International Research Journal of Engineering and Technology (IRJET) **e-ISSN: 2395-0056**
Volume: 09 Issue: 08 | Aug 2022 **www.irjet.net** **p-ISSN: 2395-0072**

Studying the Influence of Polycarboxylic Ether on Properties of Concrete

Shafaqat Bhat[1], Jaswant Singh[2]

[1]*Mtech Student , CBS Group of Institution , Haryana, India.*
[2]*Assistant Professor , Department of Civil Engineering, CBS Group of Institutions , Haryana, India.*

***

Abstract - *The present study aims to see how different Polycarboxylic ether (PC) dosages affect the distinctive features of concrete with M-30 grade at 0.35 water-cement ratio. The results of testing concrete in its green and hardened states for M30 grade were compared to those of concrete in its normal condition. The period for which the slump value was kept and the strength at which concrete collapsed in compression, known as compressive strength, were among the parameters studied. The results of compressive strength of the concrete were analyzed after one week and then after twenty eight days, and the results were reported as 7 day strength and 28 day strength, respectively. The optimal quantity of PC based admixture is reported as the amount at which the compressive strength will be highest and the slump loss will be minimum. The entire study was studied in two phases. In the first phase of experiments, the effect of superplasticizer on concrete properties was studied while reducing the water at a variable rate and in the second phase; the effect of superplasticizer was studied by reducing the water content at constant rate. The experimental findings depicted a considerable effect of the superplasticizer dosage on concrete properties in fresh as well as hardened state. The results revealed that the effectiveness of polycarboxylic etherbased superplasticizer was maximum at a quantity of 0.8% and 0.9% by cement weight for compressive strength and slump loss respectively*.

Keywords: *Compressive strength, Concrete, Polycarboxylic ether, Slump, Slump loss, Superplasticizer, Water-cement ratio*

1. INTRODUCTION

In the structural construction industry, concrete is the widely utilized building material. It is composed of cement, coarse and fine aggregates, water, and admixtures. Cement and water combine in a concrete mix to generate a paste that covers the surface of coarse and fine aggregates and holds them together, in addition to filling fine aggregate gaps (Duggal, 2008). Concrete buildings must perform the purposes for which they were designed, and their primary requirements are strength and durability. Ready-mixed concrete has recently become popular in major constructions. The use of ready-mixed concrete can result in higher structural quality, Bas ready mixed concrete is so widely used nowadays that it is critical to use admixtures to improve its qualities. Some admixtures contain chemistry that affects a variety of concrete qualities, while others are simply added during the batching process. Admixtures are widely used because they offer significant economic and physical benefits over the regularly used concrete (Alsadey, 2021). However, using additives will not enhance the quality of substandard concrete caused by insufficient mix proportion, poor mixing skills in concrete, or challenges by B-grade raw materials (Alsadey, 2012; 2013). A superplasticizer, also known as a high range water reducer, is an additive that minimizes the amount of water needed to mix concrete. It was designed to boost the plasticity or fluidity of low-water concrete, making it easier to pump up to higher elevations without affecting strength or durability. (Wilson & Kosmatka, 2011). Superplasticizers can cut water use by up to 30%, allowing for the production of workable concrete with extremely high strength, which was previously difficult and expensive. (Hassouna, 2016).

Superplasticizers or High-range water reducers (HRWR) are chemically reactive admixtures that react with the concrete's constituents and are typically added in a concrete that must be transported from the place of manufacture to the place where it will be used to improve its properties in both the green and sett states. These Admixtures are also known super water reducers and superfluidifiers. The first HRWR was invented in Japan in the year 1964 by Kenichi Hattori. This HRWR was formaldehyde condensates of beta-naphthalene sulphonates. After this superplasticizer in the same year on other HRWR sulphonated melamine formaldehyde condensate based was known as Melmet was presented in West Germany. HRWR have the property of reducing the water requirement by about 30% of the water used in the concrete. By using HRWR we can produce the concrete of high strength, durable and high slump. Before HRWR we had conventional water reducers which could only reduce water by about 15%. We may limit the possibility of concrete segregation by adding water reducers, which lower the quantity of water required in the concrete. Using HRWR in concrete results in significant savings in construction cost, quantity of cement, and number of laborers, despite the fact that HRWR costs 120 per litre.

As in the modern world we can't think of the concrete without using admixtures, so in order to have efficient use of the admixtures known as superplasticizer, proper guidelines for its proficient use becomes a necessity. Many difficulties arise when utilizing admixtures, as the usage of admixture in concrete is dependent on numerous parameters. Such as the water cement ratio to be used, the temperature at the site, the site condition, the quantity of additive to be used, and the period in which the admixture must be added. To overcome any issue and manufacture excellent concrete with strength and serviceability, suitable action must be taken. This research took into account how to use HRWR, its mode of action, the amount that would provide beneficial outcomes, and its impact on the qualities of concrete in the set (hardened) and green (fresh) phases. After studying the various factors governing the use of HRWR, it provides the proper information to be followed by the engineers while using this in the field, such as how to add the HRWR in the concrete and the dosage at which at efficient results will be achieved. Properties of Concrete which were evaluated during the green state were Rheological properties such as slump test and in hardened state compressive strength tests were done.

1.1 Chemistry of superplasticizers

To study action of HRWR, detailed study of micro structural behavior, pattern of adsorption and action of superplasticizer in hydration process is must. These superplasticizers enhance the rheological properties of cement significantly .During the action of HRWR with the cement particles , the molecules of superplasticizer align themselves around the periphery of the cement particles , due to which watery film as shown in the fig 2 is formed. Superplasticizer molecules are attracted to cement particles from one side and to water from the other, resulting in the formation of a lubricating film surface along the surface of cement particles, which improves the rheological characteristics of cement. Microscopic examination of cement particles with superplasticizer revealed that cement particles floating in water exhibit irregular and huge agglomerates cement particles are formed into tiny particles. Figure 2 depicts the formation of needle-shaped products as a result of hydration, which are not evident in regular concrete. At six months, the concrete containing the additive has a compacted and flawless structure.

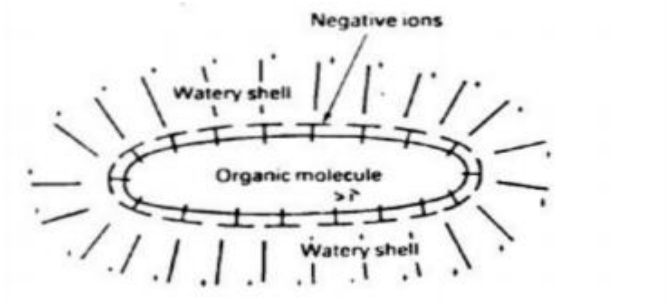

Fig – 1: Watery shell formed around cement particle (Source: Courtesy of William Wilson)

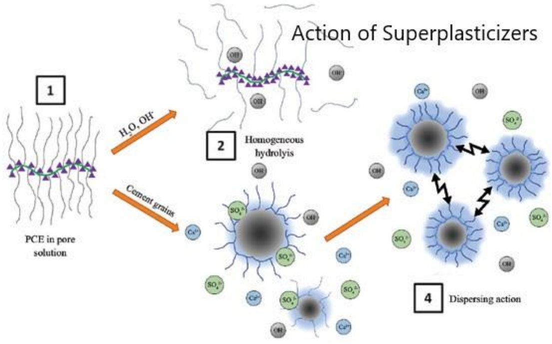

Fig – 2: Mode of Action of Superplasticizers

The type of cement used has the greatest influence on adsorption. Type III cement was discovered to have the highest degree of adsorption, followed by Type I and Type II cement. Figure 3 depicts the aqueous adsorption properties of a melamine-based superplasticizer (SMF) on cement, C_3A, and C_3S. Superplasticizer adsorption on C_3A occurs instantly. Due to the development of complexes between the SMF and the hydrating C_3A, hexagonal aluminates adsorbs a substantial quantity of superplasticizer and is not instantly transformed to the cubic form in the system C_3A-H2O-SMF. The process is analogous to C_3A hydration in the presence of calcium lignosulphonate. During the first hour, however, there is insufficient adsorption on the surface of C_3S. The adsorption process is insignificant up to around 4 to 5 hours and then rapidly rises. SMF is adsorbed by C_3A + gypsum in cement. This adsorption takes only a few minutes. It is recommended to add the admixture 5 to 30 minutes after the start of hydration to help reduce the speed and amount of adsorption. Delaying the addition of the admixture will result in a enough quantity of admixture remaining in the solution to create silicate phase dispersal and, as a result, will aid in enhancing workability. Adsorption prior to 5 hours is mostly caused by C_3S hydrates in the cement.

The concentration of superplasticizer supplied increases adsorption. Particles generate charges as a result of ion adsorption. The repulsion between particles with the same charge prevents agglomeration or precipitation and diminishes the system's uniformity. The enormous negative potentials created by the application of superplasticizer were shown to reduce over time while remaining high even after 1200 minutes. Just following initial point of contact between cement and water, cement particles re-aggregate and grow bigger in size, causing fluidity to rapidly diminish. The hydration products formed on the surface of the cement particles are separated by continuous mixing of the concrete. The combination of higher temperature and peeling action significantly increases both the pace and amount of hydration product created, resulting in a significant reduction in fluidity. The superplasticizer should work on both the cement particles and the hydration products to restore fluidity. As a result, if the time of addition is extended, a higher dosage of superplasticizer is needed. Superplasticizers based on melamine and naphthalene are responsible for interfering with the hydration of C_3S and C_3A. Opinions differ on the impact of these admixtures on the rate of hydration of C_3A +gypsum mixes.

1.2 Effects on Fresh Concrete

In the present study, the effect of superplasticizer on concrete in fresh and hardened states is determined. In the fresh state, the superplasticizer has a great influence on workability, while in the hardened state; it affects its compressive strength. The workability of concrete is affected by the type and quantity of cement, the time of superplasticizer addition, the nature and dosage of superplasticizer, the initial slump, the temperature, relative humidity, the mixing situation which includes mixer type, total mixing time, and mixer speed), and the presence of other admixtures. Mixtures having a low initial slump need a higher superplasticizer dosage. The impact of initial slump on the rate of slump loss following superplasticizer addition is controversial. In general, mixes with a bigger starting slump lost droop more gradually. The cement type and quantity in the mix also affect workability. It was observed that a larger superplasticizer dosage is required for Type I cement to obtain the same workability as Type V cement. To obtain a particular slump, mixes with a higher cement percentage require less superplasticizer. This is to be expected given that high cement concentration combinations are known to be more fluid, even when no additive is used. Furthermore, mixes with a higher cement percentage lose slump at a slower pace. The type and brand of superplasticizers differ. Melamine-based superplasticizers lose their effect (with time consistency of fresh concrete will decrease) at a faster pace than other forms of superplasticizers. The rate of slump loss decreases when the superplasticizer dose is increased. Excess superplasticizer in the mixture enhances workability even further, leading in a very high slump, but it can also cause excessive bleeding and segregation.

The moment at which the superplasticizers are introduced is another factor that influences workability. Superplasticizers' ability to increase workability deteriorates with time. It is better to wait until some C_3A has been hydrated and so then removed from the mixture before adding it. Slump loss is greatly reduced as a result of this. Low temperatures generate less workability loss and thus increase the dosage required to get the desired slump, particularly below 20°C. Superplasticizers can be used frequently to restore workability. In general, repeated dosing does not affect the concrete in any way, however it may allow entrapped air to escape, increasing the plastic unit weight. Regardless of the slump that occurs after the initial dose, repeated doses enhances workability for an additional 25 to 45 minutes. As the number of doses is increased, the efficiency of superplasticizers in enhancing workability declines, and the rate of slump loss rises with each dose.

1.3 Effects on hardened concrete

Concrete is affected by superplasticizers with extraordinarily high utility and better strength, as the superplasticizer work by integrating the particles of cement with a substantial negative charge, causing them to oppose one another because of the same charge (electrostatic charge). More water is supplied to concrete mixing by deflocculating the particles of cement (Neville, 2005). The use of superplasticizer is becoming more common as it provides benefits in both the fresh and hardened stages (Yamakawa et al., 1990). In case of hardened cement concrete, the superplasticizer improves compaction efficiency to produce denser concrete with higher compressive strength by lowering the water cement ratio (Alsadey, 2021). The concrete strength after superplasticizer addition was observed to be more than or equal to the strength of comparable concrete prepared without head mixture. Because superplasticizers enhance workability and compatibility while reducing the water-cement ratio, they boost concrete strength and so contribute to the overall progress in hardened concrete properties. In fact, using these

superplasticizers is a viable step toward enhancing the overall properties of hardened concrete. Superplasticizers have become an integral part in today's high performance concrete.

Different superplasticizers have varying impacts on the characteristics and working of concrete. Borsai (1994) analyzed the influence of 2 categories of superplasticizers on concrete having a high quantity of fly ash: acrylic polymer (AP) and sulphonated naphthalene (SN). Following careful analysis, it was concluded that AP-based superplasticizer surpasses SN-based superplasticizer. In the former case, it provides a greater water reduction, less slump loss, and higher slump level. Additionally, concrete containing a superplasticizer based on AP has improved durability and compressive strength (Fukuda et al., 1990; Borsai, 1994).

2. MATERIALS USED AND TESTING

Ordinary Portland cement (OPC)

ULTRATECH 43 grade cement was used, which is commercially available. This cement satisfies the IS: 8112-2013 criteria for OPC 43 grade. The following are its properties:

Coarse aggregates

In this study, two varieties of coarse aggregates having nominal diameters of 10 mm and 20 mm were employed. Course Aggregate's specific gravity was calculated to be 2.71. Crushed boulder was used as coarse aggregate. The analysis of aggregates using sieves (sieve analysis) is a method used to check the different particle sizes of aggregates in a sample, often termed as gradation. Concrete aggregates are commonly 150 micron, 300 micron, 600 micron, 2.36mm, 4.75mm, 10mm, 20mm, 40mm, and 80mm in size. The fine aggregate fraction is 4.75 mm to 150 micron in size, while the coarse aggregate fraction is 80mm to 4.75 mm in size. Sifting a sample of Course aggregate or Fine Aggregate through complete sieves positioned one on another respective of their size, with the smallest sieve at the bottom, grades it. The aggregate coarser than the sieve under consideration and finer than the sieve on top is described by the material remaining on each sieve after shaking. Sieving can be carried out either mechanically or by hand. During the manual operation (shaking with hands), the sieve is quivered in every direction possible to allow all particles to pass through. The procedure should be repeated until not even a single particle is going through. The particle size distribution of an aggregate sample is determined through sieve analysis. The particle size distribution is described by the fineness modulus. F.M is a thorough indicator of a substance's coarseness or fineness. It's calculated by summing together the percentage of aggregates remaining on each of the standard sieves ranging from 80mm to 150 micron and dividing the total by 100. The finer the material, the higher the figure. The following are the sieve analysis results:

Table – 2: Sieve analysis results of coarse aggregate (20mm)

AVERAGE INDIVIDUAL GRADATION OF 20mm COARSE AGGREGATE				
As per IS:2386(Part-1)				
Type of Material: 20 mm				
Source: LASSIPORA	Proposed Use: Concrete			
Sieve sizes (mm)	Sample No-01, 02 and 03			Average Percentage of Passing
	Sample-01	Sample-02	Sample-03	
40	100.00	100.00	100.00	100.00
20	93.60	95.20	93.20	94.00
10	8.90	9.40	8.70	9.00
4.75	-	-	-	-

Table – 3: Sieve analysis results of coarse aggregate (10mm)

AVERAGE INDIVIDUAL GRADATION OF 10mm COARSE AGGREGATE
As per IS:2386(Part-1)
Type of Material: 10mm CA

Source: LASSIPORA AWANTIPORA				Proposed Use: Concrete
Sieve sizes (mm)	SampleNo-1,2&3			Average Percentage Of Passing
	Sample-1	Sample-2	Sample-3	
12.5	100.00	100.00	100.00	100.00
10	87.88	87.48	88.60	87.99
4.75	13.88	11.56	13.48	12.97
2.36	2.16	1.76	1.96	1.96

Fine aggregates

Fine aggregates used consist of sand obtained from *Baramulla* River. As per the analysis given below, the sand used was Zone-II type.

Tests on fine aggregates

Sieve Analysis

Water

Water is the most significant component of concrete because it aids in the chemical interaction between cement and itself. While water assists to give the strength of the cement gel, its amount/volume and quality must be carefully regulated.

Superplasticizer

The superplasticizer used was AURAMIX 400, a well developed low viscosity high performance polycarboxylic ether superplasticizer.

Table – 4: Sieve analysis results of fine aggregate (Sample 01)

Table -5: Sieve analysis results of fine aggregate (Sample 02)

Total wt. of Sample= 1000gm							
IS Size of Sieve (mm)	**Material Retained [grams]**	**Percentage Retained on Sieve**	**Percentage Retained cumulative**	**Percentage Passing through Sieve**	**Specification Limits As IS383 TableNo-04**		
					Zone -I	**Zone -II**	**Zone – III**
10	0	0	0	100	100	**100**	100
4.75	68	6.8	6.8	93.2	90 - 100	**90 - 100**	90 – 100
2.36	86	8.6	15.4	84.6	60-95	**75 – 100**	85 – 100
1.18	195	19.5	34.9	65.1	30-70	**55-90**	75 – 100
0.600	168	16.8	51.7	48.3	15-34	**35-59**	60–79
0.300	371	37.1	88.8	11.2	5-20	**8-30**	12–40
0.150	78	7.8	96.6	3.4	0-10	**0-10**	0–10
Fineness Modulus:		**2.94**				Zone-II	

Table -6: Results of Sieve analysis of fine aggregate (Sample 03)

Total weight of sample = 1000gm							
IS Size of Sieve (mm)	**Material Retained [grams]**	**Percentage Retained on Sieve**	**Percentage Retained cumulative**	**Percentage Passing through Sieve**	**Specification Limits As IS-383 Table No-04**		
					Zone-I	**Zone –II**	**Zone–III**
10	0	0	0	100	100	100	100
4.75	59	5.9	5.9	94.1	90 - 100	90 - 100	90 – 100
2.36	98	9.8	15.7	84.3	60-95	75 - 100	85 – 100
1.18	161	16.1	31.8	68.2	30-70	55-90	75 – 100
0.600	180	18	49.8	50.2	15-34	35-59	60–79
0.300	394	39.4	89.2	10.8	5-20	8-30	12–40

0.150	89	8.9	98.1	1.9	0-10	0-10	0–10
Fineness Modulus		**2.91**				Zone–II	

Table – 7: Average sieve analysis results of the three samples

Total wt. of Sample = 1000gms							
IS Size of Sieve (mm)	**Percentage Passing (Sample-01)**	**Percentage Passing (Sample-02)**	**Percentage Passing (Sample-03)**	**Average percentage of Passing**	**SpecificationLimitsAsIS383 Table No-04**		
					Zone -I	**Zone - II**	**Zone - III**
10	100	100	100	100.0	100	100	100
4.75	93.1	93.2	94.1	93.5	90 - 100	90 - 100	90 -100
2.36	84.9	84.6	84.3	84.6	60-95	75 - 100	85 -100
1.18	64.2	65.1	68.2	65.8	30-70	55-90	75 -100
0.600	49.9	48.3	50.2	49.5	15-34	35-59	60-79
0.300	12.1	11.2	10.8	11.4	5-20	8-30	12-40
0.150	2.7	3.4	1.9	2.7	0-10	0-10	0-10
Average Fineness Modulus:		**2.93**				Zone –II	

Initially, approximately half of the coarse material is placed on the skip, followed by approximately half of the fine aggregate. The entire amount of cement, i.e. one bag, is then dumped on top, followed by the remaining of the coarse and fine aggregate. This keeps cement from spilling when filling the drum and keeps cement from flying away in high winds. Before releasing the full skip to the drum, approximately 25% of the total quantity of water required for mixing is pumped into the mixer drum to wet it and prevent cement from sticking to the blades or the bottom of the drum. The remaining water, except one litre, is put to the drum immediately after the dry material is discharged. The phase begins when all of the material, notably the entire amount of water, is placed into the drum. Following approximately one minute of mixing, the determined amount of superplasticizer is blended with that one litre of water and added to the mixer drum. It is desirable to mix the concrete for a little longer (half a minute longer) to ensure that the plasticizing action is fully realized through proper dispersion.

3. RESULTS AND DISCUSSIONS

VARIABLE WATER REDUCTION

Table 1 28-day compressive strength of different Trial mixes for variable water reduction

S.No	Dosage (%)	28 day compressive strength (MPa)
Trial1	Nil	41.07
Trial2	Nil	42.10
Trial3	0.7	48.71
Trial4	0.8	56.26
Trial5	0.9	51.01
Trial6	1.0	46.8
Trial7	1.1	43.5

S.No.	Dosage (%)	Slump loss(mm)		
		0min	30min	60min
Trial1	0.7	6	0	0
Trial2	0.8	40	0	0
Trial3	0.9	100	60	40
Trial4	1.0	120	105	90
Trial5	1.1	140	115	60

Table 2 Slump loss of different Trial mixes for variable water reduction

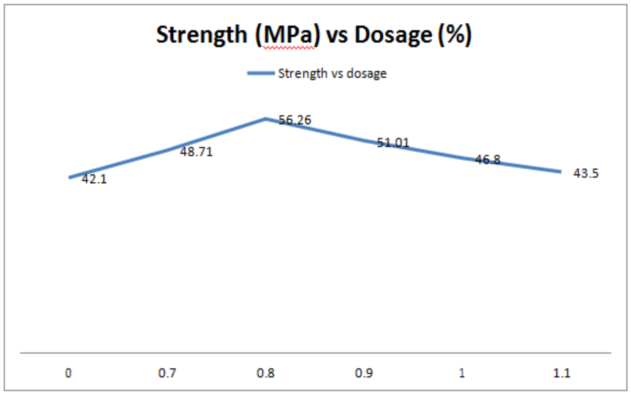

Figure 5 Strength vs Dosage of superplasticizer plot for variable water reduction

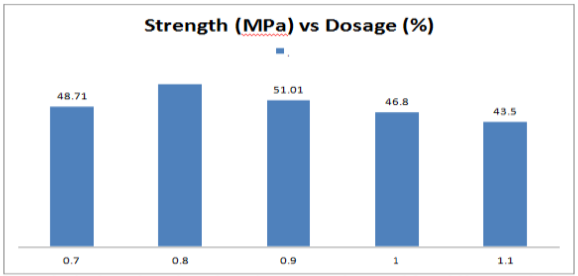

Figure 6 Plot showing optimum dosage for maximum compressive strength for variable water reduction

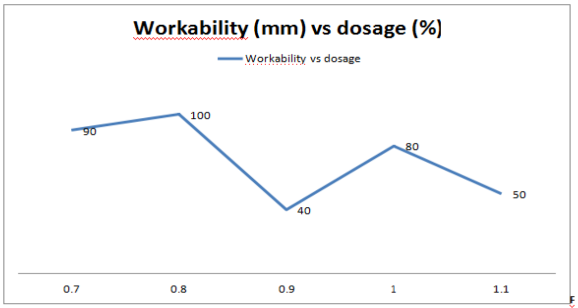

figure 7 Workability vs Dosage of superplasticizer plot for variable water reduction

S.No.	sage (%)	28 day compressive strength
Trial1	0.7	46.3
Trial2	0.8	59.56
Trial3	0.9	56.00
Trial4	1.0	50.54
Trial5	1.1	47.87

Table 3 28-day compressive strength of different Trial mixes for constant water reduction

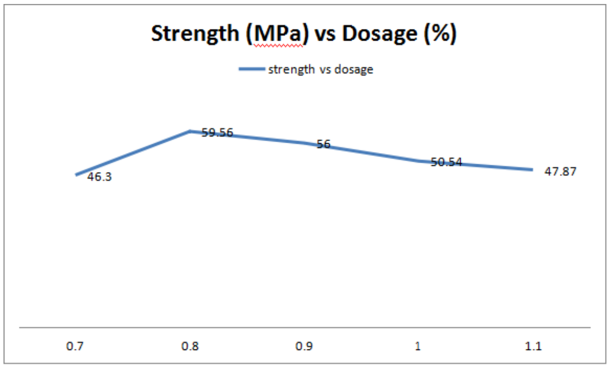

Figure 9 Strength vs. dosage of superplasticizer plot for constant water reduction.

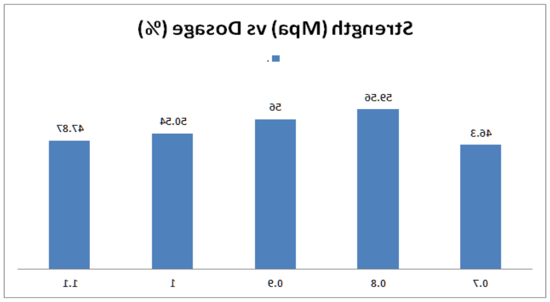

Figure 10 Plot showing optimum dosage for maximum compressive strength for constant water reduction

From the above, it can be referred that for strength criteria to be best the optimal dosage of HRWR is **0.8%.**

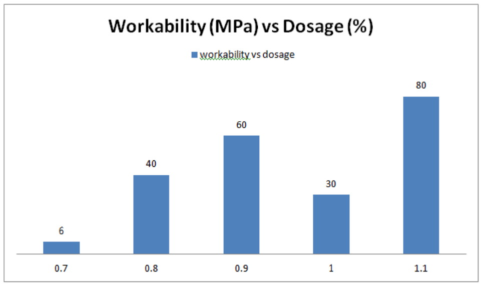

Figure 12 Plot showing optimum dosage for workability for constant water reduction

Based on the above, the optimal superplasticizer dose based on workability requirements is 1.0 percent.

4. CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusion

The main objective of this research was to assess the impact of superplasticizer on the characteristics of freshly and hardened cured concrete (M30 at 0.35 water/cement ratio) with variable water reduction in the first trials and constant water reduction in the second trials owing to superplasticizer. The qualities of concrete that were tested were slump retention and compressive strength. Within the scope of the laboratory testing, the following conclusions can be reached:

- For Trials in which water reduction was taken variable, the optimal quantity of Superplasticizer for which strength was found maximum was 0.8 percent by weight of cement (22 percent water reduction), with a strength of 56.26 MPa obtained, and the optimal quantity for highest slump retention was observed to be 0.9 percent by weight of cement used when reduction for water taken as 24 percent.
- For Trials with constant water reductions of 30%, the optimal quantity for which compressive strength was maximum was found to be 0.8 percent by weight of cement, with strength of 59.56MPa obtained, while the best dosage for minimum slump loss was found to be 0.9 percent by weight of cement.
- The inclusion of superplasticizer increases the workability of concrete; nevertheless, excessively large dosages of HRWR tend to compromise cohesiveness characteristic of concrete.
- Superplasticizer improves strength; however, its final strength is greater than the intended characteristic strength.
- The optimum dose for maximal compressive strength in all scenarios, whether constant or variable water reduction has been determined to be 0.8 percent of the combination quantity.
- For all conditions, the optimal dose for minimum slump values or highest retention was determined to be 0.9 percent of the quantity of HRWR.

Future scope and recommendations

This study includes a method for the proper use of superplasticizing admixtures, also named as HRWR admixtures, in the production of concrete with high quality with the regular and steady constancy. The technique discussed here is designed to assist employees at field in formulating a easy plan of work for the proper application of superplasticizers in concrete to achieve properties which are required for the particular type of concrete. After a thorough analysis of technical and construction problems for each individual application, a choice on how to employ superplasticizers should be taken. If properly utilized, this sort of additive may be a beneficial ingredient of the mixture, producing concrete of better rheology, good strength, and ease with which it can be worked. In contrast, if not handled appropriately, these admixtures might cause extra problems that exceed their advantages. Because the efficiency of superplasticizers is affected by a variety of elements such as field conditions, equipments required at the construction site, resources, surroundings and the plan of work must be tailored accordingly. Furthermore, field experiments must be carried out under identical conditions to those predicted during construction.

Superplasticizer is fairly expensive, costing around hundred twenty per litre which results in rise in cost of project, however regardless of capital, the admixture can achieve significant reductions in human labor and manufacturing expenses. Furthermore, the use of superplasticizer minimizes the quantity of cement that must be added to the concrete mixture, lowering the cost even further. As a result, superplasticizers supply us with both economical and high-quality concrete.

The following are a few suggestions that may be implemented to improve the value of the current research:

- UHSP (Ultra high strength concrete) may be produced by integrating superplasticizers at the optimal quantity together with various mineral additives such as silica fume, fly ash, and so on.
- Furthermore, the current study may be expanded by employing other types of admixtures to determine their optimal dose and then increasing the strength of the same by addition of those mineral additives or admixtures.
- Different admixtures can be compared to find which one works best under various exposure scenarios.
- By reducing the difference between two successive dosages, a more accurate optimal dosage may be determined.
- As we selected Zone-II sand and boulder crushed coarse aggregate, investigations with different types of fine and coarse aggregates may be conducted and comparisons made.

References

Alsadey S (2012) Effects of Superplasticizing and Retarding Admixtures on Properties of Concrete. Paper presented at International Conference on Transport, Environment and

Civil Engineering (ICTECE-1012). Kuala Lumpur (Malaysia), August 25-26, 2012.

Alsadey S (2013) Effects of Superplasticizing and Retarding Admixtures on Properties of Concrete. International Conference on Innovations in Engineering and Technology (ICIET), Bangkok (Thailand).

Alsadey S (2015) Effect of Superplasticizer on Fresh and Hardened Properties of Concrete. Journal of Agricultural Science and Engineering, 1(2): 70-74.

Borsai A (1994) Effect of superplasticizer type on the performance of high-volume fly ash concrete.

Duggal SK (2008) Building Materials. 3rd Ed. India: New Age International Publishers.

Fukuda M, Mizunuma T, Iumi T and Iizuka M (1990) Slump control and properties of concrete with a new superplasticizer. Chapman and Hall.

Hassouna FMA (2016) Effects of Superplasticizers on Fresh and Hardened Portland Cement Concrete Characteristics. International Journal of Applied Science and Technology, 5(2): 32-36.

Neville AM (2005) Properties of concrete. Pearson, Prentice Hall, 255-262.

Wilson ML and Kosmatka SH (2011) Design and Control of Concrete Mixtures. 15th Ed. United States of America: Portland Cement Assn.

Yamakawa C, Kishitani K, Fukushi I and Kuroha K (1990) Slump control and properties of concrete with a new uperplasticizer. II: High strength in-situ concrete work at Hikariga-oka Housing Project, Chapman and Hall, 94.