

# Compatibility of Ether-Based Poly-Carboxylate Superplasticizer with Mineral Admixtures Blended with OPC

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**Abstract** The marsh cone test is a defined procedure to determine the quantitative fluidity of cement with mineral admixtures along with the saturation dosage and the efficiency of the superplasticizer (SP). In the present study, three mineral admixtures, micro-silica (MS), fly ash (FA), and ground granulated blast furnace slag (GGBFS) were used as cement replacement. Poly-carboxylate ether-based superplasticizer was used as a chemical admixture. Blends of cement and mineral admixtures with water/binder (w/b) ratios ranging from 0.40 to 0.60 at every interval of 0.05 were examined against the different dosages for SP. All the binder mixes reached a saturation dosage for SP, after which there is no change in the fluidity of the mix. The obtained dosage is considered the maximum amount of SP added to the concrete with the respective binder type. The replacement percentage of cement with mineral admixture also affected the fluidity of the binder mix. A decrease in the fluidity of binder mix was observed on increasing the amount of mineral admixture in it. At a higher w/b ratio, a significantly less SP dosage is required to attain saturation point and vice-versa. Based on the experimental investigation, it is concluded that the efficiency of SP depends on its dosage, the w/b ratio, the type and amount of mineral admixture.

**Keywords** Cement, Fly Ash, Micro Silica, GGBS, Mineral Admixture, Superplasticizer, Fluidity, Marsh Cone

## 1. Introduction

Concrete has widespread applications in different spheres of infrastructure, and sometimes ordinary concrete alone may not withstand certain adverse conditions due to its lesser longevity and lower strength. Therefore, chemical or mineral admixtures are applied to enhance the properties of the concrete. The properties of the concrete are affected differently by different admixtures [1].

Admixtures are components injected into the concrete mix during the mixing. They have many beneficial influences on concrete, including reduced water requirements, enhanced workability, controlled setting, accelerated hardening, improved strength, better durability, desired coloration, volume changes, etc. The pozzolanic mineral admixtures are finely divided materials used in cement mortar and concrete to achieve specific engineering properties. Using mineral admixtures in concrete serves the dual purpose of economic and environmental benefits, as almost all of them are derived as waste from various industries [2].

The latest trend is to utilize more mineral admixtures as a direct replacement in the range of 5-70% by mass of total cementitious materials. In addition to reducing the use of cement, mineral admixtures also enhance the chemical, mechanical, and physical qualities [3,4]. The Concrete Admixture Handbook [2] describes that finely divided mineral admixture reduces the quantity of water required to achieve specific consistency of mortar or concrete;

however, when the same is used in a large amount, water demand increases. In such cases, chemical additives like superplasticizers and air-entraining agents are used to maintain a particular consistency. The fine mineral admixtures do not lead to a denser granular packing of the cementitious matrix without SP [5].

The polycarboxylate (PC) SP has a high water absorption rate and long-term slump retention at a low dosage. Still, its chemical structures determine its predominant mechanism and efficiency in cement-based materials [6].

SPs were first employed in concrete in 1931 when a road construction organization in Massachusetts utilized naphthalene sulfonate formaldehyde condensate (NSFC) to construct a road [7]. The other SP of different chemical families that appeared since 1930 are lignosulfonates, polymelamine sulfonates, vinyl copolymers, polyethylene oxide phosphonates (PEG). The development of the new generation of SPs replaced the older SPs in many applications [8]. Compared to poly-carboxylate and poly naphthalene-based SPs, lignosulfonates-based SPs have a longer workable time and initial setting time [9].

High-range water-reducing admixtures or SPs are critical ingredients in modern concrete to improve flowability at low water content. SPs are commonly used in high-performance, self-consolidating, fiber-reinforced concrete, and other applications [10]. SPs are surface-active agents that change the surface charges of cement particles to disperse them into smaller agglomerates. The formation of such cement clusters during the initial mixing of Portland cement with water is due to relatively large Van der Waals forces of attraction, which work at inter-particle distances of 5 to 7 nanometres (nm). Plasticizers can overcome this force by exerting a strong repulsive force at the surface-liquid interface, allowing the trapped water to escape. The loosely entrapped water particles are associated with the clustered particles of the cement. This water is then used in the hydration process, thus decreasing the amount of water that is to be added additionally otherwise [11]. The entrapped water between the cement particles is released when the SP is present; as a result, the fluidity or workability of concrete increases [12].

As a consequence, the ability to maintain consistency and flow is enhanced. These chemical admixtures are active for a certain amount of time before their effect wears off, and the cement paste starts to stiffen [13]. Since the dispersion of cement particles is the primary activity of SP, it is critical to investigate and comprehend dispersion behavior.

The molecules of the SP get adsorbed on the surface of the hydrated cement matrix and create an electrostatic repulsive force that releases the entrapped water molecules from the agglomerated cement particles, thus avoiding flocculation [2,14,15]. According to [16], the anionic charge density of additives plays a significant role in their

adsorption onto the binder surface; additives with high anionic charge density adsorbed strongly onto the surface binder compared to additives with low anionic charge density. [17], reported that the amount of  $C_3A$  and the formation of soluble alkali sulfates significantly influence the adsorption rate of SP. [18] said that the dispersal of the cement particles could be attributed to the formation of the highly negative zeta potential of the cement pastes by the SP.

It is essential to ascertain whether a particular SP is compatible with the cement before employing it in mass concrete works [19,20] cited a total loss of fluidity when Portland cement was replaced by blended cement, and the SP content increased from 0.5 to 3%. The paper also reported that when SP exhibits compatibility with a specific mix composition, it loses compatibility with the incorporation mineral admixture. By measuring the flow time of the paste, the cement-SP compatibility can be investigated.

The primary purpose of this study is to investigate the interaction between cementitious material and SP by determining the fluidity of a binding paste/slurry with or without mineral admixtures. The efficiency of SP for different binder mixes is also calculated. A cementing material and SP are compatible if the definite saturation point of SP dosage can be determined from the graph of flow time vs SP dosage, as shown in Fig. 9. If such criteria are not fulfilled, the cement and the SP are labelled as incompatible.

## 2. The Marsh Cone Test

The Marsh cone test is used to resolve the comparative fluidity of pastes with the presence of SP. It helps to understand the fluidity of the cement paste by calculating the time taken for the discharge of a specified amount of paste through a small opening of a cone, with the longer time required signifying lesser fluidity [21]. The type of admixtures, their content, and the dosage of SP influence the Marsh cone flow time [22]. The amount of time it takes for a paste to flow through the cone is proportional to its viscosity. The flow time increases as the viscosity increases, and so it becomes an index of the fluidity of paste [23]. When the flow time stops decreasing, or the dose of the SP reaches a point beyond which it has no fluidizing effect, the dosage of SP is said to get a saturation point [24,25]. The shape of the Marsh cone flow time vs. SP dosage curve can provide a general understanding of the saturation point. A more quantitative description is possible by analyzing the slope of the curve [21].

According to [21], the cement-SP combinations that do not display a well-defined saturation point suggest an incompatible cement-SP relation. The saturation point can help determine the amount of SP to be added. The saturation level is the maximum for the specific type of

cement, w/b ratio, and amount of admixture used. The above research also suggests that the cement paste should be considered to assess the saturation dose of SP rather than the mortar. This is because the sand content is not defined until the concrete has been optimized, and a priori assumption of the mortar composition would restrict the scope of the paste optimization to only fluidity.

The admixture dosage is measured as a weight-to-weight ratio between the solid substance and the cement [21]. Concrete is a non-Newtonian fluid with rheological properties that can be represented by the Bingham model [26]. According to [27], the Marsh cone accuracy rapidly diminishes beyond a plastic yield of 20 Pa. The cement paste is considered Newtonian fluid in the Marsh cone test, which is never ideally accurate. Bingham Model [20,21] suggested that the addition of superplasticizer decreases the yield shears stress by keeping the plastic viscosity unaffected [20,22], [23].

The study found that when a large amount of PCE is added, the dynamic yield stress lowers, and the cement particles or agglomerates become more diffused, resulting in smaller agglomerates [28]. According to [29], a low dose of PCE resulted in a significant reduction of the yield stress of over 70%. Thus, it can be well estimated that the flow times obtained from the Marsh cone will have equivalent results as the yield shear stress, just like workability is determined using a slump test with Abram's cone's help [21]. Also, the rheology of the paste used in concrete differs from that synthesized independently [14,24,25]. This indicates that the ultimate development of the configuration should be done directly during tests conducted on concrete [19,30] observed that the Marsh cone has two limits. First, if the viscosity of the tested fluid is too low, there is no linear relationship between viscosity and flow time. Second, if the pressure gradient created by the fluid weight above the nozzle is insufficient for the shear stress to overcome the yield stress of the tested fluid in the nozzle, the flow may not occur.

A metal Marsh cone with the dimensions and experimental setup depicted in Fig. 1 and Fig. 2 was used to determine SP's optimum dose and efficiency. The time it took 1000 ml of paste to flow through the cone's orifice was measured. Marsh cone flow time is the name given to this period.

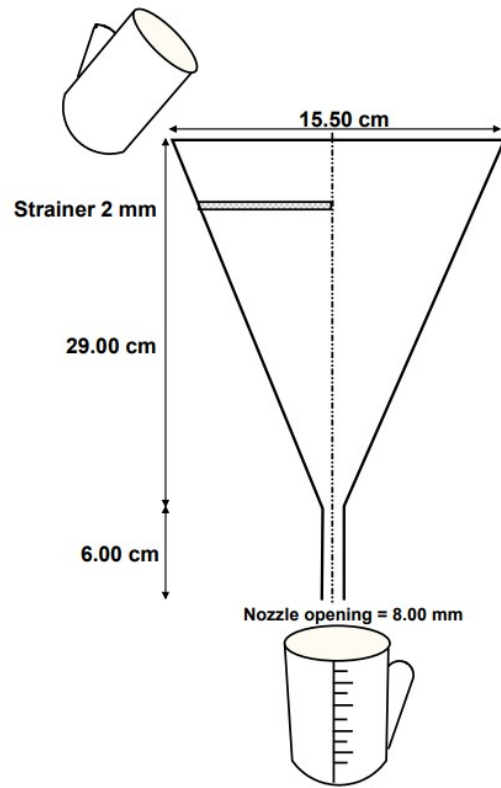


Figure 1. Marsh Cone dimension [21,31]



Figure 2. Experimental setup

### 3. Experimental Program

#### 3.1. Materials

##### 3.1.1. Cement

This analysis used the OPC 43 grade conforming to [32]. The chemical composition and SEM image of OPC are shown in Fig. 3. Its specific surface area, mean particle size, density, and specific gravity were 3312 cm<sup>2</sup>/g, 16 μm, 1440 kg/m<sup>3</sup>, and 3.16, respectively.

##### 3.1.2. Micro Silica

Micro silica was used as a mineral admixture conforming to [33]. The chemical composition and SEM image of MS are shown in Fig. 4. Its specific surface area, mean particle size, density, and specific gravity were 4200 cm<sup>2</sup>/g, 13 μm, 962 kg/m<sup>3</sup>, and 2.16, respectively.

mean particle size, density, and specific gravity were 16280 cm<sup>2</sup>/g, 0.6 μm, 851 kg/m<sup>3</sup>, and 2.20, respectively.

##### 3.1.3. Fly Ash

Class F fly ash was used and conforming to [34]. The chemical composition and SEM images of FA are shown in Fig. 5. Its specific surface area, mean particle size, density, and specific gravity were 4200 cm<sup>2</sup>/g, 13 μm, 962 kg/m<sup>3</sup>, and 2.16, respectively.

##### 3.1.4. GGBS

The GGBS was also used as a mineral admixture conforming to [35]. The chemical composition and SEM image of GGBS are shown in Fig. 6. Its specific surface area, mean particle size, density, and specific gravity were 4000 cm<sup>2</sup>/g, 13 μm, 1200 kg/m<sup>3</sup>, and 2.75, respectively.

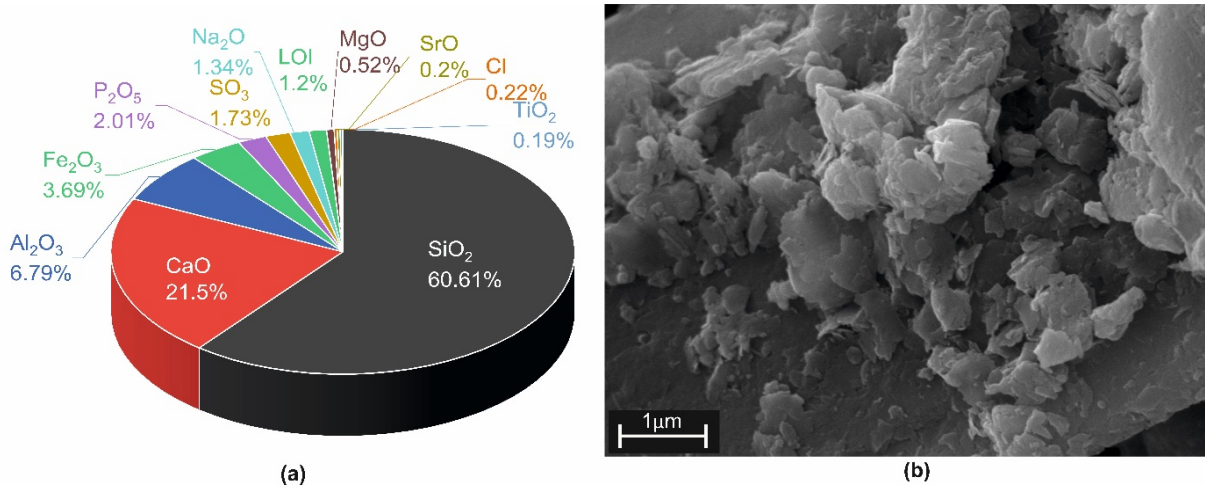


Figure 3. (a) Chemical composition and (b) SEM micrograph at 20,000 times magnification of OPC

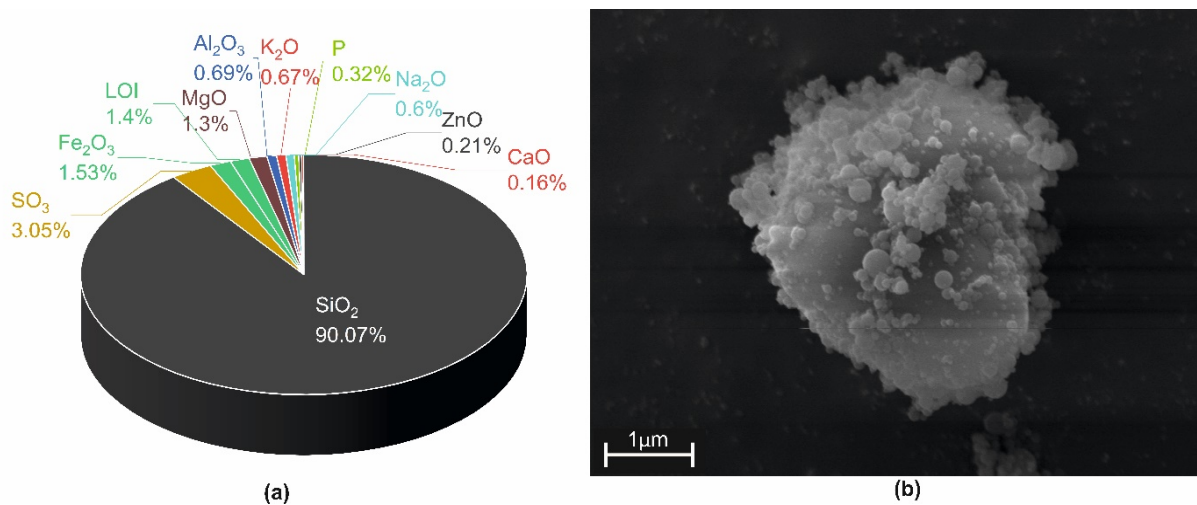


Figure 4. (a) Chemical composition and (b) SEM micrograph at 20,000 times magnification of MS

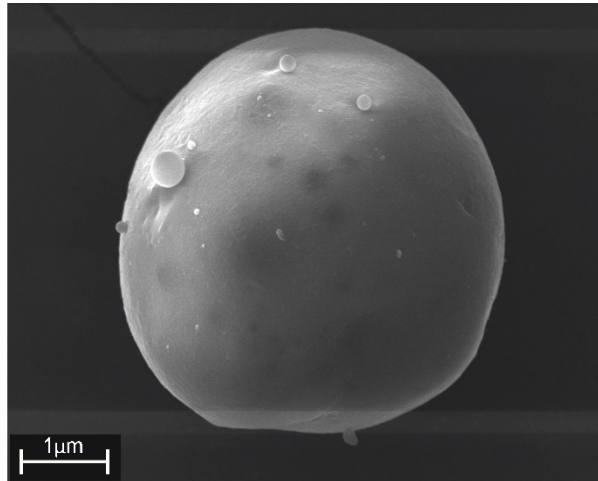
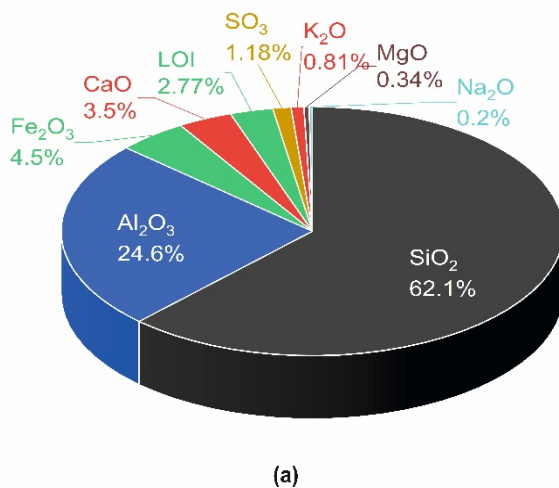


Figure 5. (a) Chemical composition and (b) SEM micrograph at 20,000 times magnification of FA

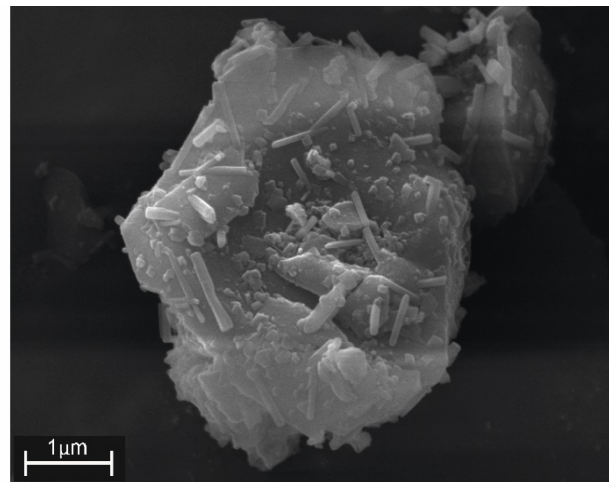
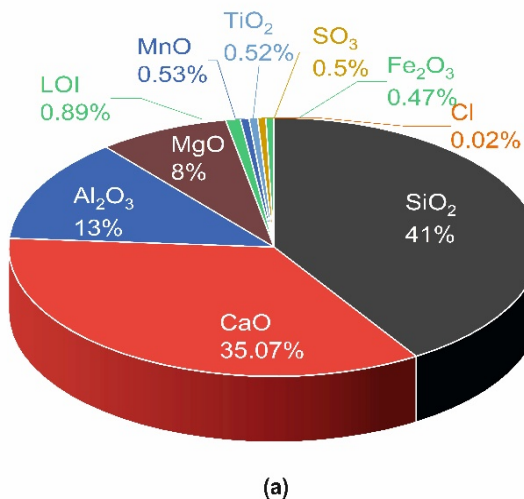


Figure 6. (a) Chemical composition and (b) SEM micrograph at 20,000 times magnification of GGBS

### 3.1.5. Superplasticizer

High range water reducer poly-carboxylate ether-based superplasticizer having a density of 1.12 Kg/l at 25° C and pH >6 was used, conforming to [36].

## 3.2. Methodology

### 3.2.1. Mixes Production

The fluidity of the paste is evaluated according to the type of the cement, the PCE SP dosage, the mineral admixture and the w/b ratio.

The fluidity of the paste was assessed at the replacement percentage of 10% MS, 30% FA, and 50% GGBS. The replacement percentage of mineral admixture was decided on literature review [37-43]. Based on the findings of several studies in this field, a 30% replacement of cement with FA was considered [37]. According to Indian Standard, the percentage of fly ash in PPC should be between 15 and 35% [38]. Literature studies showed that

the MS dosage between 7.5 and 12.5% had considerably improved the properties of the concrete [39-41], and the MS dosage considered in this study was 10%. The commercially available sulphate-resistant cement contains 40-60% GGBS. Many investigations have observed that GGBS up to 50% has greatly enhanced the properties of concrete [42,43]. Thus the replacement of GGBS used in this study was 50%.

The binder was mixed with water for various w/b ratio; 0.40, 0.45, 0.50, 0.55, and 0.60. Dosages of PCE SP used in the range of 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 1.2%, 1.4%, 1.6%, 1.8% and 2.0%.

Four sets of paste are used in this experimental study presented in Table 1, abbreviated as S-I/C, S-II/MS, S-III/FA and S-IV/GGBS. The term (S-I/ C) denotes OPC 43 grade cement that contains no mineral admixtures. S-II/MS has MS, S-III/FA contains FA, and S-IV/GGBS contains GGBS. The physical properties of a different combination of materials and the experimental setup are shown in Table 2 and Fig. 2, respectively.

**Table 1.** Mix proportions of the binder used in the study

Binder (abbreviations)	Replacement rate (%) of mineral admixture	w/b ratio	Superplasticizer dosage (%)
OPC (S-I/C)	0	0.40, 0.45, 0.50, 0.55, and 0.60	0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0
OPC + MS (S-II/MS)	10	0.40, 0.45, 0.50, 0.55, and 0.60	0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0
OPC + FA (S-III/FA)	30	0.40, 0.45, 0.50, 0.55, and 0.60	0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0
OPC +GGBS (S-IV/GGBS)	50	0.40, 0.45, 0.50, 0.55, and 0.60	0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0

**Table 2.** Physical properties of cement and cement with mineral admixture

Physical Properties	S-I/C	S-II/MS	S-III/FA	S-IV/GGBS
Fineness by IS Sieve 9 (%) - 90 micron	5	5	6	6
Specific gravity	3.16	3	2.86	2.95
Unit Weight (Kg/m <sup>3</sup> )	1410	1354.1	1275.6	1305
Mean Particle Size (µm)	16	14.46	14.2	14.5
Specific Surface Area (cm <sup>2</sup> /g)	3312	4608	3578	3656
Normal consistency (%)	34	35	37	36
Soundness (mm)	2	2	3	3
Setting time (Minute)				
Initial setting time	105	145	180	160
Final setting time	420	450	510	480
Compressive strength (MPa)				
3 Days	26.28	25.72	15.25	24
7 Days	30.25	31.42	22.75	27.65
7 Days	46.02	47	33.54	35.07

### 3.2.2. The Optimum Dosage of Superplasticizer

Binding material and water were mixed thoroughly by hand to prepare the paste/slurry till uniformity was achieved. One litter of the slurry was taken and poured into the Marsh cone apparatus by duly closing the opening with one finger. Then the time took for the slurry to empty the Marsh cone was calculated with a smart stopwatch. The experiment was repeated for different plasticizer dosages

for the slurries of all combinations of cement and mineral admixtures (MS, FA, and GGBS) with different w/b. Flow time vs. SP dosage graphs were plotted and given in Fig. 9 to Fig. 12, and the dose with the least flow time was termed the saturation point for each combination. The flowchart presented in Fig. 7 depicts finding the saturation dosage of SP.

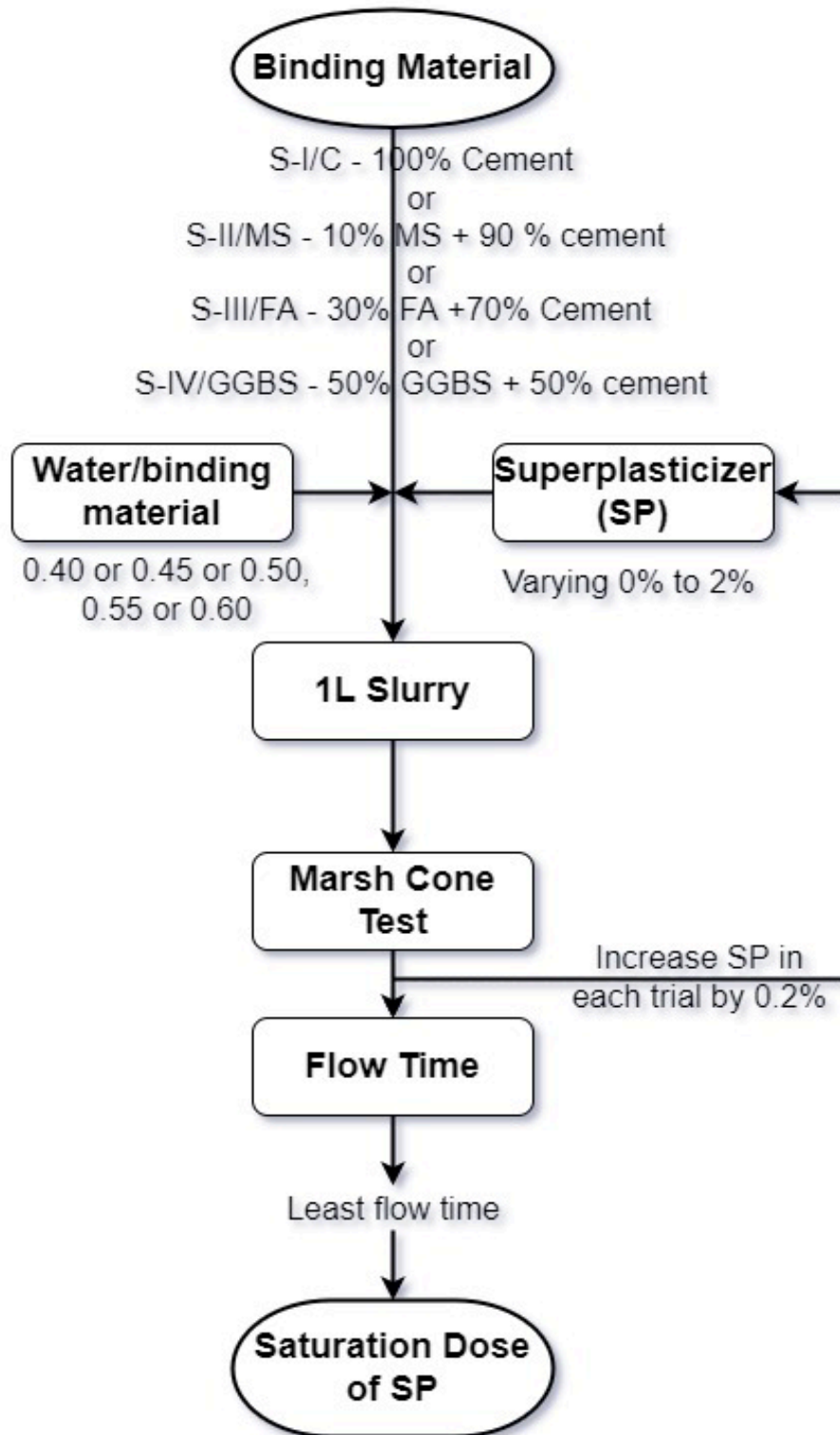


Figure 7. Process of finding saturation dosage of SP

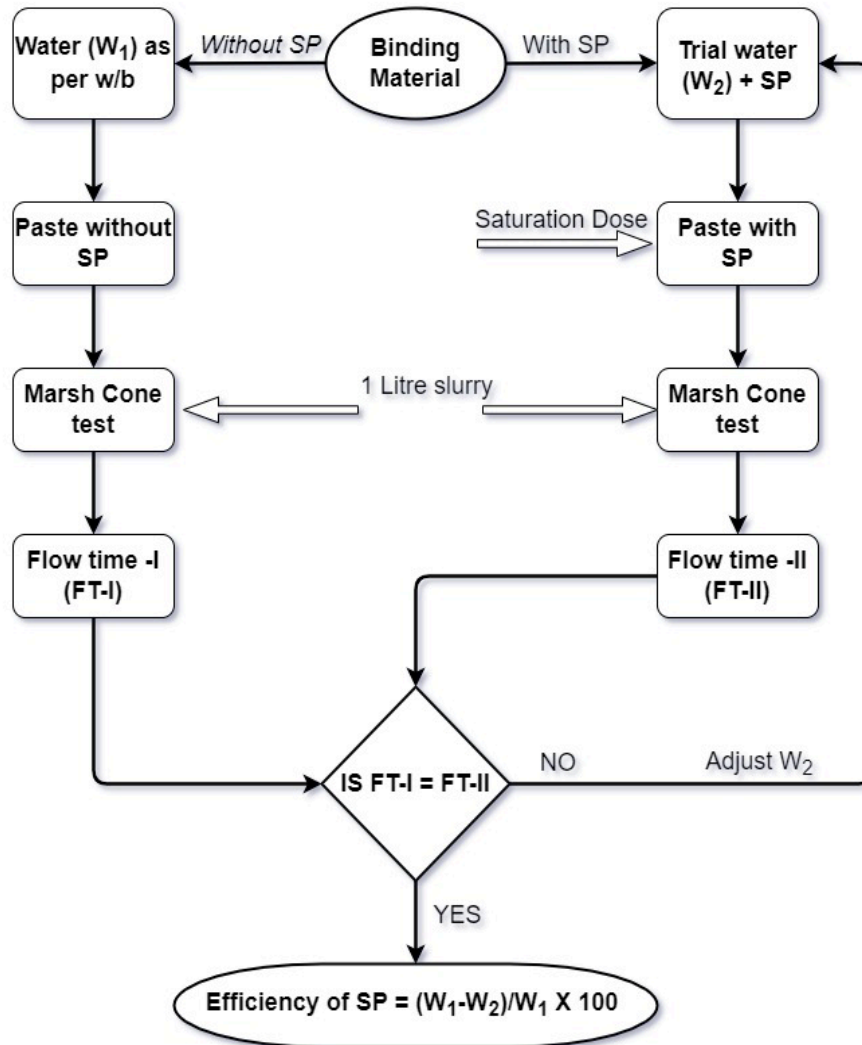


Figure 8. Flowchart for finding out efficiency of SP

### 3.2.3. Efficiency of Superplasticizer

With binding material and required w/b, a slurry/paste was made without adding SP. The Marsh cone test was performed on the paste to evaluate FT-I's flow time (for paste without SP). Then a new slurry of binding material and water with a saturation dose of SP was prepared, but the amount of water in this paste was adjusted till the flow time FT-II equals the flow time FT-I. The efficiency of the SP for each paste sample S-I/C, S-II/MS/, S-III/FA, and S-IV/GGBS at all w/b was evaluated as follows ( Equation 1) and tabulated in Table 4, Fig. 8 shows a flowchart for determining the efficiency of the SP.

$$\text{Efficiency of admixture} = \frac{(W_1) - (W_2)}{(W_1)} \times 100 \quad (1)$$

$W_1$  = water content without superplasticizer

$W_2$  = water content with superplasticizer

As described above, the experiments repeated on slurries of all samples with w/b of 0.40, 0.45, 0.5, 0.55, and 0.6. The efficiency of the SP in pastes with different admixtures

at different w/b is shown in Table 4.

## 4. Results and Discussion

### 4.1. Effect of the Water-Binder Ratio

The w/b is the most significant feature of concrete, which determines its properties in both the fresh and hardened phases and its durability[44]. According to [45], Low w/b increases the mechanical qualities of concrete, and by using SP, the water content in modern concrete can be reduced significantly. The inclusion of high surface mineral particles in cement mixtures necessitates more water or plasticizers to maintain the workability of concrete [46]. From the experimental results, flow time and saturation dose of SP for all the mixes decreases as w/b increase, as shown in Fig. 9 to Fig. 12. Decrease flow time and saturation dose are because of four reasons mainly for high w/b – the viscosity of the cement paste decreased [47],

the yield stress of paste decreases [48], strong zeta potential starts weakening [49], and extra water will be available after the adsorption of the surface of the cementitious particle.

From Table 3, it is observed that when w/b is increasing, the flow time decreases. However, when the w/b increases from 0.40 to 0.45, the flow time decreases drastically up to 95% for sample S-I/C, S-II/MS, and S-IV/GGBS, but for S-III/FA, flow time decreases up to 50%. When the w/b ratio increases from 0.45 to 0.60, flow time reduces about 68%, 77%, and 69% for sample S-I/C, S-II/MS, and S-IV/GGBS, respectively. Although for sample S-III/FA, flow time decreases 98% when w/b increases 0.45 to 0.60.

From the experiment, it was observed that after adding the SP, flow time decreases rapidly for all the samples; this is because the anionic carboxylic acid groups adsorbed on the surface of binding material and provide electrostatic repulsion, whereas the non-ionic ether groups do not adsorb and float freely in the solution. When two polymer-covered particle surfaces get close together, the

loss of entropy caused by mixing the dangling chains renders the process thermodynamically unfavourable, so the particles repel each other [50,51].

Fig. 9 to Fig. 12 and Table 4 show SP saturation doses for control and mineral admixed pastes with various w/b. The saturation doses of SP in the control paste were 1% at 0.4, 0.45 w/b, 0.8% at 0.5 w/b, and 0.6% at 0.55 and 0.6 w/b. The highest dose of SP in the MS admixed paste, S-11/MS, was 1.2% at 0.4 w/b, and the lowest SP dose came to be 0.8% at 0.55 and 0.6 w/b. Among all samples, the FA admixed paste S-III/FA needed the highest amount of 1.6% of SP for its saturation at 0.4 w/b. Lowest SP saturation dose in S-III/FA was 0.8% at 0.50, 0.55 and 0.6 w/b. In the case of GGBS admixed paste, the highest saturated dose of SP came to be 1% at 0.4 and 0.45 w/b, and at the remaining w/b, the saturation dose was 0.8%. Compared to control sample S-I/C, the fluidity of admixed cement pastes decreased significantly due to higher surface area and shear thickening properties of mineral admixtures and subsequent increase in water adsorption [20,52].

**Table 4.** Efficiency of superplasticizer for different pastes

Water to binder (w/b) ratio	Saturation dose of SP (%)	Water Content (ml)		Time (Sec) At 0% SP	Efficiency (%)
		Without SP	With SP		
<b>S-I/C</b>					
0.4	1	680	500	230	26.47
0.45	1	765	600	20	21.57
0.5	0.8	850	680	10	20
0.55	0.6	935	785	8.5	16.04
0.6	0.6	1020	870	7.5	14.71
<b>S-II/MS</b>					
0.4	1.2	680	520	>30 min	23.53
0.45	1	765	615	34	19.61
0.5	1	850	700	11.5	17.65
0.55	1	935	780	8.1	16.5
0.6	0.8	1020	860	7.61	15.69
<b>S-III/FA</b>					
0.4	1.6	680	490	Stiff Paste (No Fluidity)	27.94
0.45	1	765	589	>30 min	23
0.5	0.8	850	705	27	17.06
0.55	0.8	935	785	11.6	16.04
0.6	0.8	1020	870	8.54	14.70
<b>S-IV/GGBS</b>					
0.4	1	680	503	>30 min	26.03
0.45	1	765	665	26	15.03
0.5	0.8	850	750	21	11.76
0.55	0.8	935	835	9.09	10.7
0.6	0.8	1020	920	7.91	9.8

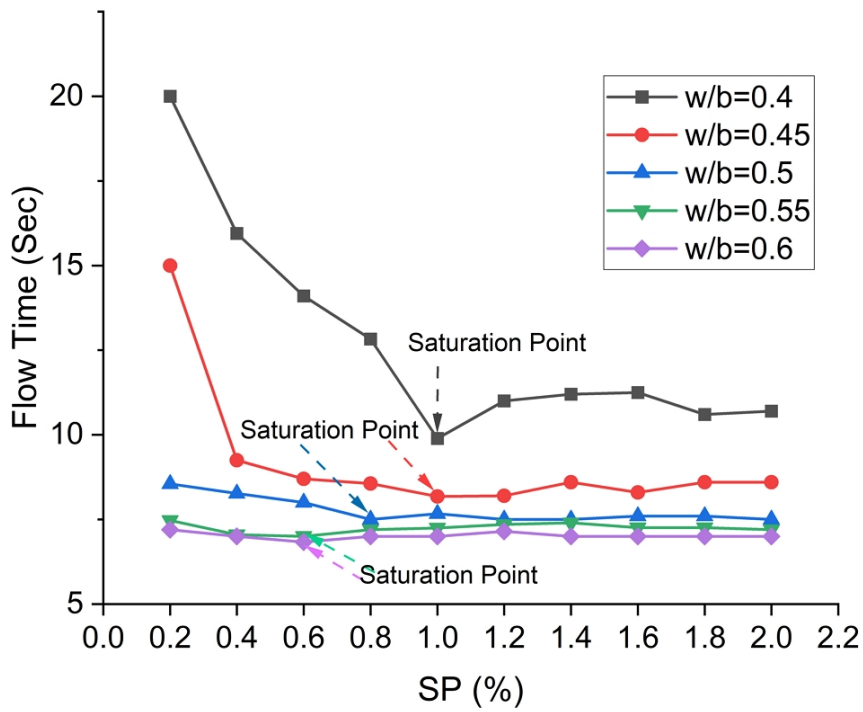


Figure 9. SP vs. FT for different w/b S-I/C

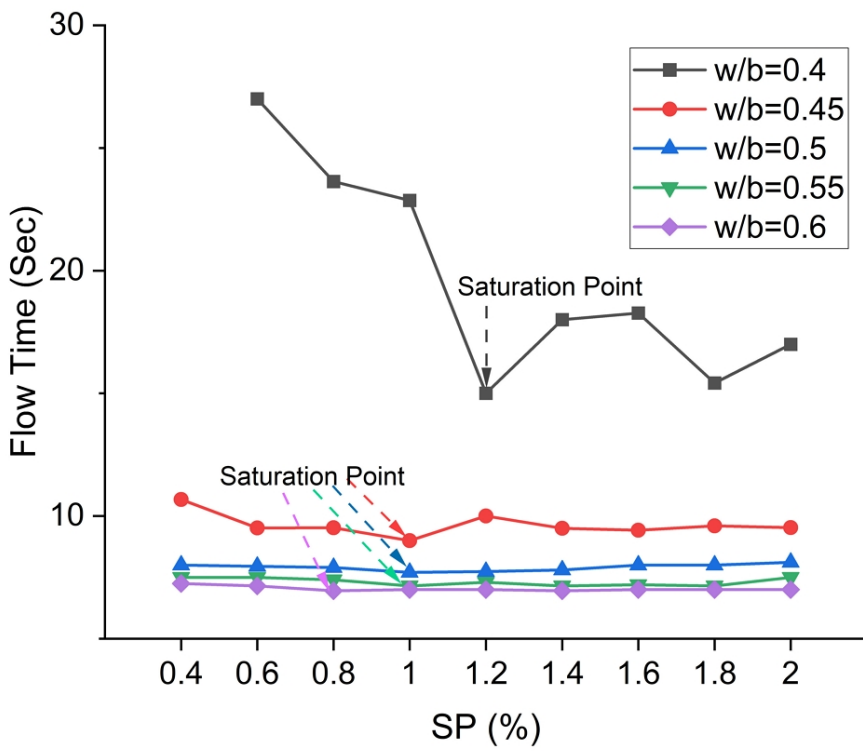


Figure 10. SP vs. FT for different w/b S-II/MS

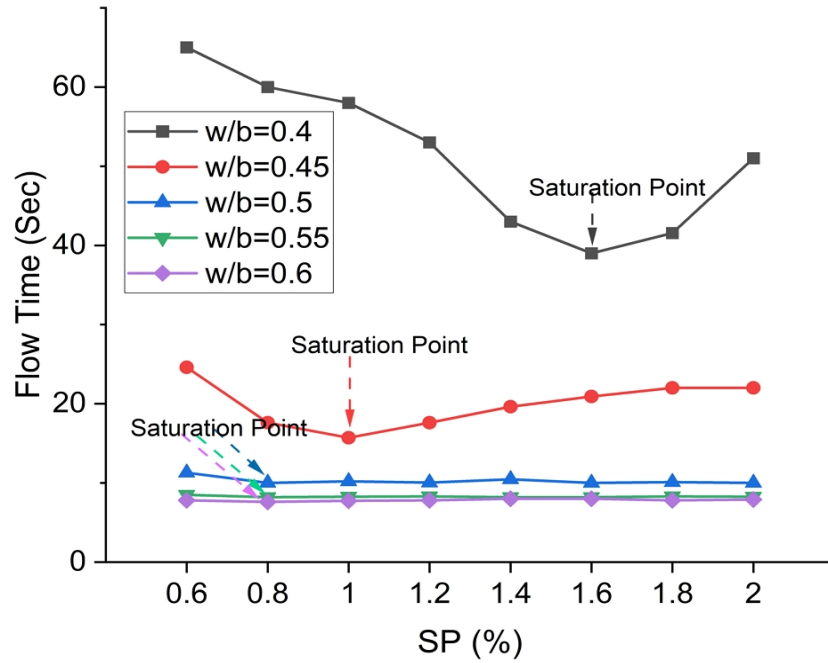


Figure 11. SP vs. FT for different w/b S-III/FA

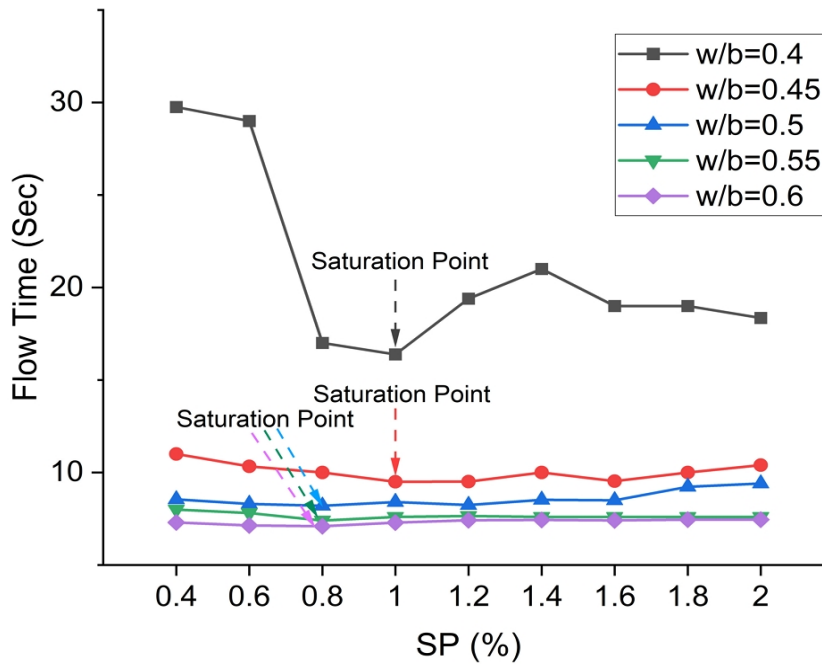


Figure 12. SP vs. FT for different w/b S-IV/GGBS

Table 3. Flow time for OPC and mineral admixed cement paste without SP at different w/b

Sample	w/b = 0.40	w/b = 0.45	w/b = 0.50	w/b = 0.55	w/b = 0.60
S-I/C	230	24	10	8.5	7.5
S-II/MS	1800	34	11.5	9	7.61
S-III/FA	3600	1800	27	11.6	8.54
S-IV/GGBS	1800	26	21	9.09	7.91

## 4.2. Effects of the Type of Mineral Admixture

Superplasticizers have to be added in conjunction with mineral admixtures on multiple occasions to ensure appropriate fluidity. The dosage of SP to be added depends on the type of mineral admixture and its percentage. PCE-based SP is more effective with fly ash at higher water demand because of the steric hindrance effect [53].

The flow time of the pastes at different w/b is shown in Fig. 13 to Fig. 17. With the addition of a mineral admixture, the flow time increased significantly. However, pastes with fly ash have higher viscosity and lesser fluidity, as shown in Fig. 13 to Fig. 17 among all mineral admixtures. The result indicates that cement with fly ash requires a higher dosage of water-reducing admixture. It is observed that cement with mineral admixture does not have fluidity at lower w/b, as shown in Table 3, and SP contributes fluidity to the paste. From Fig. 16 to Fig. 17, it is also seen that at higher w/b, all the pastes have good fluidity. For admixed pastes, the saturation dosage of the SP varied from 1.6 to 0.8% at lower to higher w/b, as seen in Fig. 13 to Fig. 17.

From the experiment, as seen in Fig. 13, it was observed that at 0.40 w/b, FA admixed paste has the least fluidity, higher SP saturation dose, and highest flow time followed by MS, GGBS, and OPC admixed paste. However, for 0.45, 0.50, 0.55, 0.60 w/b FA admixed (S-III/FA) paste have least fluidity, highest flow time, followed by GGBS (S-IV/GGBS), MS(S-II/MS), and OPC(S-I/C) admixed paste as shown in Fig. 14 to Fig. 17.

The lower specific gravity and smaller unit weight of S-III/FA, as shown in Table 2, create less self-weight, which is insufficient to resist yield stress, resulting in a higher flow time, more SP dose, and stiff paste in the S-III/FA sample. Another reason is the FA particle's ball bearing shape, as seen in SEM image Fig. 5, which causes overall higher surface area and higher adsorbed SP and water on its surface to counter strong zeta potential. A similar finding was also reported by [1]. S-II/MS samples have a lesser flow time than S-III/FA and S-IV/GGBS samples but a higher flow time than S-I/C. S-II/MS has a higher SP dose at 0.50, 0.55, and 0.60 w/b as seen in Fig. 13 to Fig. 17 as compared to S-I/C, S-III/FA, and S-IV/GGBS samples, which could be owing to the tiny spherical shape particle as seen in SEM image Fig. 4, which causes a higher surface area of MS particle as indicated in Table 20, similar finding also reported by [46].

The S-IV/GGBS sample has a higher flow time than the S-I/C and S-II/MS sample, as seen in Fig. 13 to Fig. 17, but less SP than the S-II/MS sample. Higher flow time is due to lower unit weight which causes less self-weight to

overcome yield stress than that of S-I/C and S-II/MS samples, and lower SP than S-II/MS paste is due to the glassy texture of GGBS particle, which also acts as SP [54,49] as seen in Fig. 6. S-I/C has the least flow time and lower SP dose than all admixed samples. This may be of higher unit weight, less normal consistency, lesser overall surface area, and higher specific gravity, as shown in Table 2, contributing to comparatively lower flow time.

## 4.3. Efficiency of Superplasticizer

As the w/b ratio increased, the efficiency of SP decreased, as can be seen in Table 4 and Fig. 18. The lower efficiency of SP at higher w/b is because high fluidity is generally associated with SP adsorption on cement grains, and maximum fluidity is attained when the adsorption is saturated. The initial adsorbed layer of superplasticizer (PCE) on cement grains determines the fluidity of cement paste, while the secondary adsorbed layer does not affect fluidity. A similar finding is also observed by [55-57]. The efficiency of SP in different pastes is shown in Table 4. It can be seen from the results that, at 0.4 and 0.45 w/b, S-III/FA admixed cement paste with saturation dose of SP has the highest efficiency, followed by S-I/C, S-IV/GGBS, and S-III/MS pastes, as shown in Fig. 19 to Fig. 22. However, at 0.50 w/b with a saturation SP dose of 1%, S-I/C cement showed the highest efficiency, followed by S-II/MS, S-III/FA, and S-IV/GGBS samples. S-II/MS showed higher efficiency at 0.55 and 0.6 w/b, followed by the S-I/C, S-III/FA, and S-IV/GGBS samples.

The paste with FA had the best SP efficiency at lower w/b, as shown in Table 4 and Fig. 21. Higher saturation dose of SP provided in FA admixed sample which causes a decrease in viscosity of cement paste and maybe adsorbed SP on the surface of cementitious ball bearing grains as seen in SEM image Fig. 5(b) causes higher negative repulsive force contributing to the higher efficiency of SP.

The efficiency of SP in plain concrete paste (S-I/C) was found between FA and MS pastes. However, at 0.45, 0.50, 0.55, and 0.60 w/b, S-IV/GGBS showed the least SP efficiency. The lower efficiency of S-IV/GGBS samples is may be due to incompatibility of current SP used in this study or maybe less repulsive force generated by adsorbed SP on GGBS glass textured grain as seen in SEM image Fig. 6(b), similar finding also reported by [1]. Micro silica as a mass replacement for cement improved concrete cohesiveness. It required more water to maintain fluidity, which is the fundamental reason for SP's high efficiency even at a higher w/b ratio. A similar finding was reported by [58,59].

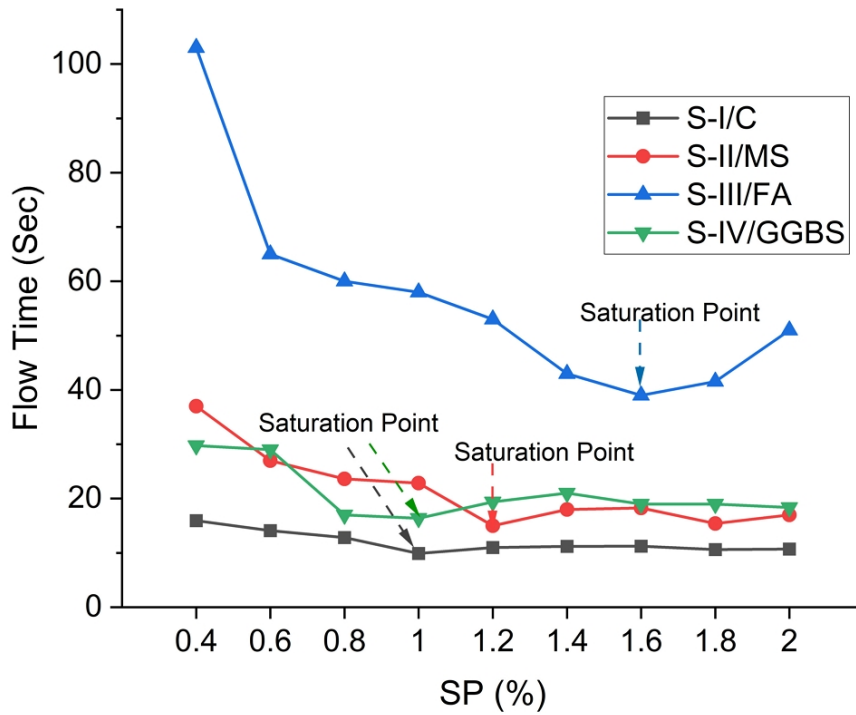


Figure 13. SP dosage vs. flow time at 0.4 w/b ratio

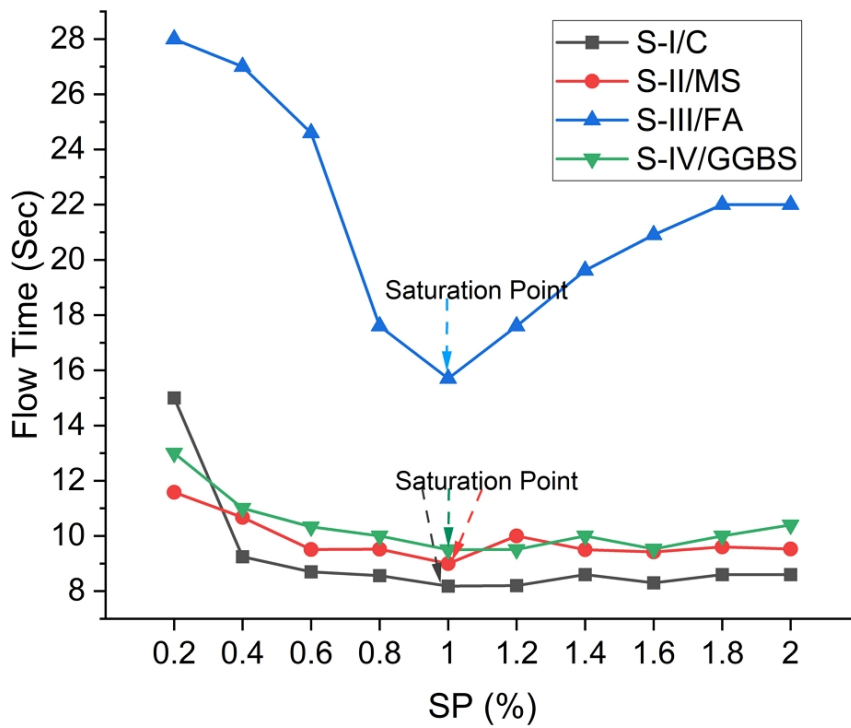


Figure 14. SP dosage vs. flow time at 0.45 w/b ratio

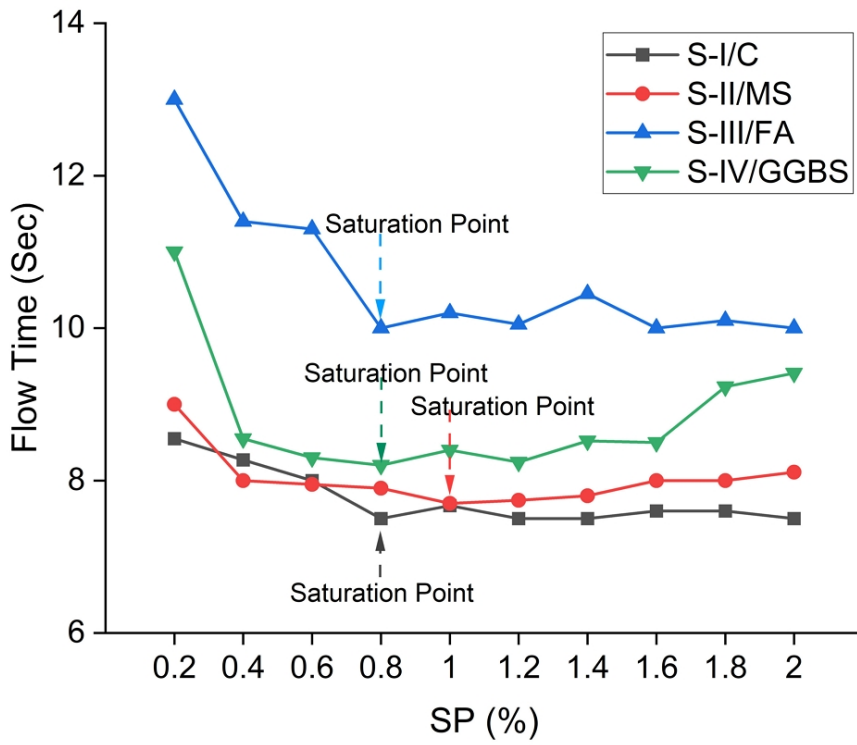


Figure 15. SP dosage vs. flow time at 0.5 w/b ratio

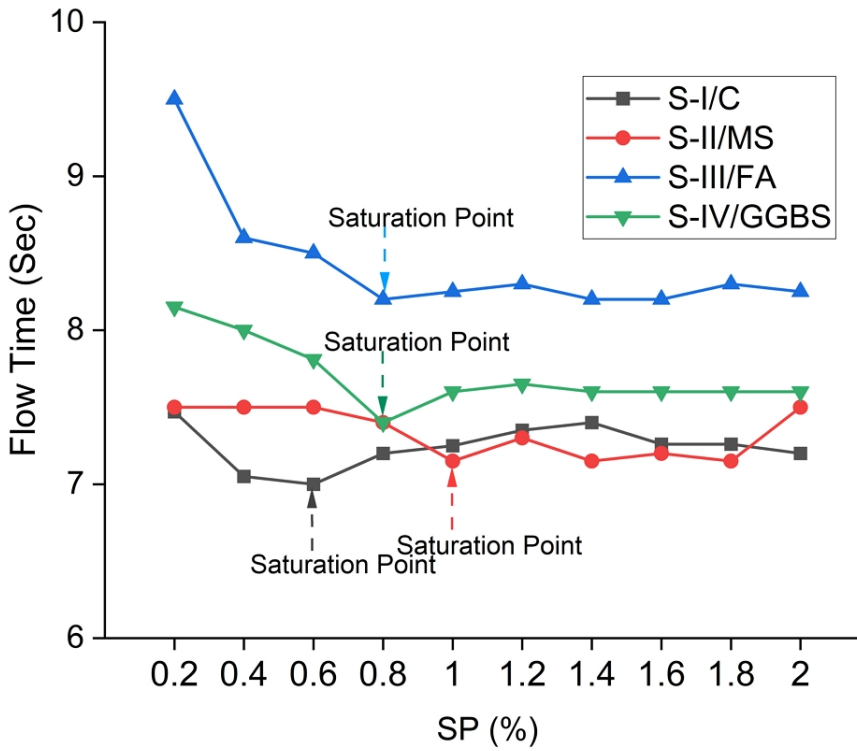


Figure 16. SP dosage vs. flow time at 0.55 w/b ratio

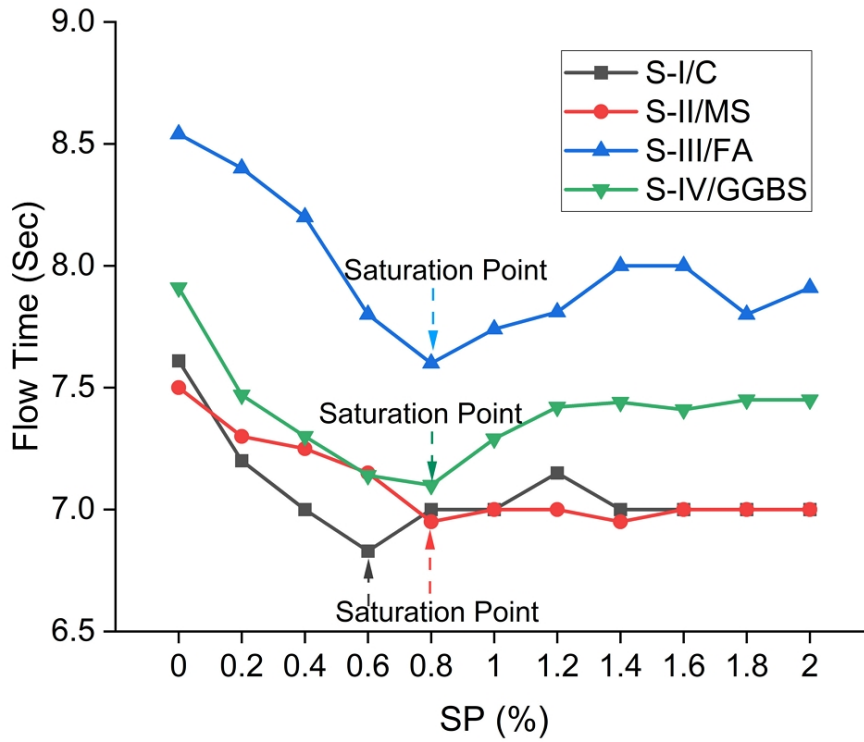


Figure 17. SP dosage vs. flow time at 0.60 w/b ratio

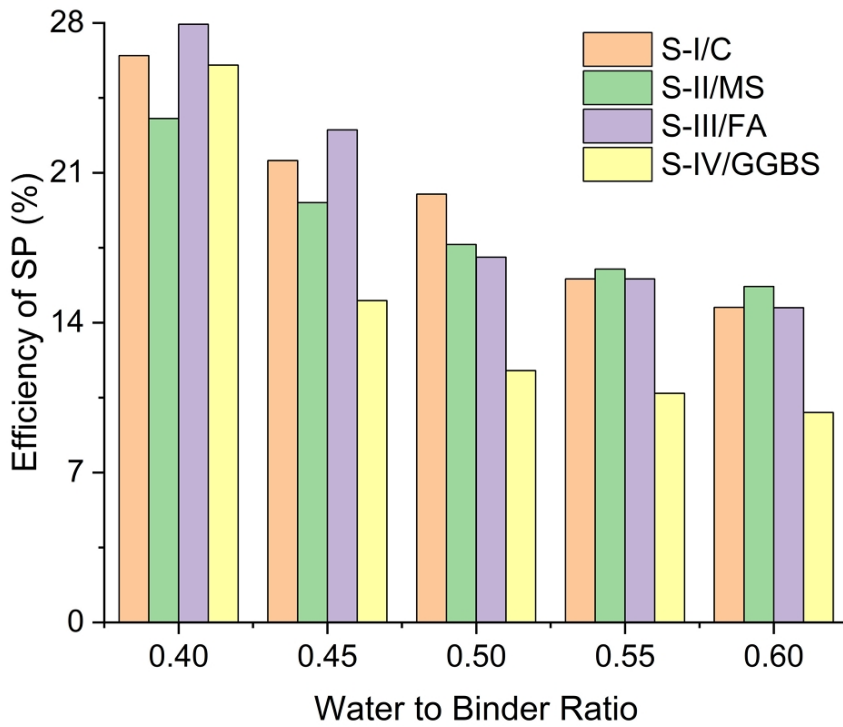
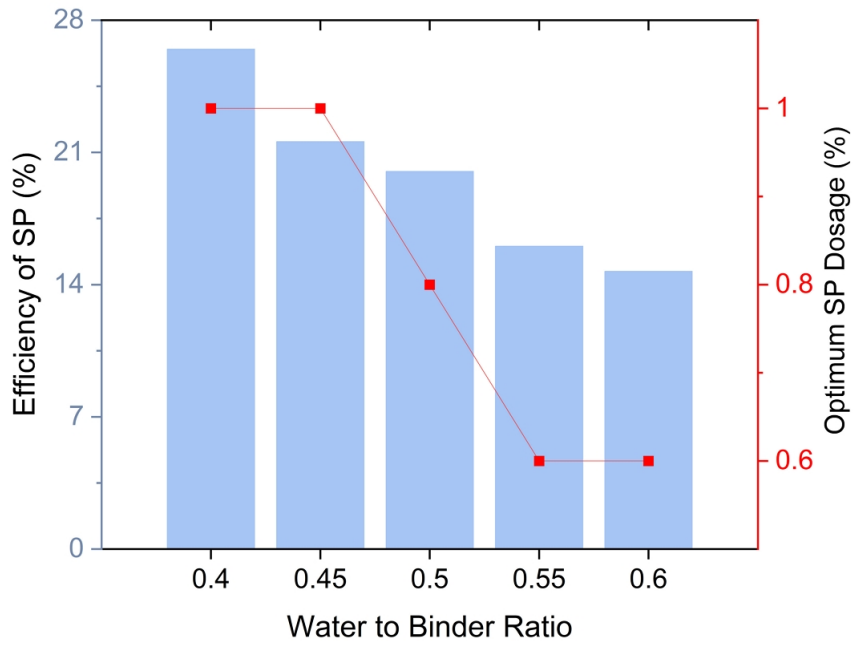
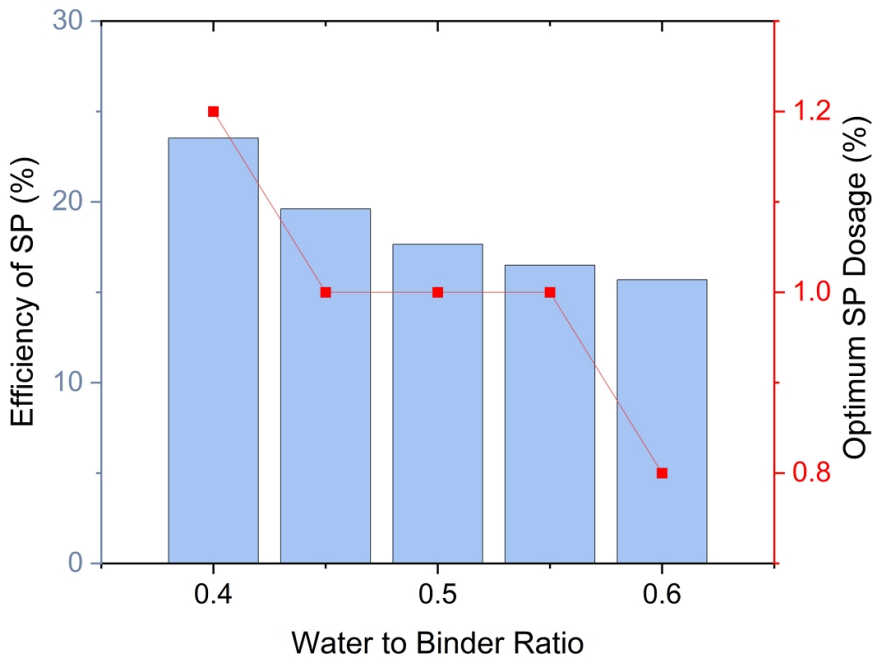


Figure 18. Efficiency of superplasticizer on various pastes at different w/b



**Figure 19.** Efficiency of superplasticizer on paste S-I/C



**Figure 20.** Efficiency of superplasticizer on paste S-II/MS

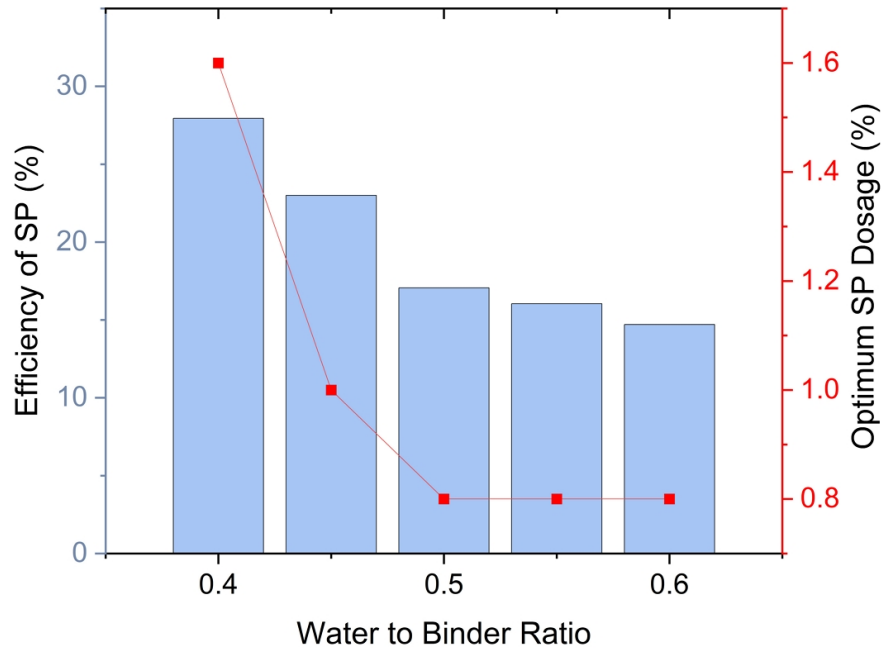


Figure 21. Efficiency of superplasticizer on paste S-III/FA

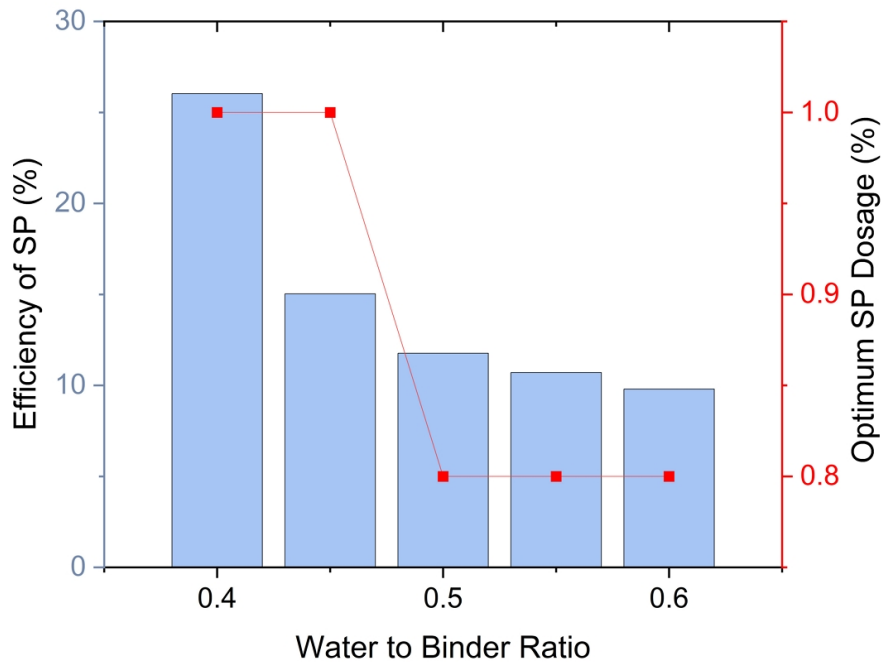


Figure 22. Efficiency of superplasticizer on paste S-IV/GGBS

## 5. Conclusion

- For the selection of SPs and its ideal dosage in the presence of mineral admixtures, determination of flow time of the respective binder paste is essential. The comparative fluidity of the cement pastes with varied dosage of superplasticizer was measured using the marsh cone test.
- Flow time of cement paste without any mineral admixtures was compared with cement paste containing MS, FA and GGBS. Flow time of cement paste was contemplated to increase significantly by adding mineral admixtures as cement replacement. From the experimental investigation, it was observed that saturation level of SP is inversely proportional to the w/b ratio. The type of mineral admixture used and

their properties as well as the shape of cementitious grain have influence on altering the saturation level of SP.

- Cement paste with fly ash showed a higher saturation level than GGBS and MS corresponding to its higher water demand. Even at higher SP dosages, FA-based pastes showed longer flow time. Lower specific gravity and unit weight, also the high surface area of FA reduce the shear stress induced by the self-weight of paste which eventually is insufficient to overcome its yield stress.
  - SP in cement with GGBS had lower efficiency at higher w/b ratio, as glassy texture of GGBS contribute in the fluidity of cement paste.
  - MS as a mass replacement for cement improved concrete cohesiveness but required more water to maintain fluidity, which is the fundamental reason for the high efficiency of SP in MS-cement paste even at a higher w/b ratio.
3. Dosage of SP also plays very important role in SP efficiency; from the experimental results, it was observed that the higher saturation dose lead to higher efficiency. Grain size and chemical composition of cementitious material play a very important role in SP effectiveness. From the experimental investigation, it was observed that on increasing the w/b ratio, the efficiency of SP decreases. All the cement paste with and without mineral admixtures shows the similar trend. As the water content is increasing in the paste, dispersion activity in binder grains due to the SP reduces; therefore, the efficiency of SP decreases.

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