Optimization of Comprehensive Strength of Concrete by adding different Dosages of Superplasticizers via Marsh Cone Test

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Abstract

Concrete is the most widely used construction material in the world, and its performance depends heavily on its mix design. The strength and workability of concrete are two crucial parameters that determine its suitability for a variety of applications. Workability refers to the ease with which the concrete can be mixed, transported, placed, and finished, while compressive strength is a measure of the concrete's ability to resist axial loads. These properties are closely interrelated and can be influenced by several factors, including the water-cement ratio, the type and amount of aggregate, and the addition of chemical admixtures such as superplasticizers. Superplasticizers (SPs) are chemical admixtures used in concrete to enhance its workability without increasing the water content. They are particularly useful in producing high-performance concrete mixes, such as those used in high-strength concrete, self-compacting concrete, and in situations requiring improved pumpability. This study aims to explore the effect of varying superplasticizer dosages on both the workability and the compressive strength of concrete. The workability is assessed using the Marsh Cone Test, a widely accepted method for determining the flow characteristics of concrete mixes. The incorporation of superplasticizers (SPs) into cement-based materials, such as cement paste and mortar, has become a significant area of study due to its potential to improve workability, reduce water content, and enhance mechanical properties. The proposed research paper is based on the Marsh Cone Test are conducted to evaluate the fresh properties of various combinations of cement and superplasticizer. Compressive strength test is also conducted to assess the hardening properties of cement mortar. The effects of different types of superplasticizers, dosage variations, and their interactions with other additives are examined. Experimental data, including archaeological behavior, compressive strength, and microstructural analysis, are discussed to present a comprehensive understanding of how superplasticizers contribute to the performance of cement-based materials.

Keywords : Superplasticizers, Concrete, Marsh Cone Test, Compressive Strength, Optimization, Dosage, Workability

1. Introduction

Concrete is a versatile and commonly used construction material composed of cement, aggregates, and water. Its strength is an essential factor in determining the durability and stability of concrete structures [1]. Compressive strength is a critical parameter for assessing the quality of concrete, and several methods have been developed to enhance its performance. One of the most effective ways to improve the performance of concrete is by adding superplasticizers (SPs), which are chemical admixtures that significantly improve the workability of concrete without increasing water content [2].

Superplasticizers are also known as high-range water reducers, as they allow a significant reduction in the water-to-cement ratio while maintaining or improving the flowability of the mixture [3-4]. Their primary function is to increase the mobility of the cement particles, leading to a more uniform mixture and enhanced properties. However, the impact of superplasticizers on compressive strength is influenced by the dosage, type of SP, and the water-to-cement ratio. Hence, optimizing the dosage of SPs is crucial for achieving the desired strength and workability balance. This study aims to explore the optimization of concrete's comprehensive strength by varying the dosages of superplasticizers and assessing the impact on concrete properties through the Marsh cone test, which provides a practical measure of workability.

Cement-based materials are essential in construction, offering versatility and strength. However, challenges related to workability, water-to-cement ratio, and long-term performance necessitate the development of additives to enhance these properties. Superplasticizers, or high-range water reducers, have emerged as critical additives for improving the performance of cement paste and mortar. Superplasticizers allow for a reduction in the water content while maintaining or enhancing workability, which is particularly beneficial in high-strength concrete and complex construction applications [5-6].
Superplasticizers are increasingly used in the production of construction materials, making them a relatively new addition to the composition of such materials. Various brands of cement and superplasticizers are available, and these materials comply with their respective standards. However, the performance of concrete can vary with each brand of cement and superplasticizer, even when the source and quality of the concrete are the same. This variation can cause confusion among users regarding which brand of cement and superplasticizer to choose. Additionally, selecting the optimal amount of superplasticizer for each cement brand is a complex task, influenced by factors like the composition of both the cement and the superplasticizer. Achieving the best fluidizing effect with the least amount of superplasticizer is also an important economic consideration. Incompatibility between cement and superplasticizers can lead to issues such as delayed setting, reduced strength, and the formation of micro-cracks, all of which affect the strength and durability of structures (Shrivastava and Munendra, 2016; Agarwal et al., 2000) [7]. The physical and chemical properties of both cement and superplasticizers can influence the characteristics of cement mortar and concrete. The type, dosage, and method of incorporating superplasticizers in a cement mix can impact strength development and cost-effectiveness. Therefore, it is crucial to assess the compatibility between cement and superplasticizers.

This study investigates the influence of different superplasticizers and their dosages on the rheological properties of cement paste and the compressive strength of cement mortar. A comprehensive trial study is conducted to evaluate both the fresh and hardened properties of cement paste and mortar under the effect of superplasticizers [8].

This paper aims to explore the optimization of cement paste and mortar performance by examining the effects of superplasticizers. The optimization process involves improving the rheological properties, enhancing strength development, and ensuring durability, which are vital for both fresh and hardened states of cementitious materials.

2. Literature Review

Various studies have investigated the impact of superplasticizers on concrete properties, particularly its workability and compressive strength. Superplasticizers are chemical admixtures that improve the flowability of concrete without the addition of extra water. They work by dispersing the cement particles in the mixture, preventing particle agglomeration and enabling a more homogeneous mixture. Superplasticizers are particularly beneficial in producing high-strength concrete, where a lower water-to-cement ratio is crucial to achieving desired strength. Various types of superplasticizers, such as sulfonated naphthalene formaldehyde condensates (SNF), melamine formaldehyde condensates, and polycarboxylate ethers (PCE), have been studied in the context of concrete optimization (Mehta & Monteiro, 2014) [1].

Superplasticizers can enhance the workability of concrete by reducing the viscosity of the fresh mixture. This is important in concrete placement, particularly for complex formworks or congested reinforcement areas. However, an optimal dosage of SP is necessary because an excess can lead to problems such as segregation, excessive bleeding, or a decrease in long-term strength development due to insufficient bonding of the cement paste to the aggregate (Van Breugel, 1997) [9].

According to Mehta (2001), superplasticizers improve the fluidity of concrete, which is essential for achieving a homogeneous mixture and ease of placement. However, the impact of these admixtures on compressive strength is not always linear, and excessive dosages may result in segregation and bleeding of the mixture [10].

A study by Torkaman et al. (2018) concluded that superplasticizers could reduce the water-to-cement ratio while enhancing the compressive strength of concrete [11]. They noted that the correct dosage of SPs is critical, as an excess amount may reduce the strength by causing workability issues. Additionally, the type of superplasticizer used plays a significant role. Polycarboxylate-based superplasticizers are found to be more efficient in enhancing both workability and strength compared to other types like sulfonated naphthalene formaldehyde condensates (SNF) (Gunduz et al., 2019) [12].

The Marsh cone test, widely used to assess the workability of fresh concrete, has been found to provide a reliable method for determining the flowability of concrete mixtures containing superplasticizers. Previous research by Palaniappan et al. (2020) showed that the use of the

Marsh cone test can help determine the optimal dosage of SPs for achieving the desired consistency [13].
Workability is an essential property of fresh concrete, influencing its ease of mixing, transport, and placement. The Marsh cone test is widely used as an indicator of concrete's workability, as it measures the time taken for a fixed amount of water to flow through a cone under gravity. The higher the flow rate, the better the workability (Palaniappan et al., 2020) [13].

Several studies have examined the effect of varying superplasticizer dosages on the workability of concrete using the Marsh cone test. According to Aïtcin (1998), increasing the dosage of SP reduces the flow time, improving the concrete's fluidity without increasing the water content. For instance, Zhang et al. (2019) observed that the flow time significantly decreased with increasing SP dosage in concrete, indicating improved workability. In their study, mixes with 1.5% and 2.0% SP by weight of cement showed the best workability, as measured by the Marsh cone test, due to the effective dispersion of cement particles [14].
However, while SPs improve the flowability of fresh concrete, their effect can vary based on the type of SP used, the water-to-cement ratio, and the aggregate characteristics. Li et al. (2016) concluded that the optimum dosage of SP lies between 1.0% and 2.0%, where a balance between workability and strength is achieved [15]. Beyond this range, the mixture becomes too fluid and may experience issues like segregation and loss of cohesion, which negatively affect both workability and strength.

To achieve the optimal performance of concrete, it is essential to identify the correct dosage of superplasticizers that maximizes both the workability and compressive strength of the mixture. Optimization typically involves balancing the dosage of SPs so that workability is improved without compromising strength or causing other issues like segregation.
In an investigation by Gunduz et al. (2019), different dosages of SP were tested, and it was found that a dosage of 2.0% by weight of cement provided the best balance between improved workability and compressive strength. However, the optimum dosage can vary based on the specific type of SP, the cement type, and the aggregates used [12].
Studies by Kumar et al. (2017) and Hameed et al. (2015) also support the finding that the optimum dosage for strength and workability optimization is generally between 1.5% and 2.0%. These studies suggest that higher doses of SP (above 2.0%) lead to diminishing returns in compressive strength and can even reduce the long-term strength due to issues such as excessive water retention and poor particle cohesion [16].

3. Materials and Methods

a) Materials

i. **Cement:** Ordinary Portland Cement (OPC) of grade 53 was used for all the concrete mixes.
ii. Aggregates: Fine aggregates (sand) and coarse aggregates (crushed stone) conforming to IS 383: 1970 were used in the mixture.
iii. **Water:** Potable water was used for mixing and curing.

iv. **Superplasticizers:** A commercially available polycarboxylate ether-based superplasticizer (SP) was used for the experiments. The dosage of SP was varied between 0.5%, 1.0%, 1.5% and 2.0% by weight of cement.

b) **Concrete Mix Design:** The concrete mix was designed for a target compressive strength of 30 MPa at 28 days. The water-to-cement ratio was fixed at 0.45 for all mixtures, ensuring a consistent base for comparison. The mixes were prepared with the following dosages of superplasticizer:
   i. Control Mix: No superplasticizer.
   ii. Mix 1: 0.5% SP.
   iii. Mix 2: 1.0% SP.
   iv. Mix 3: 1.5% SP.
   v. Mix 4: 2.0% SP.

c) **Mixing Process:** The materials were mixed in a standard laboratory concrete mixer. First, the dry ingredients (cement and aggregates) were thoroughly mixed, followed by the addition of water and superplasticizer. The mixing time was kept constant at 5 minutes for all mixes.

d) **Marsh Cone Test:** The Marsh cone test was conducted to determine the flowability of each concrete mix. A standard Marsh cone, equipped with a 25 mm opening at the bottom, was used to measure the time it took for a known volume of water to flow through the cone. The flow time (in seconds) was recorded for each mix, and the results were used to estimate the workability**.**

4. Aim and Objective :

The objective of this study is to examine the extent to which, the type and amount of superplasticizers may affect the properties and performance of cement mortar. The research programme is concerned with the effect of compatibility for various types of mortar made with the different cement and superplasticizers. The experimental program includes Marsh Cone Test and Normal Consistency, IST, FST and Compressive Strength Test. The properties of superplasticized cement paste and mortar are compared with cement paste and mortar without superplasticizers.

5. Proposed scheme:

In this study, three different brands of cement (C1, C2, and C3) and three types of superplasticizers (SP1, SP2, and SP3) are examined. A series of tests, including the M**ash Cone Test and Compressive Strength Tests**, are conducted to assess the impact of superplasticizers on the performance of the cements in both the fresh and hardened states. Various combinations of cement and superplasticizers are tested, including C1-SP1, C2-SP1, C3-SP1, C1-SP2, C2-SP2, C3-SP2, C1-SP3, C2-SP3, and C3-SP3. A constant water/cement ratio of 0.5 (by weight) is maintained for all mixes. The purpose of varying the dosage of superplasticizers is to evaluate their effect across different combinations of cement and superplasticizer. The experimental program is divided into two phases, which are described below.

a) **First Phase**: In this phase, Mash Cone, Normal Consistency, IST and FST tests are conducted on cement mixes using different combinations of these cements and superplasticizers. Dosage of superplasticizers 0.5%, 1%, 1.5% and 2% are used in the first phase. Marsh cone tests are conducted at 5 minutes and 60 minutes to check the retention time in each case to observe the effect of superplasticizer on flowability of fresh cement paste.

b) **Second Phase**: In this phase, a one-month study is conducted to determine compressive strength of mortar made with various combinations of cements and superplasticizers. The varying quantities of superplasticizers are used as 0.5%, 1.0%, 1.5% and 2.0% to get an idea of the effect of quantity of superplasticizers on different combinations of cement and superplasticizer, also to determine the optimum quantity of superplasticizer for the most compatible case. For determination of compressive strength at 7days, 14 days and 28 days, mortar cubes of 70.6 mm are tested. An average value of the results of 5 cube specimen is taken to be the representative value of compressive strength at 7, 14 and 28 days. For each combination of cement & superplasticizer, a control mix of the same composition, but without superplasticizer, is made. The compressive strength of all the different types of mortar mixes were compared with the compressive strength of their respective control mixes. The change in percentage of compressive strength in each case due to addition of superplasticizer is also determined

6. Result and Discussion

a) First Phase

i. **Marsh Cone Test:** In this study, fluid properties of cement paste are determined for three different brands of cement (C1, C2 & C3) and superplasticizers (SP1, SP2 and SP3) with varying quantities of superplasticizers (0.5%, 1.0%, 1.5% and 2.0%) at constant water cement ratio (0.5%) through Marsh Cone apparatus at 5 minutes and 60 minutes. The results are shown in Table 5.1. It is noticed from the results that superplasticizer SP1 provides a very viscous mixture with all cements. SP2 also works well for cement C3 but SP3 works in a better way even after 60 minutes of retention. It is seen that SP3 has best effect on all the cements. The fluid property of C3SP3 (at 1.0% dose of SP3) are better than those of all other combinations after 60 minutes retention time. The Marsh cone test results of C2SP3 are also better at 1.5% and 2% dose of SP3, however, the test result of other combinations is not found satisfactory even upto 2% of SP3 dose.

Table 6.1: Marsh Cone setting times for cement slurry at different dosages of superplasticizers and their corresponding retention times.

Cement-Superplasticizer Combination	Marsh cone time for cement slurry in sec. (for SP dose % by wt. of cement)			
	0.5	**1**	**1.5**	**2**
C1-SP1 (5 minutes)	212	130	120	120
C1-SP1 (60 minutes)	360	280	260	255
C1-SP2 (5 minutes)	165	127	100	105
C1-SP2 (60 minutes)	310	250	160	140
C1-SP3 (5 minutes)	85	71	65	65
C1-SP3 (60 minutes)	180	98	76	80
C2-SP1 (5 minutes)	210	120	106	105
C2-SP1 (60 minutes)	330	230	137	130
C2-SP2 (5 minutes)	150	100	95	80
C2-SP2(60 minutes)	240	160	130	132
C2-SP3 (5 minutes)	75	67	60	59
C2-SP3 (60 minutes)	170	86	64	63
C3-SP1 (5 minutes)	130	100	100	100
C3-SP1 (60 minutes)	320	190	133	130
C3-SP2 (5 minutes)	125	88	85	84
C3-SP2 (60 minutes)	220	130	100	105
C3-SP3 (5 minutes)	68	56	57	56
C3-SP3 (60 minutes)	130	59	58	57

The graphs also illustrate the compatibility and incompatibility of cement and superplasticizer combination. Figures 6.1 to 6.9, depict the relation between dosage of superplasticizers and marsh cone flow time determine at 5 minutes and 60 minutes.

By increasing the dosage of superplasticizer, the marsh cone time decreases since the superplasticizer helps to retain the mortar in plastic state for longer time and thus the mortar can be transported for longer distances. However, over dosage of superplasticizer leads to more marsh cone time, which is undesirable.

Finally, comparisons are made between the superplasticizer and normal mortar. It is observed that the setting time of superplasticized mortar is longer than the normal mortar. Trendline equations are also determined from the results and shown in Table 6.1.

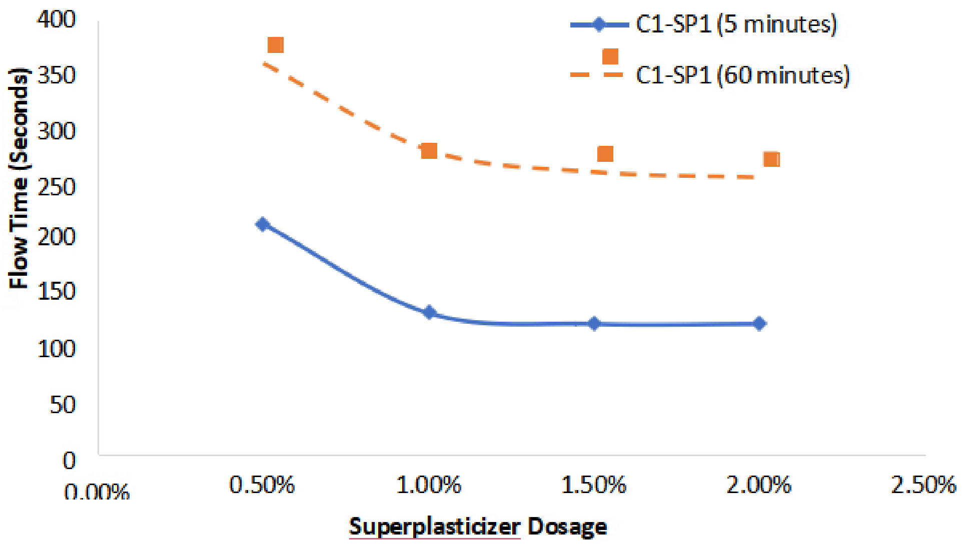
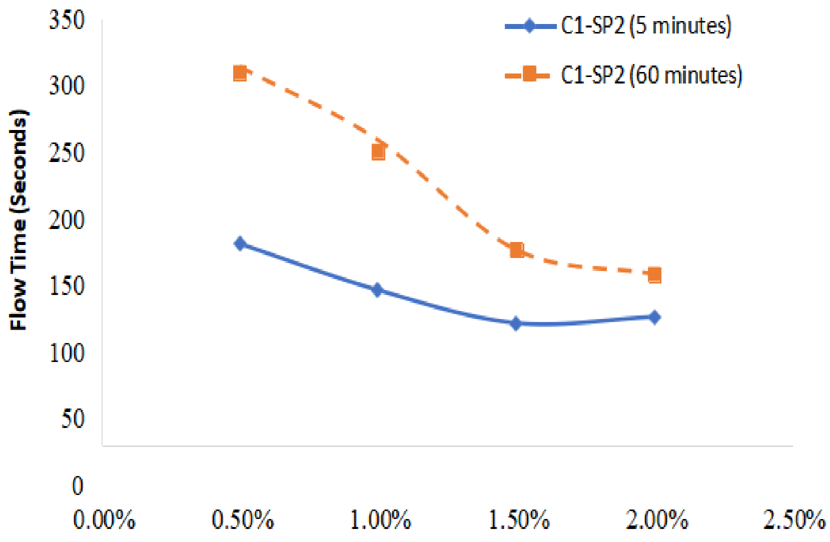


Fig. 6.1: Variation in Marsh Cone flow time of cement (C1) and superplasticizer (SP1) at different dosages, measured at 5 minutes and 60 minutes



Superplasticizer Dosage

Fig. 6.2: Variation in Marsh Cone flow time of cement (C1) and superplasticizer (SP2) at different dosages, recorded at 5 minutes and 60 minutes.

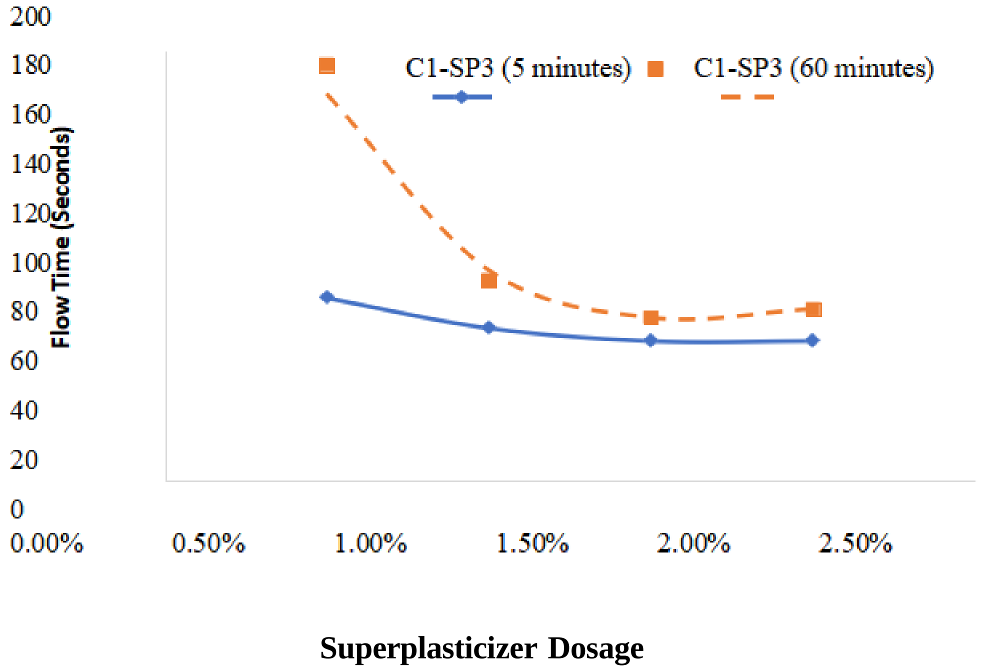


Fig. 6.3: Variation in Marsh Cone flow time of cement (C1) and superplasticizer (SP3) at different dosages, observed at 5 minutes and 60 minutes

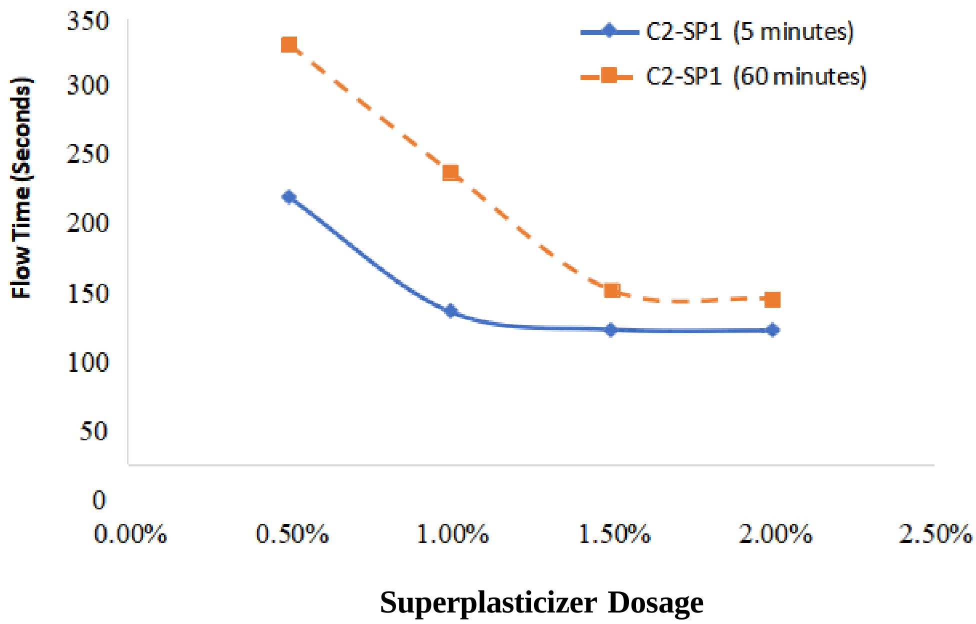


Fig. 6.4: Variation in Marsh Cone flow time of cement (C2) and superplasticizer(SP1) at different dosages, measured at 5 minutes and 60 minutes.

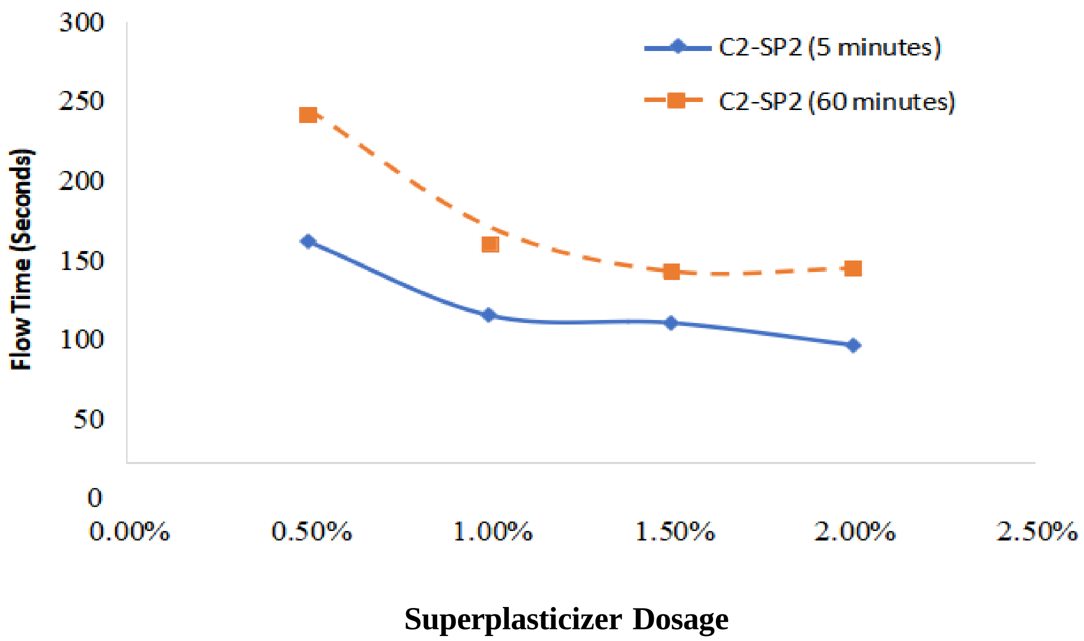


Fig. 6.5: Variation in Marsh Cone flow time of cement (C2) and superplasticizer (SP2) at different dosages, measured at both 5 minutes and 60 minutes.

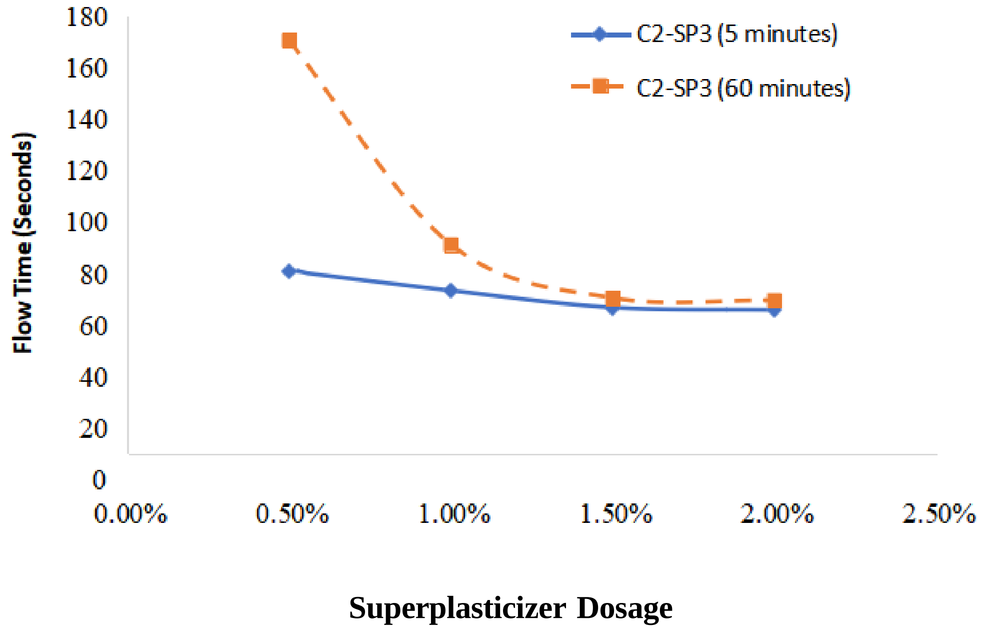


Fig. 6.6: Variation in Marsh Cone flow time of cement (C2) and superplasticizer (SP3) at different dosages, observed at 5 minutes and 60 minutes.

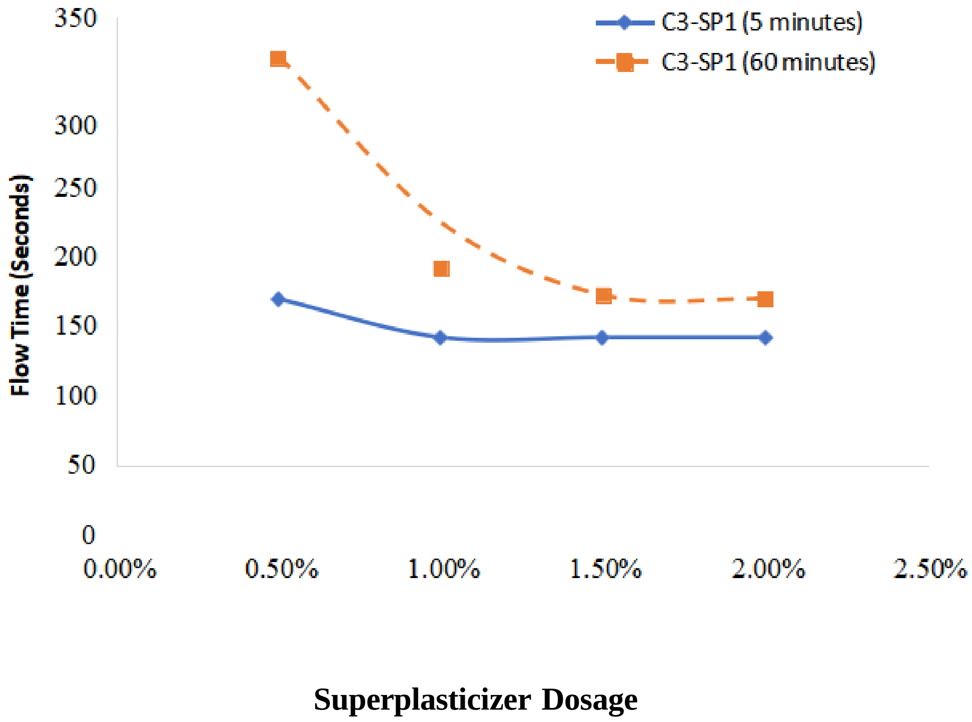


Fig. 6.7: Variation in Marsh Cone flow time of cement (C3) and superplasticizer (SP1) at different dosages, measured at 5 minutes and after 60 minutes of retention

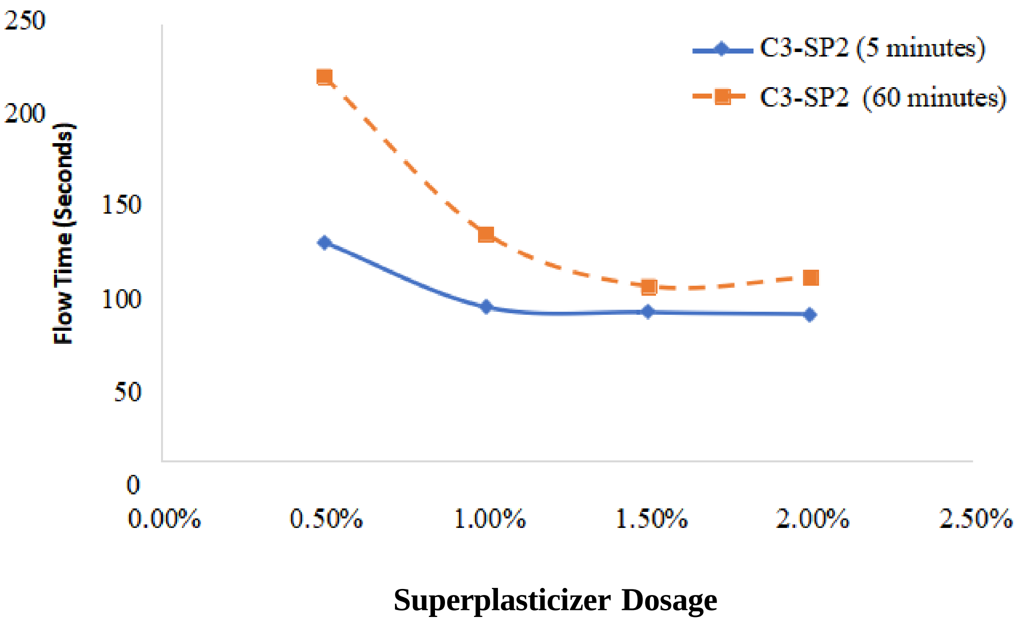


Fig. 6.8: Variation in Marsh Cone flow time of cement (C3) and superplasticizer (SP2) at different dosages, recorded at 5 minutes and after 60 minutes of retention

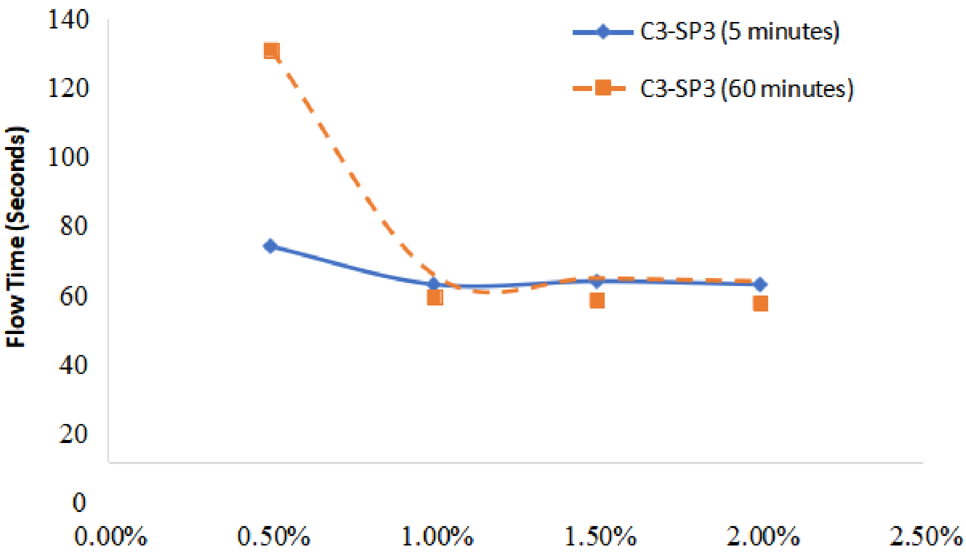


Fig. 6.9: Variation in Marsh Cone flow time of cement (C3) and superplasticizer (SP3) at different dosages, measured at 5 minutes and after 60 minutes of retention

Table 6.2: Equation of the trendline for the results of the Marsh Cone Test.

Cement- Superplasticizer Combination	Trendline Equation	General Equation
C1-SP1 (5 minutes)	y = -6700x + 372.5	y = -6210x + 294.75
C1-SP1 (60 minutes)	y = -5720x + 217	
C1-SP2 (5 minutes)	y = -12000x + 365	y = -8070x + 270.5
C1-SP2 (60 minutes)	y = -4140x + 176	
C1-SP3 (5 minutes)	y = -6440x + 189	y = -3880x + 138.5
C1-SP3 (60 minutes)	y = -1320x + 88	
C2-SP1 (5 minutes)	y = -13860x + 380	y = -10220x + 298.75
C2-SP1 (60 minutes)	y = -6580x + 217.5	
C2-SP2 (5 minutes)	y = -7080x + 254	y = -5690x + 207
C2-SP2 (60 minutes)	y = -4300x + 160	
C2-SP3 (5 minutes)	y = -6860x + 181.5	y = -3980x + 130
C2-SP3 (60 minutes)	y = -1100x + 79	
C3-SP1 (5 minutes)	y = -7520x + 127	y = -4660x + 128.5
C3-SP1 (60 minutes)	y = -1800x + 130	

Cement- Superplasticizer Combination	Trendline Equation	General Equation
C3-SP2 (5 minutes)	y = -7500x + 232.5	y = -5010x + 179.75
C3-SP2 (60 minutes)	y = -2520x + 127	
C3-SP3 (5 minutes)	y = -4400x + 131	y = -2550x + 99.5
C3-SP3 (60 minutes)	y = -700x + 68	

From this analysis, it can be concluded that the fluid property of cement superplasticizer combination C3SP3 is satisfactory at a lower percentage of SP3 dosage than other combinations after 60 minutes retention time. Hence, combination C3SP3 is the most compatible pair of cement & superplasticizer depending on the marsh cone flow time at 5 minutes and 60 minutes retention time.

6.1 Workability (Marsh Cone Test)

The flowability of the concrete mixes, measured using the Marsh cone test, showed a clear trend of improvement with increasing dosages of superplasticizer. The control mix (without SP) had the lowest flow rate, taking approximately 45 seconds for 1000 mL of water to flow through the cone. As the dosage of SP increased, the flow time decreased, indicating enhanced workability.

- **Control Mix:** 45 seconds
- **Mix 1 (0.5% SP):** 40 seconds
- **Mix 2 (1.0% SP):** 35 seconds
- **Mix 3 (1.5% SP):** 30 seconds
- **Mix 4 (2.0% SP):** 25 seconds

The results demonstrate that increasing the dosage of SP improves the workability of the concrete, making it easier to handle and place.

6.2 Compressive Strength

The highest compressive strength values of a mix (1:4) at 28 days for C1SP3, C2SP3 and C3SP3 are observed as 25 MPa, 27 MPa and 30.66 MPa at 2%, 1.5% and 1% respectively. The highest compressive strength at 28 days is obtained for C3SP3 combination at 1.0% SP3 dose indicating most compatible pair.

7. Discussion

The results show that the addition of superplasticizers improves both the workability and compressive strength of concrete. The increase in workability is particularly important for high-strength concrete, where reduced water content is crucial for achieving optimal strength. However, excessive amounts of superplasticizer (above 2.0%) can lead to a slight decrease in strength, possibly due to an imbalance in the cement paste and aggregate interface, which could cause issues such as segregation and water bleeding.

8. Conclusion

This research demonstrates the beneficial effects of superplasticizers on both the workability and compressive strength of concrete. The Marsh cone test provided a practical means of assessing the workability of concrete mixes with varying dosages of superplasticizer. The optimal dosage for enhancing both workability and strength was found to be 2.0%. Beyond this dosage, the improvements in strength were marginal, indicating that an excessive amount of superplasticizer may negatively affect the mixture's properties. Thus, the study provides a basis for the optimization of concrete mixtures for high-strength applications by balancing superplasticizer dosages to achieve the desired workability and compressive strength.

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