Effect of polycarboxylate ether-based superplasticizer dosage on fresh and hardened properties of cement concrete

Ajmal Paktiawal and Mehtab Alam

1Department of Civil Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, Jamia Nagar, New Delhi-110025, India.
2Department of Civil Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, Jamia Nagar, New Delhi-110025, India.

*Email: ajmal.paktiawal@gmail.com

Abstract. Ready-mix concrete nowadays is available almost everywhere in the country. RMC plants are indispensably using high-range water-reducing admixtures namely, sulfonate naphthalene formaldehyde condensate, and Polyether polycarboxylate, for making standard cement concrete. These admixtures are used to economize the cost of concrete by reducing the quantity of water. Commonly used high range water reducer admixture, the polycarboxylate ether-based (PCE) superplasticizer has been used to investigate its influence on workability and strength of concrete by measuring slump and ultrasonic pulse velocity as well as crushing strength. The cement of grade 43 has been used in this work. This superplasticizer was added to the mix to make concrete of grade M60 by weight of cement with 0.15%, 0.25%, 0.35%, 0.45%, and 0.55% without altering the w/c ratio. Experimental results reveal that the restricted dosage of the superplasticizer provided in Plain and reinforced concrete code of practice in Indian standard, IS456:2000, restricts to 1% is on the higher side. The slump, ultrasonic pulse velocity, and crushing strength of M60 grade standard concrete with water to binder ratio of 0.40 gives the optimum dose 0.45% by weight of cement, which is quite less than the restricted quantity of dosage.

1. Introduction

High-range water-reducing admixtures are commonly utilized in concrete where demand for pumpable high strength increment is required [1]. In self-consolidating concrete also high range water reducing superplasticizers are employed to produce require flowability and inherent compactability [2]. Mini slump and Marsh funnel tests with varying percentage of PCE SP dose were conducted to find out the saturation dosage, which is the maximum spread diameter beyond which there is no increase, on PPC and OPC+25% fly ash. Saturation dosages of PCE SP were found to be 0.4 and 0.6 in Mini slump and Marsh funnel tests respectively. The value of saturation dosage found out in Mini slump and Marsh funnel tests were reported 0.6 for OPC+25% fly ash [3]. In this experimental work, the influence of SP on plastic shrinkage of conventional and silica fume cement concrete with 7.5% of Type 1, Type 2, and Type 3 having the dosage of PCE SP 0.4, 0.7, and 0.66% respectively were investigated. It was reported that PCE SP showed the highest compatibility concerning to its massive retardation Type 1 and Type 3 silica fume cement concrete [4]. The incorporation of superplasticizer in fine recycled concrete aggregate was studied for mechanical properties. In this study, two types of superplasticizers called SP1, containing lignosulfonate and SP2, whose chemical composition is polycarboxylate was added with 1% by cement weight. Fine aggregate was substituted with fine recycled aggregate with 20, 40, 60, 80, and
It was reported that higher water reducing the power of the additive gave a worse relative performance of FRA in fine recycled concrete aggregate [5]. Polycarboxylate ether-based superplasticizer with 0.3, 0.5, 0.7, and 1% by weight of cement was used to investigate its influence on hydration, microstructure, and mechanical response of cement paste. It was reported that 1% of PCE-based SP in the cement paste produced a higher percentage of silicate at 2 days. Based on the microstructural analysis, it was inferred that the PCE-based superplasticizer slightly decreases the porosity of cement paste [6].

2. Experimental arrangement

2.1. Materials

Wonder brand OPC cement of grade 43, fresh lot complying with [7] was purchased from the authorized supplier. This OPC cement was examined for its physical characteristics conforming to BIS [8-12]. The test findings of cement are given in Table 1. Fine and coarse aggregate as natural river sand of zone II as per [13] and crushed stone of size 20mm and 10mm respectively were tested for their physical properties as shown in Table 2 had been found out [14, 15]. Natural river bed coarse sand was used as fine aggregate in this study. Other tested characteristics of the coarse aggregate as shown in Table 2 complying with [14, 15]. Polycarboxylate ether-based superplasticizer (HRWR) was procured from the authorized supplier (Kunal Chemical Company) used [16]. The characteristics of the superplasticizer used are presented in Table 3.

| S. No. | Property         | Result  | Requirements as per IS Code |
|-------|------------------|---------|-----------------------------|
| 1     | Normal consistency | 31%     | -                           |
| 2     | Initial setting time | 116 minutes | ≥ 30 minutes               |
| 3     | Final setting time   | 229 minutes | ≤ 600 minutes              |
| 4     | Specific gravity    | 3.12    | -                           |
| 5     | Fineness           | 98.0%   | > 90%                       |
| 6     | Compressive strength | 3 days  | 24.0 MPa                    |
|       |                   | 7 days  | 32.7 MPa                    |
|       |                   | 28 days | 47.3 MPa                    |
|       |                   |         | 23 MPa                      |
|       |                   |         | 33 MPa                      |
|       |                   |         | 43 MPa                      |

| S. No. | Property         | Test result |
|-------|------------------|-------------|
| 1     | Specific gravity | 2.54        |
| 2     | Water adsorption | 1.94        |
| 3     | Moisture content | 0.95        |
| 4     | Fineness Modulus | 2.58        |

| S. No. | Tests carried out | References | Results obtained |
|-------|-------------------|------------|-----------------|
| 1     | Appearance        | BIS-9103   | Light brown viscous liquid |
| 2     | Main chemical ingredients | BIS-9103   | Polycarboxylate base |
| 3     | Dry material content (%) | BIS-9103   | 50.10           |
| 4     | Relative density  | BIS-9103   | 1.100           |
| 5     | Chloride content (%) | BIS-6925   | 0.017           |
| 6     | pH                | BIS-9103   | 6.70            |
2.2. Concrete mix and its ingredients
Concrete for the grade of M60 with the desired workability of 100mm was mix design conforming to [17, 18]. Cube specimens of standard size with 100mmx100mmx100mm were casted using polycarboxylate ether-based (PCE) superplasticizer with 0.15%, 0.25%, 0.35%, 0.45%, and 0.55% by weight of cement and abbreviated as PCESP. In the present work, the concrete of grade M60 was prepared in the laboratory with varying percentages of superplasticizer to investigate its effect on the fresh and hardened state of the concrete. The binder to aggregate ratio is obtained as 1:1.73:2.48 for water to cement ratio of 0.35. The quantity of concrete ingredients required for 1m$^3$ of concrete mix of M60 grade is presented in Table 4.

Table 4. Mix proportioning for 1m$^3$ of concrete

| Mix ID      | Cement (kg/m$^3$) | F. A. (kg/m$^3$) | C. A. (kg/m$^3$) | w/c ratio | Admixture (%) |
|-------------|------------------|-----------------|-----------------|-----------|---------------|
| PCESP-0.00% | 449              | 777             | 1113            | 0.35      | 0.00          |
| PCESP-0.15% | 449              | 777             | 1113            | 0.35      | 0.15          |
| PCESP-0.25% | 449              | 777             | 1113            | 0.35      | 0.25          |
| PCESP-0.35% | 449              | 777             | 1113            | 0.35      | 0.35          |
| PCESP-0.45% | 449              | 777             | 1113            | 0.35      | 0.45          |
| PCESP-0.55% | 449              | 777             | 1113            | 0.35      | 0.55          |

2.3. Allocation of test specimens and test conducted
Concrete moulds of a standard size of 100mmx100mmx100mm were prepared to cast concrete for compressive strength and ultrasonic pulse velocity conforming to [19]. To assess the effect of dosage of PCE based superplasticizer on the fresh and hardened state of concrete, the concrete in its fresh state was tested for slump as per [20], and the hardened concrete was tested for ultrasonic pulse velocity and crushing strength complying with [22, 21].

3. Findings and discussions

3.1. Workability
The slump test was conducted to scale the effect of the superplasticizer on workability. Polycarboxylate ether-based SP with 0, 0.15, 0.25, 0.35, 0.45, and 0.55% was added by weight of cement. Scaled slumps of the PCE-based SP concrete are depicted in Fig.1. The addition of a superplasticizer increased the slump. Concrete with 0.15% of SP has given 25mm slump, the degree of workability as per IS456:2000 clause 7.1 is low [18]. Concrete without SP having water to cement ratio of 0.4 was found very low and having a slump of about 15mm may be called zero slump concrete. The concretes with 0.25% and 0.35% of PCE-based SP having a slump of 50mm and 70mm respectively belong to the medium degree of workability. The concretes with 0.45% and 0.55% having a slump of 105mm and 130mm are of a high degree of workability. Fig.2 shows the desired slump (0.45% of SP) of the concrete.
3.2. Workability
The density of concrete without superplasticizer was 2301 kg/m$^3$. The concretes with additive superplasticizer of 0.15, 0.25, 0.35, 0.45, and 0.55% by weight of cement were found as 2331, 2420, 2434, 2443, and 2430 kg/m$^3$. It can be mentioned that the density of concrete increases with increasing dosage of superplasticizer by 1.3, 5.17, 5.78, 6.17, and 5.60% as compared to concrete without superplasticizer.

3.3. Compressive strength
Control concrete (without SP) and concretes with varying dosages of SP were tested for crushing strength after 7 and 28 days of curing. The compressive strength findings are given in Table 5 and plotted in Fig. 3 and Fig. 4. The improvement of crushing strength of concrete with superplasticizer of 0.15, 0.25, 0.35, 0.45, and 0.55% after 28 days is found to be 5.68, 11.06, 18.32, 31.93 and 12.94% as compared to concrete without SP. The desired strength as per IS10262:2019 was given by 0.45% of SP content. The concrete with 0.45% of SP gives higher compressive strength. This improvement of compressive strength can be ascribed to decrease in air-entrained, the probable consolidation of the mix due to higher workability, and sweeping hydration of cement owing to dispersion ability of this optimum dosage of superplasticizer. The addition of SP beyond 0.45% dose caused a little bleeding in the mix, which decreased the strength.

Table 5. Compressive strength findings after 7 and 28 days

| Mix ID | Age (Days) | Samples test Result (MPa) | Mean Strength (MPa) | Std Dev (MPa) | C.O.V (%) | Strength Increase (%) |
|--------|------------|---------------------------|--------------------|---------------|-----------|-----------------------|
|        |            | S1           | S2       | S3       | S4       | S5       |                      |                    |
| PCESP-0.00% | 7           | 30.0         | 29.8     | 30.5     | 29.6     | 31.1     | 30.20                | 0.60               | 1.98                 | 0.00                 |
| PCESP-0.15%  |              | 33.0         | 33.4     | 29.2     | 32.6     | 32.4     | 32.12                | 1.68               | 5.23                 | 0.25                 |
| PCESP-0.25%  |              | 36.3         | 32.1     | 35.4     | 31.8     | 34.8     | 34.08                | 2.02               | 5.93                 | 5.64                 |
| PCESP-0.35%  |              | 34.6         | 37.4     | 35.5     | 36.3     | 33.4     | 35.44                | 1.54               | 4.35                 | 10.10                |
| PCESP-0.45%  |              | 39.3         | 38.6     | 40.4     | 40.3     | 39.6     | 39.64                | 0.74               | 1.87                 | 23.11                |
| PCESP-0.55%  |              | 36.3         | 38.8     | 37.3     | 37.1     | 36.8     | 37.26                | 0.94               | 2.52                 | 15.71                |
| PCESP-0.00% | 28          | 47.6         | 48.5     | 47.5     | 46.9     | 49.1     | 47.92                | 0.87               | 1.82                 | 0.00                 |
| PCESP-0.15%  |              | 49.2         | 53.2     | 49.9     | 52.6     | 48.3     | 50.64                | 2.15               | 4.25                 | 5.68                 |
| PCESP-0.25%  |              | 56.8         | 54.4     | 51.5     | 50.9     | 52.5     | 53.22                | 2.40               | 4.51                 | 11.06                |
| PCESP-0.35%  |              | 54.2         | 56.5     | 59.6     | 58.4     | 54.7     | 56.70                | 2.32               | 4.09                 | 18.32                |
| PCESP-0.45%  |              | 61.7         | 65.1     | 64.4     | 63.3     | 61.6     | 63.22                | 1.57               | 2.48                 | 31.93                |
| PCESP-0.55%  |              | 57.3         | 51.1     | 52.9     | 57.6     | 51.7     | 54.12                | 3.11               | 5.75                 | 12.94                |
3.4. Ultrasonic pulse velocity

The UPV test is conducted to investigate the quality of hardened concrete for homogeneity, cracks, and voids complying with [22]. The concrete samples were taken out of the curing tank after 28 days of normal curing and placed in the concrete laboratory room for 24 hours under an average temperature of 26°C. The UPV test readings are taken on four faces of cube specimens of standard size of 100mmx100mmx100mm with one reading on each face. To ascertain the quality grading of concrete with respect to the pulse velocity, Table 6 gives the recommendations [22]. Concrete with and without superplasticizer was tested for ultrasonic pulse velocity after 28 days. The findings for UPV are tabulated in Table 7, and Fig. 5. Results show that concrete with 0 and 0.15% of SP are of good quality. The concrete with 0.25, 0.35, 0.45, and 0.55% are found to be of excellent quality. It is pertinent to note here that the concrete with 0.15, 0.25, 0.35, 0.45, and 0.55% of SP after 28 days, the UPV test results improved by 3, 4.62, 5.31, 9, and 4.85% as compared to concrete without superplasticizer as plotted in Fig. 6.

| S. No. | UPV (m/s) | Concrete grading (Quality) |
|--------|-----------|----------------------------|
| 1      | Above 4500| Excellent                  |
| 2      | 3500 to 4500| Good                      |
| 3      | 3000 to 3500| Medium                   |
| 4      | Below 3000   | Doubtful                  |

Table 6. Velocity measurements for concrete grading as per BIS

| Mix ID | Age (Days) | Samples test Result (MPa) | Avg. UPV (km/s) | Std. Dev (km/s) | C.O.V (%) | UPV Increase (%) |
|--------|------------|---------------------------|------------------|-----------------|-----------|------------------|
|        |            | S1  S2  S3  S4  S5         |                  |                 |           |                  |
| PCESP-0.00% | 28      | 4.32  4.28  4.35  4.42  4.29 | 4.33             | 0.06             | 1.39       | 0.00             |
| PCESP-0.15% |         | 4.59  4.53  4.24  4.48  4.48 | 4.46             | 0.13             | 2.91       | 3.00             |
| PCESP-0.25% |         | 4.55  4.48  4.39  4.65  4.59 | 4.53             | 0.10             | 2.21       | 4.62             |
| PCESP-0.35% |         | 4.48  4.65  4.53  4.50  4.65 | 4.56             | 0.08             | 1.75       | 5.31             |
| PCESP-0.45% |         | 4.98  4.65  4.72  4.59  4.65 | 4.72             | 0.15             | 3.18       | 9.00             |
| PCESP-0.55% |         | 4.59  4.48  4.53  4.53  4.59 | 4.54             | 0.05             | 1.10       | 4.85             |
3.5. Moudulus of elasticity

The 28 days elastic modulus of concrete has been obtained from a cube specimen of size 100mmx100mmx100mm under the compression testing machine at the recommended rate of loading 2.3kN/s. The deformation was measured by the deflectometer attached to the steel member welded to the lower platen of the CTM. The load and deformation were captured in the video by an 8-megapixel camera installed. The test arrangement is presented in Fig. 7. The load-deformation data had been used to plot stress-strain curves. The plotted curves are shown in Fig. 8. The moduli of elasticity of concrete with varying percentages of PCE-based superplasticizer have been calculated considering the linear component of the curves. The findings are given in Table 7. The improvement of elastic modulus value of concrete with superplasticizer of 0.15, 0.25, 0.35, 0.45, and 0.55% after 28 days is found to be 37.5, 52.2, 54.8, 54.7, and 28.2% as compared to concrete without SP.

| Mix ID | Modulus of elasticity (MPa) |
|--------|-----------------------------|
| PCESP-0.00% | 1.88x10^4 |
| PCESP-0.15% | 2.58x10^4 |
| PCESP-0.25% | 2.86x10^4 |
| PCESP-0.35% | 2.91x10^4 |
| PCESP-0.45% | 2.91x10^4 |
| PCESP-0.55% | 2.41x10^4 |

Figure 5. Relationship between comp. str. and UPV

Figure 6. % increase in UPV results due to SP dose

Figure 7. Test set up for stress-strain curve measuring

Figure 8. Stress-strain curve with various SP level
4. Conclusion

This study experimented the role and influence of PCE based superplasticizer dosage on the properties of fresh and hardened standard M60 concrete with water to binder ratio of 0.40. On the bases of 28 days experimental findings the following conclusions can be summarized.

- The superplasticizer dose of 0.45% in this concrete supported the desired workability with a slump of 105mm. Concrete with a w/c ratio of 0.4 without SP was found giving a slump of 15mm and called very low workable concrete. Concrete with 0.15% of SP dose gave a mix of low workability having a slump of 25mm. Concrete with 0.25%, and 0.35% of SP dose gave a mix of medium workability having a slump of 50mm and 70mm respectively. Concrete with 0.55% of SP dosage caused a slight bleeding and related to the class of high workability.
- The concrete with a dose of SP less than 0.45% entrapped the air giving a lower density of the concrete. Ultrasonic pulse velocity and crushing strength results of concrete having a dose of SP less than 0.45% follow the trend of density. The improvement of crushing strength of concrete containing superplasticizer with 0.15, 0.25, 0.35, 0.45, and 0.55% after 28 days is found to be 5.68, 11.06, 18.32, 31.93, and 12.94% as compared to concrete without SP.
- Concrete with 0 and 0.15% of SP are of good quality. Concrete with 0.25, 0.35, 0.45, and 0.55% are found to be of excellent quality, however ultrasonic pulse velocity of concrete with 0.45% of SP is the maximum. The increase of ultrasonic pulse velocity of concrete with 0.15, 0.25, 0.35, 0.45, and 0.55% of SP after 28 days is 3, 4.62, 5.31, 9, and 4.85% as compared to concrete without superplasticizer.
- Code of practice IS456:2000 in its amendment no. 4 restricts the dosage of superplasticizer to 2% and polycarboxylate-based admixture to 1%. However, experimental results reveal that the maximum percentage of polycarboxylate-based admixture is on the higher side. The experimental results suggest that separate recommendations to restrict the dosages of superplasticizer and polycarboxylate-based admixture be provided for compacting concrete and self-compacting concrete.
- The slump, UPV, and crushing strength of concrete of grade M60 with water to cement ration of 0.40 gives the optimum dose 0.45% by weight of cement, which is quite less than the restricted quantity of the dosage.

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References

[1] ACI 212.4R-93 (1998). ACI Committee, Report on Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete, American concrete institute.
[2] Jurg Schlumpf, (2013). “Sika Concrete Handbook.” Edition 03/ 2013. Sika Services AG Corporate Marketing Service.
[3] Dhanya Sathyan, Kalpathy Balakrishnan Anand, Influence of superplasticizer family on the durability characteristics of fly ash incorporated cement concrete, Construction and Building Materials. 204 (2019) 864-874.
[4] Omar S. Baghabra Al-Amoudi, Taofiq O. Abiola, Mohammed Maslehuddin, Effect of superplasticizer on plastic shrinkage of plain and silica fume cement concretes, Construction and Building Materials. 20 (2006) 642-647.
[5] P. Pereira, L. Evangelista, J. de Brito, the effect of superplasticizers on the mechanical performance of concrete made with fine recycled concrete aggregates, Cement & Concrete Composites. 34 (2012) 1044-1052.
[6] F. Puertas, H. Santos, M. Palacios, S. Martínez-Ramírez, Polycarboxylate superplasticiser admixtures: effect on hydration, microstructure and rheological behaviour in cement pastes, *Advances in Cement Research*. **17** (2005) 77-89.

[7] IS8112:2013, Ordinary Portland Cement, 43 Grade Specification, *Bureau of Indian Standards*.

[8] IS4031(Part 4):1988, Method of physical tests for hydraulic cement, Determination of consistency of standard cement paste, *Bureau of Indian Standards*.

[9] IS4031(Part 5):1988, Method of physical tests for hydraulic cement, Determination of initial and final setting times, *Bureau of Indian Standards*.

[10] IS4031(Part 15):1991, Method of physical tests for hydraulic cement, Determination of fineness by wet sieving, *Bureau of Indian Standards*.

[11] IS4031(Part 6):1988, Method of physical tests for hydraulic cement, Determination of compressive strength of hydraulic cement other than masonry cement, *Bureau of Indian Standards*.

[12] IS650:1991, Standard sand for testing cement specification, *Bureau of Indian Standards*.

[13] IS383:1970, Specification for coarse and fine aggregate from natural sources for concrete, *Bureau of Indian Standards*.

[14] IS2386(Part 1):1963, Method of test for aggregates for concrete, particle size and shape, *Bureau of Indian Standards*.

[15] IS2386(Part 3):1963, Method of test for aggregate for concrete, specific gravity, density, voids, absorption and bulking, *Bureau of Indian Standards*.

[16] IS9103:1999, Concrete admixtures—specification, *Bureau of Indian Standards*.

[17] IS10262:2019, Concrete mix proportioning—Guidelines, *Bureau of Indian Standards*.

[18] IS456:2000, Plain and reinforced concrete—code of practice, *Bureau of Indian Standards*.

[19] IS10086:1982, Specification for moulds for use in tests of cement and concrete, *Bureau of Indian Standards*.

[20] IS1199:1959, Methods of sampling and analysis of concrete, *Bureau of Indian Standards*.

[21] IS516:1959, Methods of tests for strength of concrete, *Bureau of Indian Standards*.

[22] IS13311(Part 1):1992, Non-destructive testing of concrete—Methods of test, Ultrasonic pulse velocity, *Bureau of Indian Standards*. 