CHAPTER 4 MATERIAL PROPERTIES AND MARSH CONE TEST

4.1 GENERAL

The characteristics of hardened cement paste, mortar, and concrete are largely influenced by the unique attributes of the materials that comprise them. The impact of hydrated cement paste on the physical properties of mortar and concrete is more notable than the influence of the aggregates used in these materials. To comprehensively evaluate the effects of mineral and chemical admixtures on the properties of cement paste, mortar, and concrete, it was crucial to examine their behavior with OPC.

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 [55].

When Portland cement and water react, they form hardened cement paste, which mainly consists of CSH gel, CAH, and portlandite ($Ca(OH)_2$). The microstructure of the hardened cement paste depends on factors such as the composition of the cement particles, the water-to-cement (w/c) ratio, the temperature at which the hydration reaction takes place, and the use of admixtures (mineral or chemical). Some cement particles remain inactive during the initial hydration reaction but contribute to improving cement paste properties in later stages. Hydration products such as CSH gel and portlandite usually fill the spaces between these unhydrated cement particles.

The inclusion of mineral admixtures is known to enhance the characteristics of hardened cement paste. Nevertheless, the addition of mineral admixtures significantly impacts the water requirement of the cementitious system [258][259][138]. Consequently, the water requirement of fresh cement paste (referred to as normal consistency) was evaluated for different ratios of mineral and chemical admixtures. This chapter presents the determination of setting times for fresh cement paste admixed with mineral and chemical admixtures, as well as the assessment of the soundness of various cementitious pastes. In this chapter, the results highlighting various properties of mineral admixtures and the properties of other constituents of concrete have been studied and discussed in detail. 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.

4.2 AGGREGATE

In accordance with IS 383 [260] basalt-based crushed coarse aggregates with a maximum nominal size of 20 mm and 10 mm were recovered from the Dalla quarry in the Sonebhadra district of Uttar Pradesh, India. In accordance with IS 383 [260], riverbed sand was utilized as fine aggregate and was collected from Chopan quarry in the Sonebhadra district of the Indian state of Uttar Pradesh. The results of the sieve examination for both coarse and fine aggregates are presented in Table 4.1, while

Table 4.2 provides a compilation of their mechanical characteristics. Each mechanical property, including fineness modulus, specific gravity, water absorption, crushing and impact value, flakiness and elongation index, and abrasion value, falls within the permissible range.

4.3 BINDING MATERIAL

4.3.1 Cement

This analysis used the OPC 43 grade conforming to IS 8112 [261]. The chemical composition and SEM image of OPC are shown in Figure 4.1 and Figure 4.2 respectively.

Its specific surface area, mean particle size, density, and specific gravity were 3312 cm^2/g, 16 µm, 1410 kg/m3, and 3.16, respectively as given in Table 4.4.

Table 4.1 Percentage passing of coarse and fine aggregates

Sieve Size (mm)	**Percentage Passing**								
	Coarse Aggregate						**Fine aggregate**		
	20 mm			**10 mm**			**Sand (Zone II)**		
	Min Limit	**Maximum Limit**	**Obtained**	**Min Limit**	**Maximum Limit**	**Obtained**	**Min Limit**	**Maximum Limit**	**Obtained**
20	85	100	94	-	-	100	-	-	-
12.5	0	0	-	-	100	-	-	-	-
10	0	20	0.4	85	100	94.6	0	100	-
4.75	0	5	-	0	20	3.4	90	100	95.2
2.36	-	-	-	0	5	1.64	75	100	93
1.18	-	-	-	-	-	-	55	90	74
0.6	-	-	-	-	-	-	35	59	45.4
0.3	-	-	-	-	-	-	8	30	18
0.15	-	-	-	-	-	-	0	10	6

Table 4.2 Mechanical properties of coarse and fine aggregates

Properties	Specifications	Coarse Aggregate			Fine Aggregate	
		Limit	**Obtained**			
			20 mm	**10 mm**	**Limit**	**Obtained**
Fineness Modulus	IS 383 [260]	6-10	7.05	6	2.1-3.37	2.68
Specific Gravity	IS 2386 (III) [251]	2.5-3	2.86	2.74	2.5-3	2.64
Water Absorption (%)	IS 2386 (III) [251]	< 2	0.75	0.82	0.3-2.5	1.15
Unit Weight (kg/m^3)	-	-	1738	1678	-	1665
Crushing Value (%)	IS 2386 (IV) [250]	< 30	16.70	19.1		
Impact Value (%)	IS 2386 (IV) [250]	< 30	12.8	14.85		
Flakiness Index (%)	IS 2386 (IV) [250]	< 30	20.3	23.4		
Elongation Index (%)	IS 2386 (IV) [250]	< 35	22.2	21.5		
Abrasion Value (%)	IS 2386 (IV) [250]	< 35	17.56	19.80		

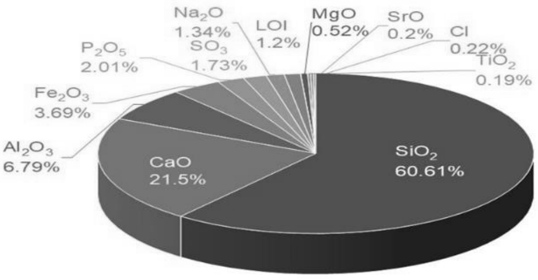


Figure 4.1 Chemical composition of OPC

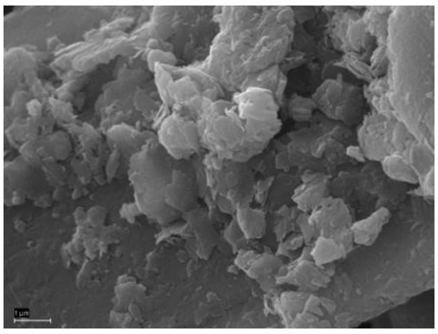


Figure 4.2 SEM micrograph at 20,000 times magnification (1µm scale) of OPC

4.3.1 Micro Silica (MS)

Micro silica was used as a mineral admixture conforming to IS 15388 [262].. The chemical composition and SEM image of MS are shown in Figure 4.3 and Figure 4.4. Its specific surface area, mean particle size, density, and specific gravity were 16280 cm^2/g, 0.6 µm, 851 kg/m3, and 2.20, respectively as given in Table 4.4. In the course of this research, micro silica, a key admixture utilized in the experimentation, was sourced from commercially available suppliers in the local market.

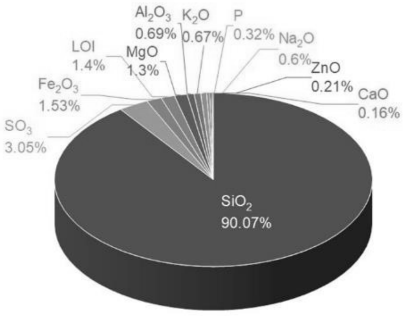


Figure 4.3 Chemical composition of MS

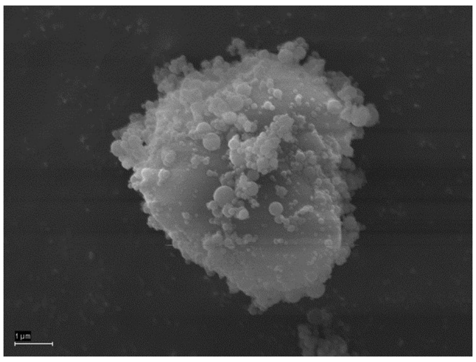


Figure 4.4 SEM micrograph at 20,000 times magnification (1µm scale) of MS

4.3.2 Fly Ash (FA)

Class F fly ash was used and conforming to IS 3812 [263]. The chemical composition and SEM images of FA are shown in Figure 4.5 and Figure 4.6. Its specific surface area, mean particle size, density, and specific gravity were 4200 cm2/g, 13μm, 962 kg/m3, and 2.16, respectively as given in Table 4.4. In the course of this research, fly ash, a key admixture utilized in the experimentation, was sourced from commercially available suppliers in the local market.

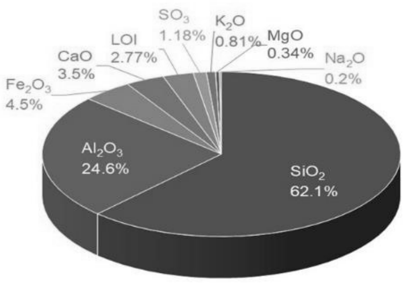


Figure 4.5 Chemical composition of FA

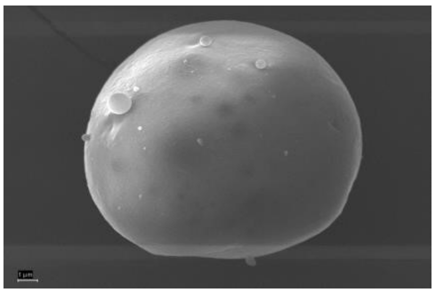


Figure 4.6 SEM micrograph at 20,000 times magnification (1μm scale) of FA

4.3.3 GGBS

The GGBS was also used as a mineral admixture conforming to 12089 [264]. The chemical composition and SEM image of GGBS are shown in Figure 4.7 and Figure 4.8. Its specific surface area, mean particle size, density, and specific gravity were 4000 cm2/g, 13μm, 1200 kg/m3, and 2.75, respectively as given in Table 4.4. In the course of this research, fly ash, a key admixture utilized in the experimentation, was sourced from commercially available suppliers in the local market.

4.3.4 Superplasticizer

High range water reducer poly-carboxylate ether-based superplasticizer (PCE) having a density of 1.12 Kg/l at 25° C and pH >6 was used, conforming to IS 9103 [265]

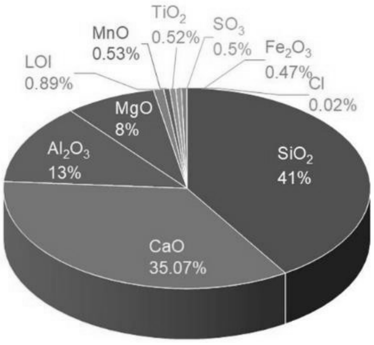


Figure 4.7 Chemical composition of GGBS

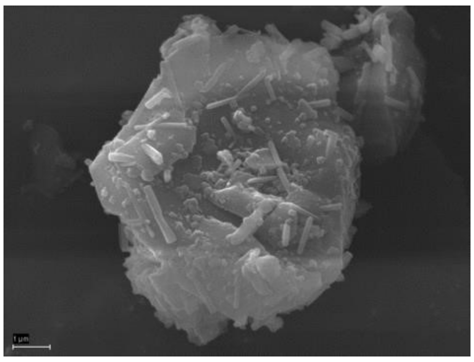


Figure 4.8 SEM micrograph at 20,000 times magnification of GGBS (1μm scale)

4.4 STUDY ON PROPERTIES OF BINDING MATERIAL

Table 4.3 Notation used for different samples

Description of samples	Notation
100% OPC (Control)	S-I/C
90% OPC + 10% MS	S-II/MS
70% OPC + 30% FA	S-III/FA
50% OPC + 50% GGBS	S-IV/GGBS

4.4.1 Consistency

Based on the test result as shown in Table 4.4, the consistency of the control sample (Blank Cement OPC) is 34%, while the consistency of the samples with mineral admixtures are as follows: S-II/MS (35%), S-III/FA (37%), and S-IV/GGBSMB50 (36%). Compared to the control sample, the S-II/MS sample shows a 1% increase in consistency, the S-III/FA sample shows a 2% increase in consistency, and the S-IV/GGBS sample shows the highest increase in consistency at 3%. Mineral admixtures like micro silica, fly ash, and GGBS contain very fine particles, which can fill the voids between the cement particles and lead to a denser paste. This, in turn, can increase the water demand to maintain the same consistency as the control sample.

Therefore, when mineral admixtures are added to cement, the water demand to achieve the same consistency as the control sample is generally higher. This is why the normal consistency is higher with mineral admixtures than OPC.

4.4.2 Setting Time

Based on the experimental data as given in Table 4.4, S-I/C has a faster initial setting time compared to S-II/MS, S-III/FA, and S-IV/GGBS. Specifically, the initial setting time of S-I/C is 105 minutes, which is lower than the other types. However, when it comes to the final setting time, S-I/C has a faster final setting time compared to S-II/MS and S-IV/GGBS, but a slower final setting time compared to S-III/FA. The final setting time of S-I/C is 420 minutes, which is lower than S-II/MS and S-IV/GGBS, but higher than S-III/FA.

Table 4.4 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^3)	1410	1354.1	1275.6	1305
Mean Particle Size (µm)	16	14.46	14.2	14.5
Specific Surface Area (cm^2/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	205
Final setting time	420	450	510	480
Compressive strength (MPa)				
3 Days	26.28	25.72	24.2	18.5
7 Days	30.25	31.42	27.08	20
28 Days	46.02	47	37.05	35.07

To compare the percentage increase of each type with respect to S-I/C, it is observed that S-III/FA and S-IV/GGBS have the highest percentage increase in both initial and final setting time, respectively, while S-II/MS has a moderate increase in initial setting time and a small increase in final setting time. For instance, the initial setting time of S-II/MS is 38.1% higher than S-I/C, while that of S-III/FA and S-IV/GGBS is 71.4% and 95.2% higher, respectively. Similarly, the final setting time of S-II/MS is 7.1% higher than S-I/C, while that of S-III/FA and S-IV/GGBS is 21.4% and 14.3% higher, respectively.

When mineral admixtures such as MS (micro silica), FA (fly ash), and GGBS (ground granulated blast furnace slag) are added to the concrete mix, they can change the properties of the fresh and hardened concrete. One of the changes that can occur is an increase in the setting time of the concrete.

The increase in setting time can occur because mineral admixtures have a slower rate of reaction with the cement hydration process compared to Portland cement. This slower reaction rate can delay the initial setting time and extend the final setting time of the concrete [266]. The initial setting time is the time from the addition of water to the concrete mix until the concrete starts to stiffen, while the final setting time is the time when the concrete has hardened to a point where it can no longer be worked with.

The specific increase in setting time can vary depending on the type and amount of mineral admixture used, as well as the ambient temperature and humidity. However, it is generally observed that the use of mineral admixtures can increase the setting time of the concrete.

While the increase in setting time can be seen as a disadvantage, there are also benefits to using mineral admixtures in concrete, such as improved durability, strength, and workability. Additionally, the increased setting time can allow for better finishing and consolidation of the concrete

4.4.3 Compressive Strength of Binding Material

The compressive strength test result shows as given in Table 4.4 that S-I/C has the highest compressive strength among all types of concrete tested at all ages of testing (3 days, 7 days, and 28 days). At 3 days, both S-I/C and S-II/MS have high compressive strengths, with S-II/MS having a slightly lower value. On the other hand, S-III/FA and S-IV/GGBS have lower compressive strengths than both S-I/C and S-II/MS at 3 days.

At 7 days, S-II/MS has the highest compressive strength, followed by S-I/C, S-III/FA, and S-IV/GGBS. S-II/MS has a moderate increase in compressive strength with respect to S-I/C at 7 days, while the other two types have a lower increase.

At 28 days, both S-I/C and S-II/MS have high compressive strengths, with S-II/MS having a slightly higher value. Both S-III/FA and S-IV/GGBS have lower compressive strengths than S-I/C and S-II/MS at 28 days. S-II/MS has a moderate increase in compressive strength with respect to S-I/C at 28 days, while the other two types have a smaller increase.

The reduction in strength observed in the concrete samples containing fly ash (FA) and ground granulated blast furnace slag (GGBS) can be attributed to their pozzolanic properties [20], [267]. Pozzolanic materials react with calcium hydroxide in the presence of water to form additional cementitious compounds. However, the reaction rate is slower than that of OPC, leading to a longer setting time and lower early strength development. As a result, the early strength of the concrete is reduced, but the long-term strength development is enhanced.

On the other hand, micro silica (MS) is a highly reactive pozzolan that reacts quickly with calcium hydroxide to form additional cementitious compounds. As a result, the early strength of the concrete is improved. MS also has a very fine particle size, which fills the voids between the larger cement particles, resulting in a denser and more compact concrete matrix. This leads to improved durability and reduced permeability [166].

4.5 MARSH CONE TEST

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 (GGBS) was 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 as given in Table 4.5 . 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.

Table 4.5 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		
OPC + FA(S-III/FA)	30		
OPC +GGBS(S-IV/GGBS)	50		

4.5.1 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[268]. According to [269], 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 [270]. From the experimental results, flow time and saturation dose of SP for all the mixes decreases as w/b increase, as shown in Figure 4.9 to Figure 4.12. Decrease flow time and saturation dose are because of four reasons mainly for high w/b – the viscosity of the cement paste decreased [271], the yield stress of paste decreases [272], strong zeta potential start weakening [273], and extra water will be available after the adsorption of the surface of the cementitious particle.

From Table 4.6, 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 unfavorable, so the particles repel each other [274][129].

Figure 4.9 to Figure 4.12 and

Table 4.6 , 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 [203][275].

Table 4.6 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

4.5.2 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

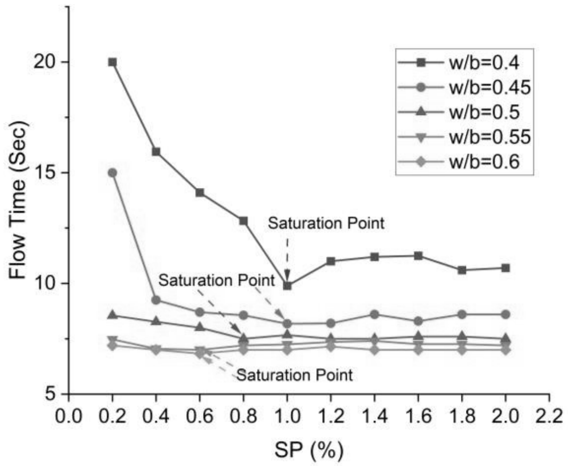


Figure 4.9 SP vs. FT for different w/b S-I/C

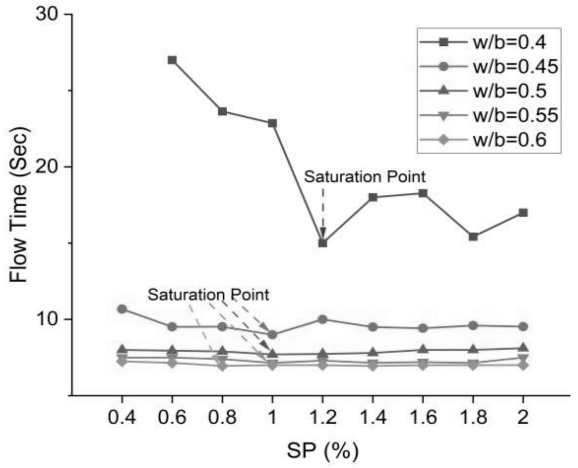


Figure 4.10 SP vs. FT for different w/b S-II/MS

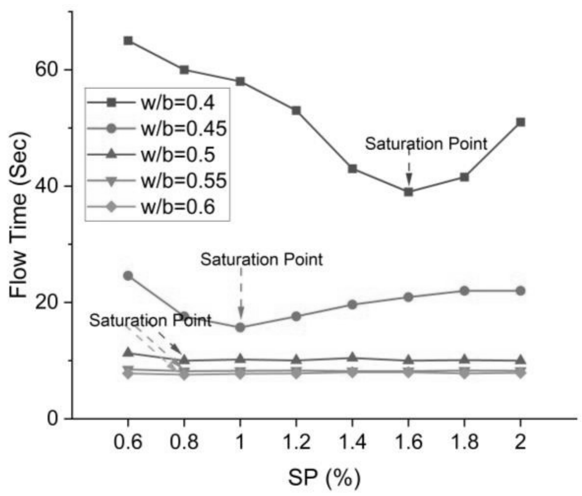


Figure 4.11 SP vs. FT for different w/b S-III/FA

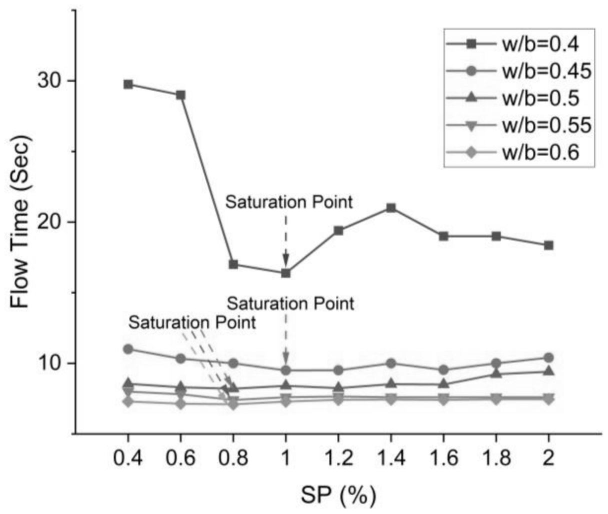


Figure 4.12 SP vs. FT for different w/b S-IV/GGBS

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 [276].

The flow time of the pastes at different w/b is shown in Figure 4.13 to Figure 4.17. 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 Figure 4.13 to Figure 4.17 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 given in

Table 4.6, and SP contributes fluidity to the paste. From Figure 4.16 and Figure 4.17, 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 Figure 4.13 to Figure 4.17.

From the experiment, as seen in Figure 4.13, 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 Figure 4.14 to Figure 4.17.

The lower specific gravity and smaller unit weight of S-III/FA, as shown in Table 4.4, 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 contributing factor is the ball-bearing shape of FA particles, as illustrated in the SEM image in Figure 4.6.This shape results in an overall higher surface area and increased adsorption of superplasticizer (SP) and water on its surface to counteract the strong zeta potential. A similar observation was also reported by [55]. 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, as depicted in Figure 4.13 to Figure 4.17, has a higher SP dose at 0.50, 0.55, and 0.60 w/b. This behavior may be attributed to the tiny spherical shape of the MS particles, as observed in the SEM image in Figure 4.4. The spherical shape contributes to a higher surface area of MS particles, as indicated in Table 4.4. A similar finding was also reported by [270].

The S-IV/GGBS sample has a higher flow time than the S-I/C and S-II/MS sample, as seen in Figure 4.13 to Figure 4.17., 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 [277] [273] as seen in Figure 4.8. 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 4.4, contributing to comparatively lower flow time.

4.5.3 Efficiency of Superplasticizer

The efficiency values of SP for different mineral admixtures with respect to S-I/C sample for all water binder ratios have been compared. S-I/C generally has the highest efficiency values among FA and MS types of mineral admixtures, except for cases where S-IV/GGBS has higher efficiency values at all w/b ratios as shown in Figure 4.18.

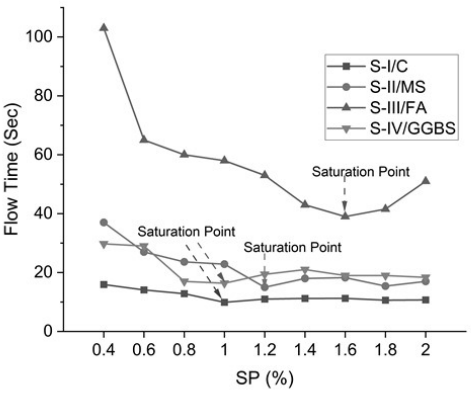


Figure 4.13 SP dosage vs. flow time at 0.4 w/b ratio

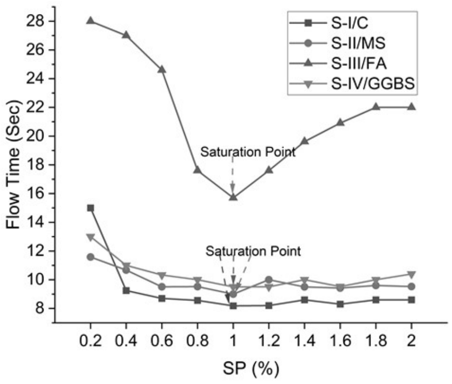
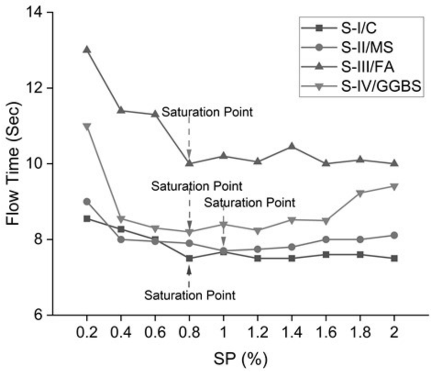


Figure 4.14 SP dosage vs. flow time at 0.45 w/b ratio



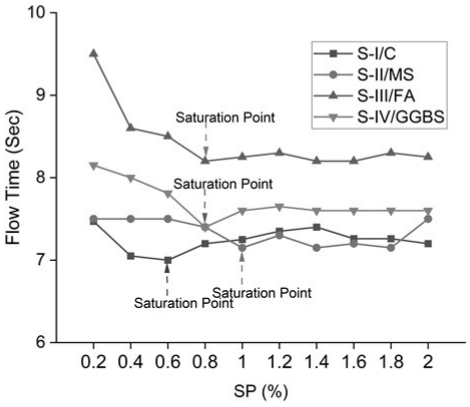


Figure 4.15 SP dosage vs. flow time at 0.5 w/b ratio

Figure 4.16 SP dosage vs. flow time at 0.55 w/b ratio

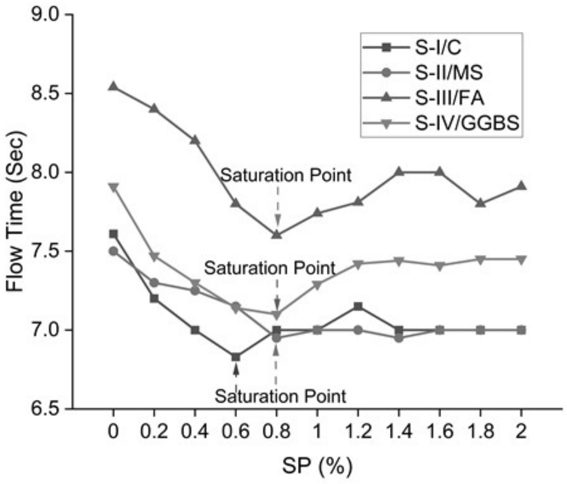


Figure 4.17 SP dosage vs. flow time at 0.60 w/b ratio

At w/b ratio of 0.55, S-IV/GGBS has the highest efficiency of 14.71%, while S-II/MS has the lowest efficiency of 9.12%. S-III/FA and S-I/C have efficiencies of 11.03% and 15.07%, respectively. At w/b ratio of 0.6, S-IV/GGBS has the highest efficiency of 14.90%, while S-II/MS has the lowest efficiency of 11.76%. S-III/FA and S-I/C have efficiencies of 11.91% and 15.15%, respectively as given in Table 4.7 and shown in Figure 4.18.

Table 4.7 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		
S-I/C					
0.4	1	680	500	230	10.59
0.45	1	765	582	20	10.76
0.5	0.8	850	680	10	12.50
0.55	0.6	935	785	8.5	14.71
0.6	0.6	1020	868	7.5	14.90
S-II/MS					
0.4	1.2	680	520	>30 min	7.84
0.45	1	765	615	34	8.82
0.5	1	850	698	11.5	8.94

0.55	1	935	780	8.1	9.12
0.6	0.8	1020	860	7.61	11.76
S-III/FA					
0.4	1.6	680	490	Stiff Paste (No Fluidity)	6.99
0.45	1	765	589	>30 min	10.35
0.5	0.8	850	705	27	10.66
0.55	0.8	935	785	11.6	11.03
0.6	0.8	1020	858	8.54	11.91
S-IV/GGBS					
0.4	1	680	495	>30 min	10.88
0.45	1	765	570	26	11.47
0.5	0.8	850	675	21	12.87
0.55	0.8	935	730	9.09	15.07
0.6	0.8	1020	814	7.91	15.5

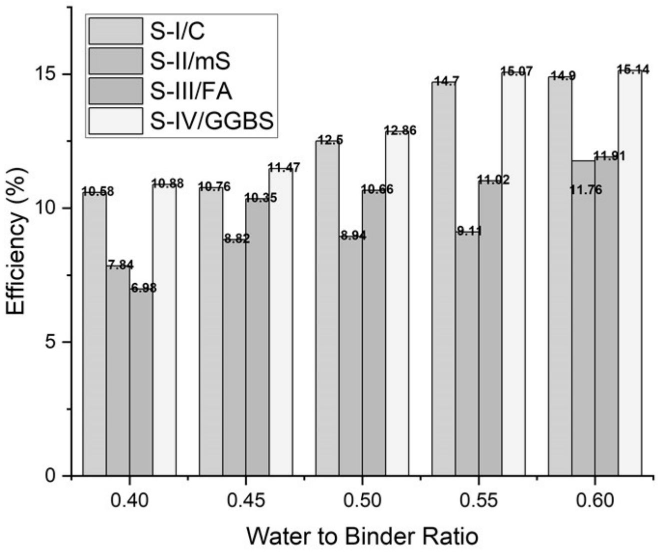


Figure 4.18 Efficiency of superplasticizer on various pastes at different w/b

4.6 CONCRETE MIX DESIGN

The mix design was done as per IS 10262 [239]. Concrete mix have been prepared using the following combination and given Table 4.8 and Table 4.9. The choice of concrete mix combinations, totaling 32, was strategic and aimed at comprehensively evaluating various factors. Four combinations within each cementing material were specifically employed to investigate the effect of water-to-binder (w/b) ratio. Additionally, the remaining 16 combinations were strategically divided to compare samples with superplasticizer against those without superplasticizer. Similarly, another set of 24 combinations facilitated a comparison between mineral admixed samples and those without mineral admixtures. This meticulous approach allows for a nuanced examination of the impact of w/b ratio, superplasticizer, and mineral admixtures on the properties of concrete mixes, contributing to a more comprehensive understanding of the experimental outcomes.

Table 4.8 Mix design proportion by volume without SP of different concret mix

Mix Design Proportion by volume								
Binding Material	**SAMPLE**	**WATER**	**CEMENT**	**Mineral Admixture**	**Binding Material**	**FA**	**CA10**	**CA20**
100% OPC	C40	0.40	1.00	0.00	1.00	1.14	0.96	1.42
	C45	0.45	1.00	0.00	1.00	1.35	1.09	1.62
	C50	0.50	1.00	0.00	1.00	1.58	1.22	1.81
	C55	0.55	1.00	0.00	1.00	1.82	1.34	1.99
70%OPC +30 % FA	CF40	0.40	0.70	0.30	1.00	1.10	0.92	1.37
	CF45	0.45	0.70	0.30	1.00	1.31	1.06	1.57
	CF50	0.50	0.70	0.30	1.00	1.54	1.19	1.76
	CF55	0.55	0.70	0.30	1.00	1.78	1.31	1.95
90% OPC +10 % MS	CM40	0.40	0.90	0.10	1.00	1.13	0.95	1.41
	CM45	0.45	0.90	0.10	1.00	1.34	1.08	1.60
	CM50	0.50	0.90	0.10	1.00	1.57	1.21	1.79
	CM55	0.55	0.90	0.10	1.00	1.81	1.33	1.98
50% OPC +50 % GGBS	CB40	0.40	0.50	0.50	1.00	1.12	0.94	1.40
	CB45	0.45	0.50	0.50	1.00	1.34	1.08	1.60
	CB50	0.50	0.50	0.50	1.00	1.56	1.20	1.79
	CB55	0.55	0.50	0.50	1.00	1.80	1.33	1.97

Table 4.9 Mix design proportion by volume with SP of different concret mix

Mix Design Proportion by volume									
Binding Material	**SAMPLE**	**WATER**	**CEMENT**	**Mineral Admixture**	**Binding Material**	**FA**	**CA10**	**CA20**	**SP%**
100% OPC	SC40	0.4	1	0	1	1.69	1.32	1.95	1
	SC45	0.45	1	0	1	1.99	1.49	2.2	1
	SC50	0.5	1	0	1	2.3	1.65	2.44	0.8
	SC55	0.55	1	0	1	2.63	1.81	2.68	0.6
70%OPC +30 % FA	SCF40	0.4	0.7	0.3	1	1.65	1.29	1.91	1.6
	SCF45	0.45	0.7	0.3	1	1.95	1.46	2.16	1
	SCF50	0.5	0.7	0.3	1	2.26	1.62	2.4	0.8

	SCF55	0.55	0.7	0.3	1	2.59	1.78	2.64	0.8
90% OPC +10 % MS	SCM40	0.4	0.9	0.1	1	1.67	1.31	1.94	1.2
	SCM45	0.45	0.9	0.1	1	1.97	1.48	2.19	1
	SCM50	0.5	0.9	0.1	1	2.29	1.64	2.43	1
	SCM55	0.55	0.9	0.1	1	2.62	1.8	2.67	1
50% OPC +50 % GGBS	SCB40	0.4	0.5	0.5	1	1.66	1.3	1.93	1
	SCB45	0.45	0.5	0.5	1	1.96	1.47	2.18	1
	SCB50	0.5	0.5	0.5	1	2.28	1.64	2.42	0.8
	SCB55	0.55	0.5	0.5	1	2.61	1.8	2.66	0.8

4.7 CONCLUSION

The addition of mineral admixtures like micro silica, fly ash, and GGBS to cement can lead to an increase in consistency compared to the control sample (Blank Cement OPC). This is because the fine particles of the mineral admixtures can fill the voids between the cement particles, resulting in a denser paste. However, this denser paste may require a higher water demand to maintain the same consistency as the control sample. As a result, the normal consistency of the mineral admixture samples is generally higher than that of OPC.

The addition of mineral admixtures like micro silica, fly ash, and GGBS to concrete can affect the setting time of the concrete. The experimental data show that the initial and final setting times of concrete samples with mineral admixtures are generally higher than the control sample, which is OPC. The increase in setting time can be attributed to the slower rate of reaction of mineral admixtures with the cement hydration process compared to OPC.

Based on the experimental data, it can be concluded that S-I/C has the highest compressive strength among all types of concrete tested at 3 days of testing. S-II/MS has a highest compressive strength at 7 days and 28 days of testing. S-III/FA and S-IV/GGBS have lower compressive strengths than S-I/C and S-II/MS at all ages, which can be attributed to their pozzolanic properties, leading to slower reaction rates and lower early strength development [73] [270] [278].

Flow time of cement paste without any mineral admixtures were 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 increases with a decrease in w/b and vice versa. The type of mineral admixture used and their properties as well as the shape of cementitious grain has influence in altering the saturation level of SP.