Effect of Super-plasticizer Dosages on Fresh State Properties and Early-Age Strength of Concrete

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Abstract. Concrete is the most widely used composite material made up of different ingredients i.e. aggregates (fine, course), cement and water. The early age properties of concrete like workability, setting time and initial strength are continuously changing due to its transient behavior. So it is important to improve the properties of fresh concrete as per the requirements of the structure. The early age properties of concrete control the hardened properties of concrete such as creep, durability and its performance. Admixtures are added to the concrete to achieve a desired change in its properties. This study focuses the effects of super-plasticizer (Duraplast SP-400) dosages on the early age properties of concrete. Six different mixes were prepared with varying SP dosages. Workability, setting time and concrete compressive strength were determined at early age. With the increase in SP dosage, concrete compressive strength at early age reduced however its strength at 28 days increased by adding SP dosage up-to 2%. Workability and setting time were increased but their values decreased down beyond 2 % dosage.

1. Introduction
Concrete is the most widely used construction material which is heterogeneous in nature and is composed of different ingredients like fine aggregate, course aggregate, cement and water. Some additional ingredients i.e. additives and admixtures are also added for the improvement of its properties.[1-3] Concrete properties i.e. compressive strength, hardness, durability, workability etc. vary with time. It has versatile behavior and can be molded into any shape. It is very important to evaluate the concrete properties at early age to achieve construction quality.[3-5]. The early age properties of concrete greatly affect the long-term performance of concrete.[6] But the basic reasons affecting the early age nature of concrete have not yet completely implicit.[7]

The definition of early age of concrete is somewhat controversial among the researchers. The time required to achieve a desired property of concrete is known as early age which is 1-2 days[8].According to Khan early age period is 3 days after concrete casting.[9]. Similarly, Kahouadji considered early age to be 4 days after casting. However according to some of the researchers the early age is 24 hour after placing the concrete.[10]. So, shortly it is the first few hours or days after concrete casting.

Most important early-age attribute of concrete is the compressive strength. In addition, some of the early age properties include workability, setting time (initial, final) and early age compressive strength. If fresh concrete can easily be placed, transported and compacted without any bleeding and segregation then the phenomenon is called Workability of concrete. Workability is mostly measured
by the Consistency of the mix.[11] The amount of wetness of concrete is called consistency.[12] Various tests can be used for the measurement of consistency of concrete i.e. Slump test, Flow test and Kelly-Ball test. Workability is affected by different factors like W/C ratio, type and amount of aggregates, type and amount of cement, sand to aggregate ratio and chemical admixtures. Improper mixing and excess of water cement (w/c) ratio can lead to segregation and bleeding. Segregation and bleeding have worse effects on the quality and strength of concrete. Setting time of concrete is the duration when concrete hardens before it achieves strength or in other words the conversion of concrete from plastic stage to harden stage is known as setting of concrete. [13] It depends on w/c ratio, type and contents of cement, fineness of cement, temperature and admixtures. Standard penetration test based on ASTM C 403 is used for the setting time of concrete. [14]. Admixtures are chemicals which are added to concrete for the enhancement of its fresh and harden properties. ASTM C 494/C 494M – 04 defined seven types of admixtures and each one is used for specific purpose and this study is based on Type-G i.e. Water-reducing, high range, and retarding admixtures.[11]

Accelerating admixtures can be used in cold regions to speed up the construction work. These admixtures can also be used if early removal of formwork or repairing work is required in cold regions. Accelerating admixture reduces the setting time and enhances the early-age strength of concrete. (ASTM Standard C494 (ASTM, 2010). Retarding admixtures are used when site is away from batching plant and delaying in setting time of concrete is required.

Super-plasticizers are highly water reducing second generation admixtures. They are made up of soluble organic polymers which are products of synthetic chemicals and are used to enhance the workability of concrete without increase in amount of water. Some super-plasticizers contains calcium salts which are comparatively less soluble than the super-plasticizers having sodium salts. Super-plasticizers are categorized into four groups i.e. Lignosulphonate (1st generation SP), Sulphonated Naphthalene Formaldehyde (SNF) Condensates, Sulphonated Melamine Formaldehyde (SMF) Condensates (2nd generation SP) and Polycarboxylates (3rd generation SP). Melamine and Naphthalene based Super-plasticizers are in common use.[15] SMF which is commonly referred as Super-plasticizer is when added into the concrete disperses the cement agglomerates. This repulsion in cement particles causes an effective cement hydration with high strength and more durable concrete. SMF is used where low w/c ratio is required like ready mix, pre-stressed and pre-cast concrete structures.

Extensive work has already been done on the effect of admixtures on the early age properties of concrete by the researchers. Khan studied the fly-ash effects on the early age properties of concrete including mechanical, viscoelastic and cracking.[16] Moncef studied the Nano-Caco3 effect on the fresh properties of high performance concrete. [17]

This study focuses the effects of Duraplast 400 SP, Super-plasticizer dosages on the fresh state properties and early the early-age compressive strength of concrete. Excessive dosage may be detrimental due to likelihood of bleeding and segregation [18], hence determining the optimal dosage becomes imperative.

2. Experimental Work
2.1. Materials
Ordinary Portland cement from Best-way group of Company was used as a binding material. Its chemical composition, i.e. percentage of different major oxides, satisfy the requirements of British Standard (BS) [19].

Lawrancpur Sand; (locally available fine aggregate) having fineness modulus of 2.3 was used as a fine aggregate. The specific gravity of sand was determined 2.762. Margala crush, having maximum size of 19 mm, was used as a coarse aggregate. The specific gravity and bulk density for coarse aggregate are 2.757 kg/m³ and 1577 kg/m³ respectively. The properties of aggregates meet the requirements of ASTM C33-03[20]. Portable water was used as mixing water. Duraplast 400 SP, a Synthetic based Super-plasticizer which is highly water reducing admixture, was used which fulfilled ASTM C-494 Type-G.
2.2. Mixture Composition
Six mixtures were prepared using Duraplast 400 SP as Super-plasticizer. Table 1 shows the mixture proportions. The letter ‘S’ shows mixture having Super-plasticizer while the number written in subscript shows the percentage of SP dosage. Mixture S0 does not contain any super-plasticizer while mixtures S0.5, S1.0, S1.5, S2.0, and S2.5 contain 0.5 %, 1.0 %, 1.5 %, 2.0% and 2.5% super-plasticizer dosages respectively. ACI mix design method (Volumetric) was followed for mix design and the volumetric ratio of ingredients (1:1.354:2.876) was selected after trials. Cement, fine aggregate and course aggregates were first mixed in dry condition for a period of one minute and then mixed for 3 minutes after the addition of water and required super-plasticizer dosages.[6] The temperature at the time of mixing was noted.

Table 1: Concrete ingredients per cubic meter volume.

| Mix ID | Cement kg/m³ | Sand kg/m³ | Course aggregate kg/m³ | Water Ltr/m³ | SP Ltr/m³ |
|--------|--------------|------------|-------------------------|--------------|-----------|
| S₀     | 422.86       | 764.81     | 1056.902                | 205.8        | 0         |
| S₀.₅   | 422.86       | 764.81     | 1056.902                | 204          | 1.79      |
| S₁₀    | 422.86       | 764.81     | 1056.902                | 200          | 3.58      |
| S₁.₅   | 422.86       | 764.81     | 1056.902                | 195          | 5.37      |
| S₂₀    | 422.86       | 764.81     | 1056.902                | 187          | 7.17      |
| S₂.₅   | 422.86       | 764.81     | 1056.902                | 178          | 8.96      |

2.3. Testing Methods
After proper mixing, the slump test (ASTM C 143), flow-ability test using V-funnel apparatus and setting time using Vicat apparatus were performed for each mixture. [21]. Twelve standard cylinders (300 mm X 150 mm) were casted for each mixture and were placed on a vibrator, for 30 seconds, for better compaction. The samples were then kept in water for required curing in room temperature. The Compressive strength tests (ASTM C 39) were performed for each sample after 1, 3, 7 and 28 days in a testing machine known as Denison Compression Machine.

3. Results and Discussions

3.1. Flow-ability
Flow-ability was determined by V-funnel test and the time taken by concrete to flow through V-Funnel after 10 second of filling the funnel is called flow time. The flow-ability of concrete having different percentage of SP dosages is shown in Table 2. The flow time value recorded was zero for S₀, S₀.₅ and S₁₀ mixes. However, the flow time decreased with the increase in percentage of SP dosages. The flow time for S₁.₅, S₂₀ and S₂.₅ mixes are 129 sec, 23 sec and 20 sec respectively. The slump value was also enhanced by increasing the percentage of SP dosages as tabulated in Table 2. The control mix (S₀) had slump value of 50 mm and its value was maximum i.e. 225 mm for mix having 2.0 % SP dosage (S₂₀). The slump value was declined by further increasing the SP dosage to 2.5 %.
Table 2: Variation of SP dosages verses slump, flow-ability and Setting time.

| Properties                  | Control mix | 0.5% SP dosage | 1% SP dosage | 1.5% SP dosage | 2% SP dosage | 2.5% SP dosage |
|-----------------------------|-------------|----------------|--------------|----------------|--------------|----------------|
| Temperature (°C)            | 18          | 16.5           | 17.5         | 22             | 23           | 21             |
| Slump value (mm)            | 50          | 90             | 115          | 210            | 225          | 210            |
| Flow ability (Second)       | 0           | 0              | 0            | 129            | 23           | 20             |
| Initial Setting time (minute) | 188        | 330            | 225          | -              | 210          | -              |
| Final setting time (minute) | 330         | 540            | 600          | -              | 480          | -              |

Graphically, the slump values of concrete for all mixes are shown in Figure 1. There is abrupt rise in slump from 1.0% to 1.5%.

3.2. Setting Time
The setting time of mixtures having different percentages of SP dosages are shown in Table 2. It shows that the setting time of concrete increased with the increase in percentage of SP dosage. For example, the final setting time determined for 0%, 0.5%, and 1.0% SP dosages were 330, 540 and 600 minutes respectively. Similarly, the initial setting time noted was also prolonged by increasing the SP dosages as shown in Table 2. Graphically, both the initial and final setting time are shown in Figure 2. The initial setting time is maximum at 0.5% SP dosage. On the other hand, final setting time is maximum at 1.0% SP dosage and decreases at 2% dosage.
Compressive Strength

Concrete compressive strength was determined using standard cylinders at 1, 3, 7 and 28 days. Three specimens were tested each time and their average value was taken. Table 3 shows the compressive strength of control mix and mixes with varying super-plasticizer dosages at 1, 3, 7 and 28 days. The concrete compressive strength for control mix (having no SP dosage) at 1 day was recorded as 5.41 MPa. However its 1 day compressive strength reduced by the addition of SP dosages. The one day compressive strength dropped down to zero by the addition of 2.5 % SP dosage. The compressive strength at 3 days showed the same trend and its value decreased from 15.43 MPa at control mix to 10.11 MPa at 2.5 % SP dosage as shown in Figure 3.The strength for control mix at 7 days was determined as 19 MPa and its value increased as the super-plasticizer dosages were added. At 1.5 % dosage, the 7 days strength reduced to reached to 22 MPa while at 2.5 % dosage its value reached to 26.9 MPa which is the maximum at 7 days. The standard deviation (Std. Dev) values of concrete compressive strength are also tabulated in Table 3.

Table 3: Compressive Strength of Concrete at various percentages of SP Dosage.

| SP Dosage (%) | 1 day Strength (MPa) | Std. Dev | 3 day Strength (MPa) | Std. Dev | 7 day Strength (MPa) | Std. Dev | 28 day Strength (MPa) | Std. Dev |
|---------------|----------------------|----------|----------------------|----------|----------------------|----------|----------------------|----------|
| 0             | 5.41                 | 0.5414   | 15.43                | 2.1486   | 19                   | 0        | 30.68                | 1.2503   |
| 0.5           | 2.53                 | 0.4135   | 15.16                | 0.5414   | 21.6                 | 0.827    | 29.78                | 4.087    |
| 1             | 2.44                 | 0.2707   | 14.79                | 1.658    | 23.82                | 1.952    | 34.29                | 3.4384   |
| 1.5           | 0.72                 | 0.156    | 14.167               | 2.2047   | 22                   | 1.0828   | 36.63                | 5.0305   |
| 2             | 0.542                | 0        | 12.97                | 1.0828   | 24.7                 | 1.654    | 35.19                | 2.3599   |
| 2.5           | 0                    | 0        | 10.11                | 1.6905   | 26.9                 | 4.099    | 38.44                | 1.875    |

Similarly, the 28 days compressive strength enhanced as the percentage of SP dosage was increased. The control mix at 28 days has strength of 30.68 MPa and by adding 0.5 % SP its value dropped down to 29.78 MPa. As the percentage of dosages increased its 28 days compressive strength increased and the maximum value of 38.44 MPa was achieved at 2.5 % dosage as shown in Figure 3.
The relations between SP dosage and compressive strength at different age are developed as shown in Figure 3 where ‘x’ shows the percentage of SP dosage and ‘Y’ is the compressive strength of concrete.

Figure 3: Variation of concrete compressive strength with increase in SP dosages.

4. Conclusions

Workability and flow-ability of concrete increased with the increase in percentage of Super-plasticizer dosages with optimum limit of 2%. The initial setting time is maximum at 0.5% dosage however the optimum value for dosage is 1.0% for the final setting time. So the retarding behavior is improved using Super-plasticizer addition in the mix. The early age compressive strength decreased with the increase in percentage of dosages however the 7 and 28 days strength increased.

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