with low and high dosage. It is best suitable for concreting at high temperatures where maximum workability is required.

A total sum of 95 specimens of standard size are prepared & tested. Out of 95 specimens, there were 60 cubes and 35 cylinders. The concrete of Grade 20 with constant W/C ratio was designed by adopting British method of concrete mix design, which also known as DOE method, & was kept constant throughout the study. Whole of these specimens were divided into five batches namely B-1, B-2, B-3, B-4 and B-5. The dosage of superplasticizer is the variable parameter in all batches, starting from 0% to 2%, and tested for slump. Each batch is divided into 4 different curing conditions. The de-molding time was 20 to 24 hours. And, hence, the performance of concrete using superplasticizer is observed under different curing conditions at an average field temperature ranges between 45°C-50°C. In this research average daily temperature was considered as 50°C which is the ambient temperature of the area where this research had been performed.

Table 2 shows the mix proportion details of concrete mix according to DoE method.

Table 2 Mix design details

Design Parameters	**Design Proportions**
Characteristic compressive strength	20 Mpa (3000 psi)
OPC-42.5	-
Slump	10-30 mm
Target Mean strength	36 Mpa
Designed w/c	0.48
Cement content	395 kg/m^3
Total Agg: content	2065 kg/m^3
Fine Agg: content	557.50 kg/m^3
Coarse Agg: content	1507.50 kg/m^3
Design Ratio	1:1.42:3.84

2.2 Variable Parameters

Following are the variable parameters in this study.

2.2.1 Dosage of Superplasticizer

The specimens are divided into five batches according to the dosage of superplasticizer. Table 3 shows the details of the batches of specimens cast and tested.

2.2.2 Curing Condition

Four curing conditions were selected. Each batch was adopted to cure in all the four conditions.

The details of the curing conditions are as follows:

C_1 = 28 days immersed in water.

C_2 = 14 days immersed in water and 14 days in atmosphere (Ambient temperature i.e., 45^0C - 50^0C).

C_3 = 3 days immersed in water and 25 days in atmosphere (Ambient temperature).

C_4 = 28 days in atmosphere with daily curing (sprinkling).

Hence the above batches have been divided into four different curing conditions.

2.3 Constant Parameters

Type and quantity of cement, type and quantity of aggregates, W/C ratio and design strength have been kept constant throughout the study.

1. Concrete mix: The characteristic strength of concrete being used in the residential buildings in the surroundings of location/area of research, and also specified by several design codes [25-27], was chosen for this research. The characteristic strength at 28 days= 20 MPa.
2. Type of cement: Ordinary Portland Cement
3. Type and size of aggregate: Crushed and of maximum size = 20mm
4. W/C ratio: Constant (0.48 determined from mix design)

2.4 Parameters of Study

In this study we have two principal parameters of study:

1) Compressive strength of concrete cubes.
2) Splitting tensile strength of concrete cylinders.

2.5 Size of Specimens

The cubes of 100mm x100mm x 100mm were used to measure compressive strength and the cylinders of standard size (200mm x 100mm) were cast and tested to determine their tensile strength. ASTM C-31 method was followed for the preparation of the specimens and compaction was done manually by rodding in three layers having 25 blows per layer.

3. Results and Discussion

Table 4 shows the slump values for all the batches of concrete tested for workability. The workability of concrete enhanced with addition of superplasticizer with constant W/C ratio. However, the rate of increase diminishes with its addition beyond 1% of superplasticizer dosage. This factor may also be investigated in future, to determine optimum dosage of superplasticizer if W/C ratio is maintained at constant value.

Table 3 Classification of dosages of superplasticizers into different batches

Sr. No.	Batch	Description
1	B-1	0 litres of Superplasticizer per 100 kg of cement.
2.	B-2	0.5 litres of Superplasticizer per 100 kg of cement.
3.	B-3	1.0 litres of Superplasticizer per 100 kg of cement.
4.	B-4	1.5 litres of Superplasticizer per 100 kg of cement.
5.	B-5	2.0 litres of Superplasticizer per 100 kg of cement.

3.1 Test for Compressive Strength

In all cases at 28 days, the water curing up to testing is showing maximum strength. In this category, C_1, the Batch-1 (B-1) gives us maximum compressive strength at 28 days curing duration. The highest value of compressive strength achieved was 47.46 MPa. It can be observed that after addition of 0.5% superplasticizer in B-2, the strength increased up to 40.2 % than the reference specimen (B-1). Beyond this percentage of superplasticizer the strength showed a decline in its value. At 1% superplasticizer in B-3, the increase in strength observed was up to 10% of reference specimen. Similarly, 1.5% superplasticizer in B-4 gave only 9% increase in compressive strength than reference specimen. Finally, addition of 2% superplasticizer in B-5 reduced the compressive strength by 6% as compared to the maximum strength achieved by reference specimen. The decrease in strength percentage occurred due to the losses observed by addition of more superplasticizer which increased the workability and caused the defects in concrete like bleeding.

Table 4 Details of slump values for all batches

Sr. No.	Superplasticizer (%age)	Slump (cm)
1.	0	2.
2.	0.5	10
3.	1.0	17
4.	1.5	22
5.	2.0	25

The lowest value of compressive strength i.e. 7.45 MPa is obtained when 1% superplasticizer is used and specimen is exposed to ambient environment for 28 days.

Column 5 of the Table No. 5 shows the variations in compressive strength of the specimens cured 14 days in water and thereafter 14 days in ambient environment.

Table 5 Compressive strength at 28 Days

Sr. No.	Batch	SP	Average Compressive Strength (MPa)			
			C1 (28 days water)	C2 (14 days water, 14 days air)	C3 (3 days water, 25 days air)	C4 (25 days air)
1	B-1	0	33.85	27.33	22.59	15.27
2.	B-2	0.5	47.46	31.56	19.31	9.10
3.	B-3	1.0	37.18	20.10	11.13	7.45
4.	B-4	1.5	36.90	28.10	11.43	8.73
5.	B-5	2.0	31.87	24.40	16.58	10.40

A similar trend was observed for the specimens cured for 28 days in water (C_5) as compared to the case when specimens are cured for 14 days in water in initially and then in ambient environment up to testing. One of the anomalies is that with 1% superplasticizer, the strength obtained is lower than even that of the specimens without superplasticizer.

This might be due to some error, during the casting or testing process which may be reinvestigated. It is worthy to note that in C_5, the strength of specimens with 2% superplasticizer is greater than specimens with 1.5% superplasticizer. It is due to the accelerated strength gain because of the curing in ambient environment (without water). This also supports the reason mentioned above for the B-5 when cured 28 days in water.

Column 6 (C_3) of the Table No. 5 shows the compressive strength of the concrete for all batches cured 3 days immersed in water and then in directly in ambient environment without any initial water curing for next 25 days. In this category, the maximum strength achieved without using superplasticizer as 22.59 Mpa. An important point should be noted that the compressive strength of all the batches, including B-1 with highest compressive strength was decreased gradually as the curing duration was reduced. Additionally, it also identifies the effect of temperature on the compressive strength of concrete. The results of column 7 of Table 5 supports the above statement and it is evident from the results; the strength of concrete is lower with all the dosages of superplasticizer in all curing conditions than the strength of their respective batches cured in water up to the testing age.

This shows the significance of the water curing in general and initial water curing in particular to have the strength development of the concrete irrespective of the dosage of superplasticizer.

The addition of superplasticizer without increasing the W/C ratio shown remarkable enhancement in the strength, however further increase in superplasticizer beyond 1% is showing retro gradation in the strength due to superplasticizer, even it is lower than that without superplasticizer. This might be attributed to the slowed/delayed strength gain due to high dosage of superplasticizer which has resulted low strength at 28 days, which may be expressed to increase further with age because the superplasticizer with uniform W/C ratio works as a retarder also [28].

3.2 Test for Tensile Strength

Testing for tensile strength was done on 35 cylinders of standard size. Seven cylinders were assigned to each batch for experimental purpose. Table 6 shows the details of test results of tensile strength at 28 days. In all cases, the water curing up to testing is showed maximum strength. The highest value of tensile strength i.e. 2.61MPa is obtained when 1.5% superplasticizer is used and specimen is cured for 28 days immersed in water. In this category (C_1), B-1 with no superplasticizer, showed maximum tensile strength at 28 days curing duration. Then, after addition of 0.5% superplasticizer in B-2, 1% in B-3 and 1.5% in B-4, the maximum tensile strength of concrete increased up to 24%, 72% and 121% respectively as compared to reference specimen. But beyond 1.5% a decrease in tensile strength was observed. Adding 2% superplasticizer, the gain in strength as compared to reference specimen was reduced to 57.8% increase only.

The lowest value of tensile strength i.e. 0.68 MPa is obtained when no superplasticizer is used and specimen is exposed to ambient environment for 28 day. The results of B-3 and B-4 showed that the curing conditions have greater impact on the tensile strength of specimens as compared to the addition of increased amount of superplasticizer discussed in table 6:

Table 6 Tensile Strength of Concrete at 28 days

Sr. No	Batch	Super-plasticizer	Tensile Strength (MPa)			
			C_1	C_2	C_3	C_4
1	B-1	0	1.18	1.14	0.84	0.68
2	B-2	0.5	1.46	1.35	1.10	0.93
3	B-3	1.0	2.03	1.31	1.32	1.08
4	B-4	1.5	2.61	1.36	1.10	0.99
5	B-5	2.0	1.85	1.50	1.38	1.10

The details of ratio of compressive and tensile strength of all batches. The percent tensile strength with reference to compressive strength is calculated with respect to the relative concrete with admixture details shown in table 7.

Table 7 Ratio of Compressive and Tensile Strength of all batches

Sr.No	Batch	Tensile Strength (MPa)			
		C_1	C_2	C_3	C_4
1	B-1	5.99	6.81	7.43	9.57
2	B-2	5.47	5.56	6.78	13.07
3	B-3	5.45	9.21	14.5	14.94
4	B-4	5.39	6.48	9.84	11.11
5	B-5	5.52	6.76	7.30	11.06

4. Conclusions

The highest compressive strength was obtained in case of batch No.2 when 0.5% superplasticizer has been added and cured in water for 28 days. The lowest compressive strength obtained in case of batch No.3 when 1% superplasticizer has been added and exposed to ambient environment for 28 days without initial wet curing. Compressive strength of concrete with addition of superplasticizer keeping W/C ratio constant, increases with all dosages of superplasticizer when cured in water for 28 days. Dosage of superplasticizer equal to 0.5% has been observed to be optimum in terms of enhancement in the compressive strength, subject to maintain W/C ratio unchanged. Further water curing, or at least 3 days initial water curing, shown good effects on the strength development of concrete with all dosages of superplasticizer. Tensile strength in almost all batches tested is obtained of the order (5% to 15%) of its compressive strength which is in coincidence with the reported values in original.

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