CHAPTER 5 STUDY ON MECHANICAL STRENGTH OF CONCRETE

5.1 GENERAL

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, and relatively low cost. The strength of concrete is determined by several factors, including the type and amount of cementitious materials used, the water-to-binder ratio (w/b), and the curing conditions. In recent years, the use of mineral admixtures such as fly ash (FA), ground granulated blast furnace slag (GGBS), and micro silica (MS) in concrete has become increasingly popular due to their ability to enhance concrete properties such as strength and durability. Superplasticizers (SP) are also commonly used in concrete to improve workability and reduce water content without compromising the strength.

In this study, we investigated the effect of replacing 30% of cement with FA, 50% of cement with GGBS, and 10% of cement with MS on the compressive strength of concrete at 7, 28, and 90 days, as well as the splitting and flexural strength of concrete at 28 and 90 days for w/b ratios of 0.4, 0.45, 0.5, and 0.55. In addition, the effect of SP on the properties of concrete was also examined, as well as the combined effect of mineral admixtures and SP. The study aimed to evaluate the potential of these additives to improve the strength and durability of concrete, which can lead to a longer service life of concrete structures and reduce maintenance costs.

5.2 COMPRESSIVE STRENGTH (CS)

Compressive strength is considered as one of the most important properties of concrete, as it directly affects the structural integrity and durability of concrete structures. The compressive strength of concrete is influenced by various factors such as the water-binder ratio, type and percentage of supplementary cementitious materials (SCMs) used, curing conditions, and the age of concrete. In this study, the effects of incorporating 30% fly ash

(FA), 10% micro silica (MS) and 50% ground granulated blast furnace slag (GGBS) on the compressive strength of concrete were investigated. The water-binder ratio was varied to understand its effect on the compressive strength of concrete with these specific SCMs as given in Table 5.1 and shown in Figure 5.1

Additionally, the use of high-range water-reducing admixtures or superplasticizer (SP) was also studied to evaluate the synergetic effect of SCMs and SP on the compressive strength of concrete. The results of this study will provide insight into the optimal dosage of SCMs and SP for achieving maximum compressive strength in concrete, and have important implications for the design and construction of sustainable and durable concrete structures.

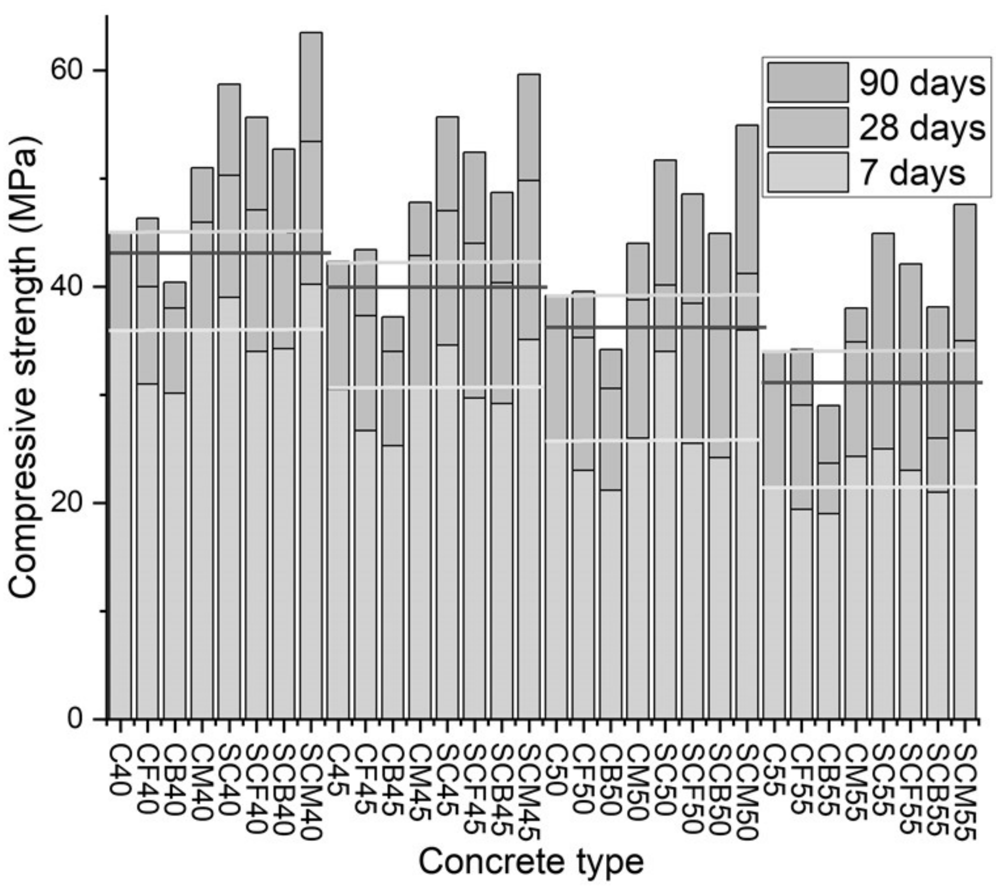

Figure 5.1 Compressive strength of different concrete mix

5.2.1 Effect of w/b

The water-to-cement ratio (W/C) is a crucial factor that affects the compressive strength of concrete. This study aimed to investigate the effect of varying w/b on the compressive strength of different types of concrete at 7 days, 28 days, and 90 days. The types of concrete studied include control concrete (C), concrete with FA (CF), concrete with MS (CM), concrete with GGBS (CB), concrete with superplasticizer (SC), concrete with superplasticizer and FA (SCF), concrete with superplasticizer and MS (SCM), and concrete with superplasticizer and GGBS (SCB).

Comparison: The study was conducted by measuring the compressive strength of concrete samples with w/b of 0.4, 0.45, 0.5, and 0.55 at 7 days, 28 days, and 90 days. The compressive strength was determined using the standard testing procedure. The results were analyzed to determine the effect of w/b on compressive strength for each type of concrete.

At 7 days, for control concrete, the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 15.21%, 28.66% and 40.48% respectively. Similarly, for concrete with FA (CF), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 10.97%, 25.81% and 37.42% respectively as shown in Figure 5.2 . For concrete with MS (CM), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 15%, 29.78% and 36.98% respectively as shown in Figure 5.2. For concrete with GGBS (CB), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 15.09%, 29.78% and 36.98% respectively as shown in Figure 5.2 and given in Table 5.1.

At 28 days, for control concrete, the decrease in compressive strength when the W/b increases from 0.4 to 0.45, 0.5 and 0.55 are 7.96%, 14.82% and 26.84% respectively.

Similarly, for concrete with FA (CF), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 4.50%, 11.75% and 27.45% respectively. For concrete with MS (CM), the decrease in compressive strength when the W/b increases from 0.4 to 0.45, 0.5 and 0.55 are 8.36%, 15.64% and 24.09% respectively. For concrete with GGBS (CB), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 10.22%, 15.06% and 34.31% as shown in Figure 5.2.

At 90 days, for control concrete(C), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 5.92%, 12.81% and 24.38% respectively. Similarly, for concrete with FA (CF), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 6.32%, 14.66% and 28.88% respectively as shown in Figure 5.2. For concrete with MS (CM), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 7.45%, 13.33% and 25.04% respectively as shown in Figure 5.2. For concrete with GGBS (CB), the decrease in compressive strength when the w/b increases from 0.4 to 0.45, 0.5 and 0.55 are 9.18%, 13.77% and 32.28% respectively as shown in Figure 5.2. Similar trend is observed in superplasticizer samples also. This is in line with the findings of previous research study [279].

It can be observed that as w/b increases, compressive strength decreases, which is more significant as the w/b increases and the decrease in compressive strength is observed at all the stages 7 days, 28 days and 90 days across all types of concrete studied. The use of supplementary cementitious materials such as FA, MS, and GGBS helps to improve the compressive strength of concrete when combined with the superplasticizer as shown in Figure 5.2

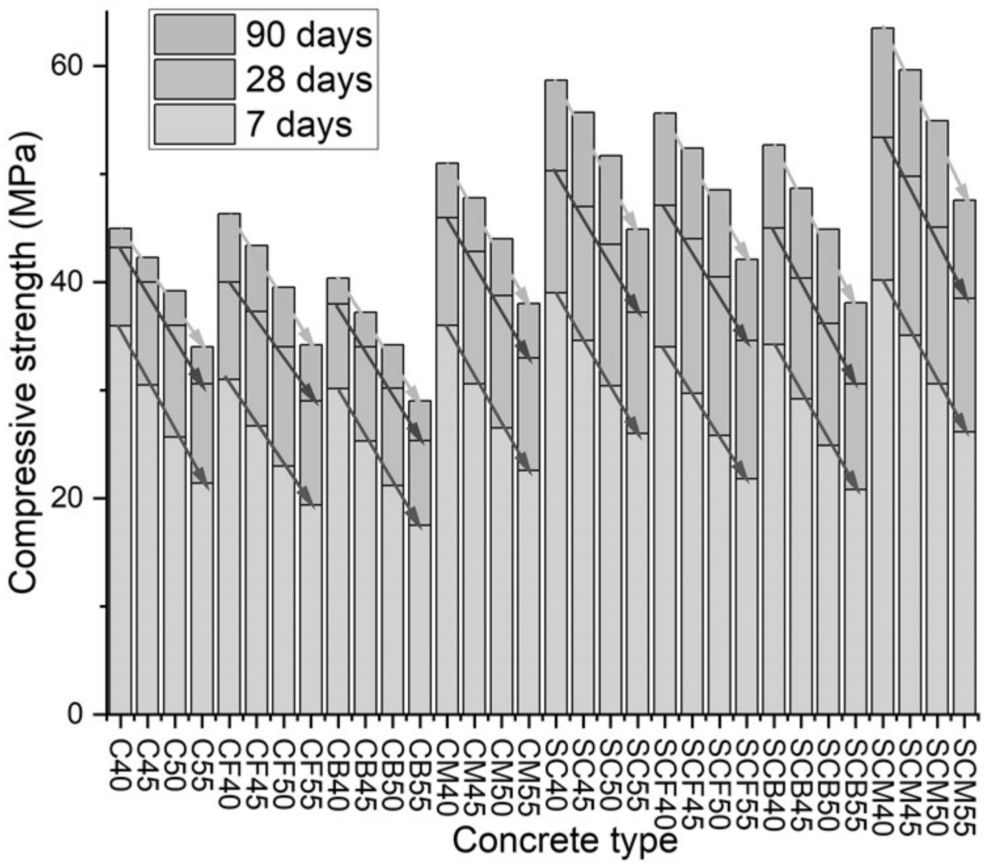

Figure 5.2 Effect of w/b on different concrete types on compressive strength

Table 5.1 CS, FS, and STS of various concrete mix

Concrete type /Curing age	**Compressive Strength (MPa)**			**Flexural strength (MPa)**		**Split tensile strength (MPa)**	
	7 d	**28 d**	**90 d**	**28 d**	**90 d**	**28 d**	**90 d**
C40	35.97	43.20	44.96	5.50	5.61	3.40	3.83
C45	30.50	40.00	42.30	5.32	5.48	3.25	3.72
C50	25.66	36.00	39.20	5.02	5.26	3.10	3.56
C55	21.41	30.60	34.00	4.70	4.92	2.75	3.16
CF40	31.00	40.00	46.33	5.29	5.70	3.25	4.05
CF45	26.70	37.30	43.40	5.14	5.55	3.10	3.90
CF50	23.00	34.00	39.54	4.86	5.27	2.92	3.70

CF55	19.40	29.02	34.20	4.55	4.92	2.58	3.24
CB40	30.15	38.00	40.39	5.20	5.36	3.02	3.50
CB45	25.30	34.00	37.20	4.92	5.14	2.82	3.30
CB50	21.17	30.20	34.20	4.62	4.91	2.62	3.10
CB55	17.50	25.33	29.00	4.23	4.52	2.32	2.75
CM40	36.00	45.96	51.00	5.80	6.20	3.54	4.20
CM45	30.6	42.85	47.80	5.53	5.95	3.40	4.08
CM50	26.5	38.77	44.00	5.13	5.57	3.26	3.89
CM55	22.6	33.00	38.02	4.80	5.18	2.90	3.45
SC40	39	50.30	58.70	6.05	6.57	3.80	4.30
SC45	34.60	47.00	55.70	5.64	6.20	3.49	4.02
SC50	30.40	43.50	51.70	5.32	5.93	3.25	3.8
SC55	26.00	37.20	44.90	4.92	5.54	2.8	3.33
SCF40	34.00	47.10	55.65	5.7	6.2	3.55	4.1
SCF45	29.70	44.00	52.40	5.4	5.95	3.35	3.88
SCF50	25.80	40.50	48.55	5.1	5.7	3.17	3.71
SCF55	21.80	34.60	42.10	4.73	5.4	2.76	3.29
SCB40	34.25	45.00	52.70	5.71	6.1	3.53	4.05
SCB45	29.20	40.36	48.70	5.44	5.85	3.31	3.88
SCB50	24.90	36.20	44.90	5.1	5.62	3.15	3.71
SCB55	20.80	30.60	38.10	4.71	5.27	2.76	3.29
SCM40	40.20	53.40	63.50	6.5	7.1	3.82	4.4
SCM45	35.10	49.80	59.63	6.1	6.8	3.54	4.2
SCM50	30.60	45.10	54.92	5.78	6.52	3.33	3.98
SCM55	26.15	38.50	47.60	5.35	6.1	2.93	3.5

5.2.2 Effect of Mineral Admixture

In this study, the effect of using mineral admixtures on the compressive strength of concrete was also investigated. The mineral admixtures used were FA, MS, and GGBS, with replacement percentages of 30%, 10%, and 50% respectively. The compressive strength of concrete with mineral admixtures was determined at 7 days, 28 days, and 90 days and the results were analyzed and presented in Table 5.3. The results were also presented in graphical form in Figure 5.3 and Figure 5.4 for better understanding.

Comparison with Control Concrete (C):

When comparing the compressive strength of concrete with FA (CF) to the control concrete (C), it was found that at 7 days, the decrease in CS was 9.4-13.8%, at 28 days the decrease in compressive strength was 7.4-5.2% and at 90 days the increase in compressive strength was 0.6-3.0% at 0.4 to 0.55 w/b as shown in Figure 5.3. Which have shown that the use of FA as a mineral admixture can improve the compressive strength of concrete over the curing age. Similarly, when comparing the CS of concrete with MS (CM) to the control concrete (C), it was found that at 7 days, the compressive strength increase negligibly around 0.1-5.6 % at 0.4 to 0.55 w/b, however at 28 days the increase in compressive strength was approximately 6.4-7.8% and at 90 days the increase in compressive strength was 11.8-13.4% as shown in Figure 5.3, which have shown that the use of MS as a mineral admixture can improve the compressive strength of concrete.

On the other hand, the addition of GGBS has shown a negative effect on the compressive strength at all curing ages, regardless of the water-binder ratio. When comparing the control concrete (C) to the concrete with GGBS (CB), it can be seen that there is an average decrease of 12-19% in compressive strength as shown in Table 5.2

Comparison with Control Concrete with Superplasticizer (SC). When comparing the compressive strength of concrete with superplasticizer and FA (SCF) to the control concrete with superplasticizer (SC), it was found that at 7 days, the decrease in compressive strength was 12.8-16.2%, at 28 days the decrease in compressive strength was 12.2-20% and at 90 days the decrease in compressive strength was 10.5-17.7% at 0.40-0.55 w/b as shown in Table 5.3, which have shown that the use of fly ash as a mineral admixture in combination with superplasticizer can further improve the compressive strength of concrete. Similarly, when comparing the compressive strength of concrete with superplasticizer and micro silica (SCM) to the control concrete with superplasticizer (SC), it was found that at 7 days, the increase in compressive strength was 0.6-3.1%, at 28 days the increase in compressive strength was 3.5-6.2% and at 90 days the increase in compressive strength was 6-8.2% as shown in Table 5.3,which have shown that the use of micro silica as a mineral admixture in combination with superplasticizer can further improve the compressive strength of concrete. Furthermore, the compressive strength of concrete with superplasticizer and GGBS (SCB) was found to be lower than control concrete with superplasticizer (SC) with an decrease of 12.2-20%, 10.5-17.7% and 10.2-15.1% at 7 days, 28 days, and 90 days respectively as shown in Table 5.3, which have shown that the use of GGBS as a mineral admixture in combination with superplasticizer can further improve the compressive strength of concrete.

In conclusion, the study showed that the use of mineral admixtures such as micro silica in concrete can significantly improve the compressive strength at all stages 7 days, 28 days, and 90 days when compared to the control concrete with SP, however CS of concrete with FA and GGBS with SP always lower than the control concrete with SP.

5.2.3 Effect of Superplasticizer

In this study, the effect of superplasticizer on the compressive strength of concrete was also investigated. The compressive strength of concrete without superplasticizer (C, CF, CM, CB) was determined at 7 days, 28 days, and 90 days and compared to the compressive strength of concrete with superplasticizer (SC, SCF, SCM, SCB). The results were analyzed and presented in Table 5.4.

Table 5.2 Change in CS of MA admixed concrete w.r.t control concrete without SP at different curing age

w/b ↓ Age →	Control Concrete (C)			Concrete with FA (CF)			Concrete with GGBS (CB)			Concrete with MS (CM)		
	Compressive Strength (MPa)			**% Change in CS With Respect to control concrete (C)**								
	7 d	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**
0.4	35.97	43.20	44.96	-13.8	-7.4	3.0	-16.2	-12.0	-10.2	0.1	6.4	13.4
0.45	30.50	40.00	42.30	-12.5	-6.8	2.6	-17.0	-15.0	-12.1	0.3	7.1	13.0
0.5	25.66	36.00	39.20	-10.4	-5.6	0.9	-17.5	-16.1	-12.8	3.3	7.7	12.2
0.55	21.41	30.60	34.00	-9.4	-5.2	0.6	-18.3	-17.2	-14.7	5.6	7.8	11.8

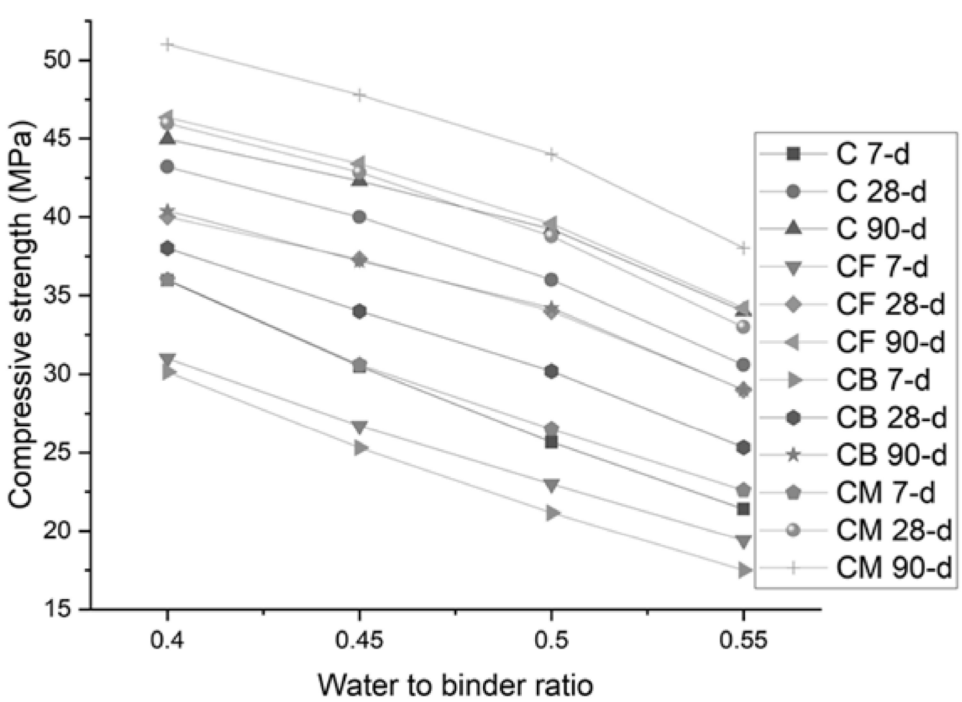

Figure 5.3 Comparison of CS of MA admixed concrete with plain concrete with varying w/b and curing age

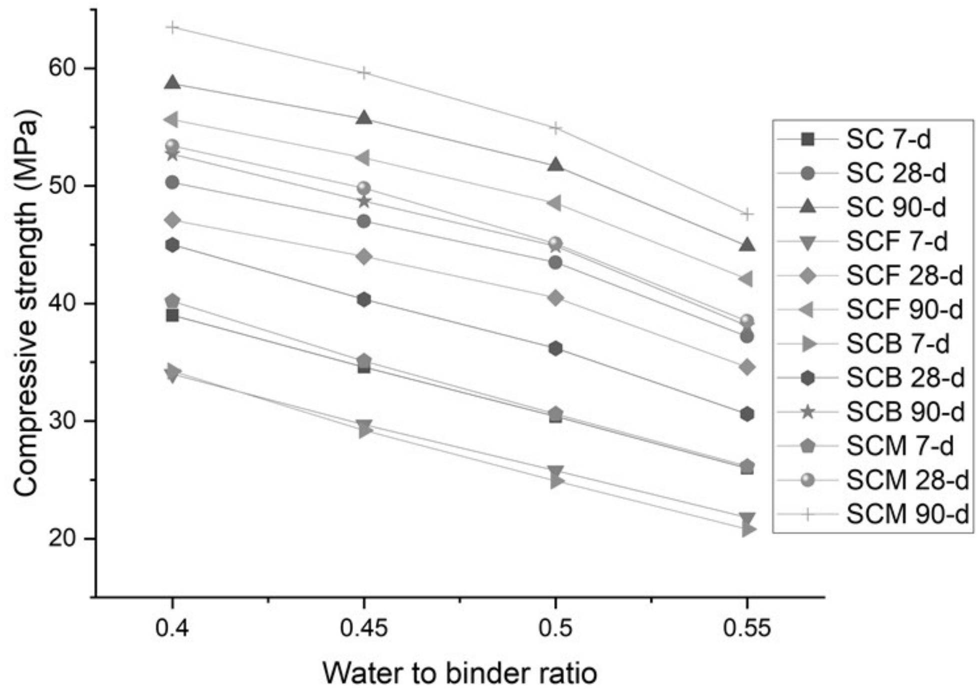

Figure 5.4 Comparison of CS of MA and SP admixed concrete with SP concrete with varying w/b and curing age

Table 5.3 Change in CS of mineral admixture with respect to control concrete with SP at different curing age

w/b ↓ Age →	Control Concrete with SP (SC)			Concrete with FA and SP (SCF)			Concrete with GGBS and SP (SCB)			Concrete with MS and SP (SCM)		
	Compressive Strength (MPa)			% Change in CS With Respect to control concrete with SP (SC)								
	7 d	28 d	90 d	7 d	28 d	90 d	7 d	28 d	90 d	7 d	28 d	90 d
0.4	39	50.30	58.70	-12.8	-6.36	-5.2	-12.2	-10.5	-10.2	3.1	6.2	8.2
0.45	34.60	47.00	55.70	-14.2	-6.38	-5.9	-15.6	-14.1	-12.6	1.4	6.0	7.1
0.5	30.40	43.50	51.70	-15.1	-6.9	-6.1	-18.1	-16.8	-13.2	0.7	3.7	6.2
0.55	26.00	37.20	44.90	-16.2	-7.0	-6.2	-20.0	-17.7	-15.1	0.6	3.5	6.0

Comparison with control concrete (C): When comparing the compressive strength of control concrete (C) with superplasticizer (SC), it was found that at 7 days, the increase in compressive strength was 8-21.4%, at 28 days the increase in compressive strength was 16.4-21.6% and at 90 days the increase in compressive strength was 31-32.1% as shown in Table 5.4 at different w/b. Comparison with concrete with fly ash (CF): When comparing the compressive strength of concrete with fly ash (CF) to the control concrete with superplasticizer and fly ash (SCF), it was found that at 7 days, the increase in compressive strength was 9.7-12.4%, at 28 days the increase in compressive strength was 17.75-19.2% and at 90 days the increase in compressive strength was 20.1-23.1% as shown in Table 5.4 at different w/b.

Comparison with concrete with micro silica (CM): When comparing the compressive strength of concrete with micro silica (CM) to the control concrete with superplasticizer and micro silica (SCM), it was found that at 7 days, the increase in compressive strength was 11.67-15.71%, at 28 days the increase in compressive strength was 16.19-16.67% and at 90 days the increase in compressive strength was 24.51-25.20% as shown in Table 5.4 at different w/b.

Comparison with concrete with GGBS (CB): When comparing the compressive strength of concrete with GGBS (CB) to the control concrete with superplasticizer and GGBS (SCB), it was found that at 7 days, the increase in compressive strength was 13.6-18.9%, at 28 days the increase in compressive strength was 18.4-20.8% and at 90 days the increase in compressive strength was 30.5-31.4%. This indicates that the use of superplasticizer in combination with GGBS can further improve the compressive strength of concrete.

In conclusion, the use of superplasticizer can significantly improve the compressive strength of concrete at all stages 7 days, 28 days, and 90 days when compared to the control concrete without superplasticizer. The improvement in compressive strength can be attributed to several factors.

One of the key factors is the reduction in water content in the mix. Superplasticizers are high range water reducing agents that help to reduce the water content in the mix while maintaining the same workability. This results in a denser microstructure and higher compressive strength.

Superplasticizers work by modifying the electrostatic repulsion between the cement particles in concrete mix. They adsorb on the surface of cement particles and form a protective film, which reduces the repulsion between cement particles. This allows the water molecules to penetrate the cement particles more easily, resulting in the formation of a denser and stronger structure.

Additionally, superplasticizers can also improve the dispersion of cement particles in the mix, leading to a more homogeneous distribution of cement and a more efficient use of cement. This leads to a greater degree of hydration and higher compressive strength.

In summary, the use of superplasticizer improves the compressive strength of concrete by reducing water content, modifying electrostatic repulsion between cement particles and improving the dispersion of cement particles in the mix, resulting in a denser and stronger microstructure.

Table 5.4 Change in CS of SP concrete with respect to without SP concrete

Type ➡	**Concrete without SP**			**Concrete with SP**			**% Change in CS with respect to without SP concrete**		
	C			**SC**					
w/b	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**
0.4	35.97	43.20	44.96	39	50.3	58.7	8	16.4	31
0.45	30.50	40.00	42.30	34.6	47	55.7	13	17.5	31.7
0.5	25.66	36.00	39.20	30.4	43.5	51.7	18.5	20.8	31.9
0.55	21.41	30.60	34.00	26	37.2	44.9	21.4	21.6	32.1
FA	**CF**			**SCF**			**% change in CS**		
w/b	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**
0.4	31.00	40.00	46.33	34.00	47.10	55.65	9.7	17.75	20.1
0.45	26.70	37.30	43.40	29.70	44.00	52.40	11.2	17.96	20.7
0.5	23.00	34.00	39.54	25.80	40.50	48.55	12.2	19.1	22.8

0.55	19.40	29.02	34.20	21.80	34.60	42.10	12.4	19.2	23.1
GGBS	**CB**			**SCB**			**% change in CS**		
w/b	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**
0.4	30.15	38.00	40.39	34.25	45.00	52.70	13.6	18.4	30.5
0.45	25.30	34.00	37.20	29.20	40.36	48.70	15.4	18.7	30.9
0.5	21.17	30.20	34.20	24.90	36.20	44.90	17.6	19.9	31.3
0.55	17.50	25.33	29.00	20.80	30.60	38.10	18.9	20.8	31.4
MS	**CM**			**SCM**			**% change in CS**		
w/b	**7d**	**28d**	**90d**	**7d**	**28d**	**90d**	**7d**	**28d**	**90d**
0.4	36.00	45.96	51.00	40.20	53.40	63.50	11.67	16.19	24.51
0.45	30.60	42.85	47.80	35.10	49.80	59.63	14.71	16.22	24.75
0.5	26.50	38.77	44.00	30.60	45.10	54.92	15.47	16.33	24.82
0.55	22.60	33.00	38.02	26.15	38.50	47.60	15.71	16.67	25.20

5.2.4 Combined Effect of Superplasticizer (SP) and Mineral Admixture (MA)

The combined effect of mineral admixture and superplasticizer on the compressive strength of concrete was also investigated in this study. The compressive strength of control concrete (C) was compared to the compressive strength of concrete containing both mineral admixture (FA, MS, and GGBS) and superplasticizer (SCF, SCM, and SCB) at 7 days, 28 days, and 90 days. The results were analyzed and presented in Table 5.5 and Figure 5.5, Figure 5.6, and Figure 5.7.

For the water-to-cement ratio of 0.4 (C40, SCF40, SCM40, and SCB40), the compressive strength of control concrete (C40) at 7 days is 35.97 MPa, at 28 days is 43.20 MPa, and at 90 days is 44.96 MPa. When compared to concrete containing FA and SP (SCF40), the compressive strength of control concrete (C40) showed a decrease of 5.5% at 7 days, and then increase of 9.03 % at 28 days, and 23.78% at 90 days. Similarly, when compared to concrete containing MS and SP (SCM40), the compressive strength of control concrete (C40) showed an increase of 3.1% at 7 days, 6.2% at 28 days, and 8.2% at 90 days. And when compared to concrete containing GGBS and SP (SCB40), the compressive strength of control concrete (C40) showed a decrease of 4.78% at 7 days, and then increase of 4.17% at 28 days, and 17.22% at 90 days.

For the water-to-cement ratio of 0.45 (C45, SCF45, SCM45, and SCB45), the compressive strength of control concrete (C45) at 7 days is 30.50 MPa, at 28 days is 40 MPa, and at 90 days is 42.30 MPa. When compared to concrete containing FA and SP (SCF45), the compressive strength of control concrete (C45) showed a decrease of 2.6% at 7 days, and then increase of 10% at 28 days, and 23.88% at 90 days. Similarly, when compared to concrete containing MS and SP (SCM45), the compressive strength of control concrete (C45) showed an increase of 15.08% at 7 days, 24.50% at 28 days, and 40.97% at 90 days. And when compared to concrete containing GGBS and superplasticizer (SCB45), the compressive strength of control concrete (C45) showed a decrease of 4.26% at 7 days, and then an increase of 0.90% at 28 days, and 15.13% at 90 days.

For the water-to-cement ratio of 0.5 (C50, SCF50, SCM50, and SCB50), the compressive strength of control concrete (C50) at 7 days is 25.66 MPa, at 28 days is 36.0, and at 90 days is 39.20 MPa. When compared to concrete containing FA and SP (SCF50), the compressive strength of control concrete (C50) showed an increase of 0.5% at 7 days, 12.50% at 28 days, and 23.85% at 90 days. Similarly, when compared to concrete containing micro silica and superplasticizer (SCM50), the compressive strength of control concrete (C50) showed an increase of 19.25% at 7 days, 25.28% at 28 days, and 40.10% at 90 days. And when compared to concrete containing GGBS and superplasticizer (SCB50), the compressive strength of control concrete (C50) showed a decrease of 2.96% at 7 days, and then an increase of 0.56% at 28 days, and 12.06% at 90 days.

For the water-to-cement ratio of 0.55 (C55, SCF55, SCM55, and SCB55), the compressive strength of control concrete (C55) at 7 days is 21.41, at 28 days is 30.60, and at 90 days is 34.00 MPa. When compared to concrete containing FA and SP (SCF55), the compressive strength of control concrete (C55) showed an increase of 1.8% at 7 days, 13.07% at 28 days, and 23.82% at 90 days. Similarly, when compared to concrete containing MS and SP (SCM55), the compressive strength of control concrete (C55) showed an increase of 22.14% at 7 days, 25.82% at 28 days, and 40% at 90 days. And when compared to concrete containing GGBS and superplasticizer (SCB55), the compressive strength of control concrete (C55) showed a decrease of 2.85% at 7 days, and then an increase of 0% at 28 days, and 12.06% at 90 days.

The results show that the addition of SP and MA has a significant impact on the compressive strength of concrete at different water-to-cement ratios. At 7 days, the compressive strength of concrete containing FA, GGBS and SP showed a decrease, while the compressive strength of concrete containing MS and SP showed an increase. At 28 days, the compressive strength of concrete containing SP and any of the MAs (FA, MS, or GGBS) showed an increase compared to the control concrete. At 90 days, the compressive strength of all the concrete containing SP and MA showed a further increase.

The cause behind these results can be attributed to the properties of the MAs and SP. The mineral admixtures, such as FA, MS, and GGBS, have pozzolanic and cementitious properties, which improve the durability and strength of concrete over time. The addition of superplasticizer improves the workability of the concrete mix, making it easier to handle and place, while also reducing the amount of water required to achieve the desired workability. This reduction in water content leads to a higher strength of concrete as the water-to-cement ratio is reduced.

When MS is added to concrete, it reacts with calcium hydroxide to form additional calcium silicate hydrate, which contributes to the strength and durability of the concrete. In addition, the small particle size and high surface area of MS allows it to fill the voids in the concrete mixture and improve the overall density of the material. This results in improved mechanical properties, such as higher compressive strength, compared to concrete without MS. Furthermore, the use of superplasticizer also has a positive effect on the compressive strength of concrete. Superplasticizers are surface-active agents that change the surface charges of cement particles to disperse them into smaller agglomerates, thus increasing the fluidity or workability of concrete. The combination of mineral admixtures and superplasticizer in our study had a synergistic effect on the compressive strength of concrete, leading to higher compressive strength values compared to when the admixtures were used individually. The chemical reactions that take place between the mineral admixtures, superplasticizer and cement, along with the water-binder ratio, play a significant role in the compressive strength development of concrete.

In conclusion, the addition of both SP and MA to concrete can significantly improve its compressive strength over time.

Table 5.5 Change in CS of MA with SP admixed concrete with respect to control concrete without SP at different curing age

w/b ↓ Age →	Control Concrete (C)			Concrete with FA and SP (SCF)			Concrete with GGBS and SP (SCB)			Concrete with MS and SP (SCM)		
	Compressive Strength (MPa)			% Change in CS With Respect to control concrete (C)								
	7 d	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**	**7 d**	**28 d**	**90 d**
0.4	35.97	43.20	44.96	-5.5	9.03	23.78	-4.78	4.17	17.22	11.76	23.61	8.2
0.45	30.50	40.00	42.30	-2.6	10.00	23.88	-4.26	0.90	15.13	15.08	24.50	7.1
0.5	25.66	36.00	39.20	0.5	12.50	23.85	-2.96	0.56	14.54	19.25	25.28	6.2
0.55	21.41	30.60	34.00	1.8	13.07	23.82	-2.85	0.00	12.06	22.14	25.82	6.0

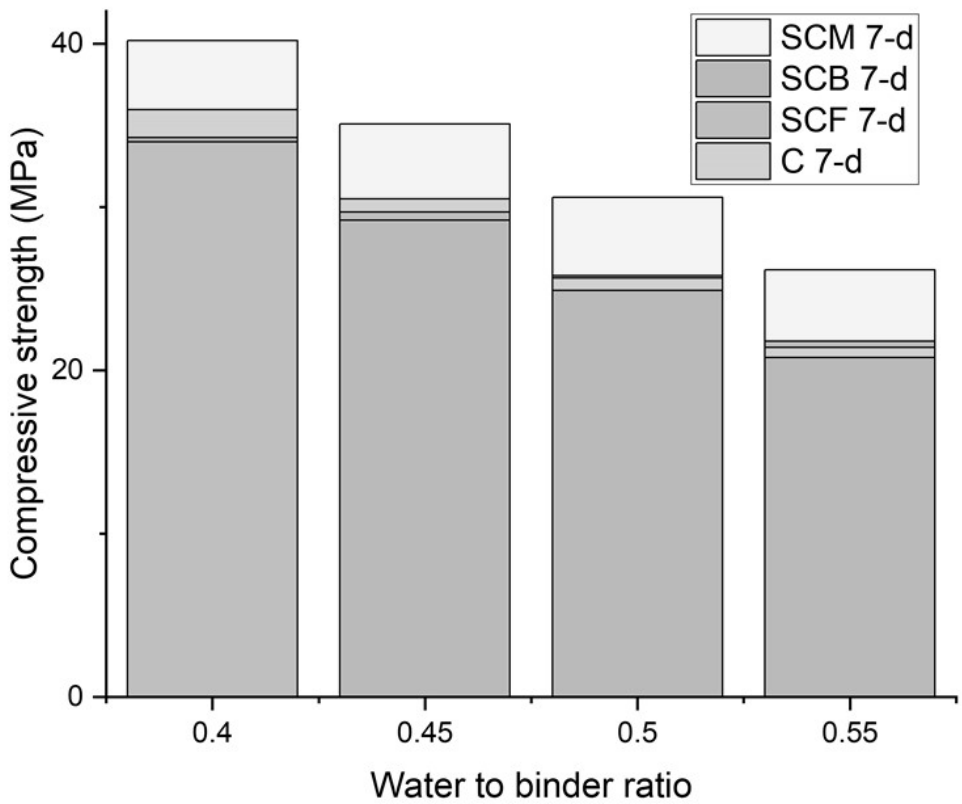

Figure 5.5 Combined effect of SP and mineral admixture on CS at 7 days

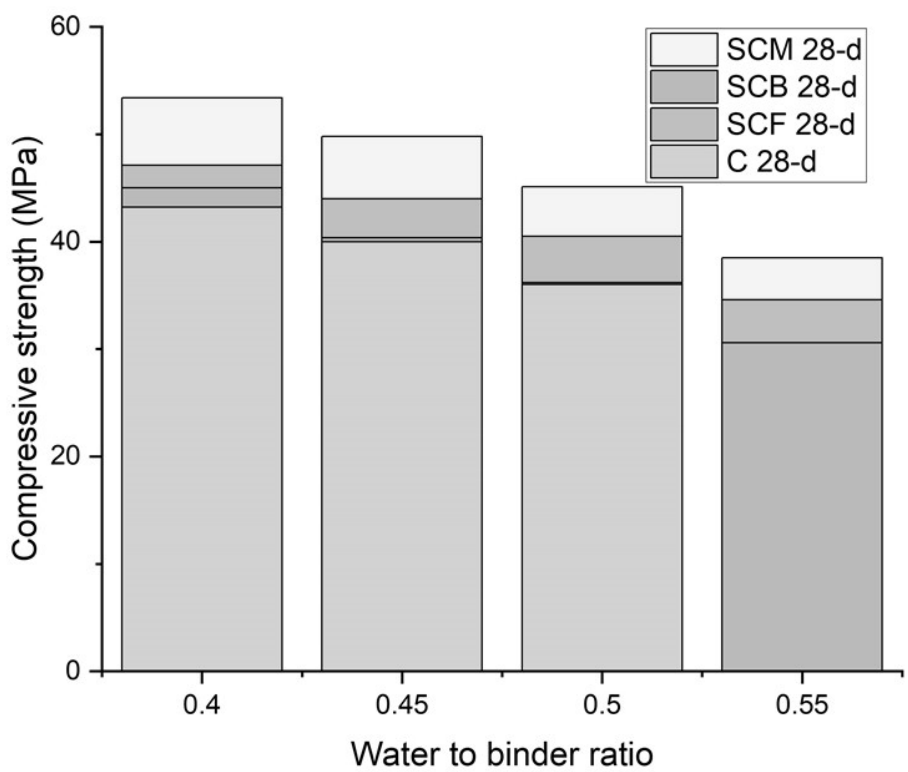

Figure 5.6 Combined effect of SP and mineral admixture on CS at 28 days

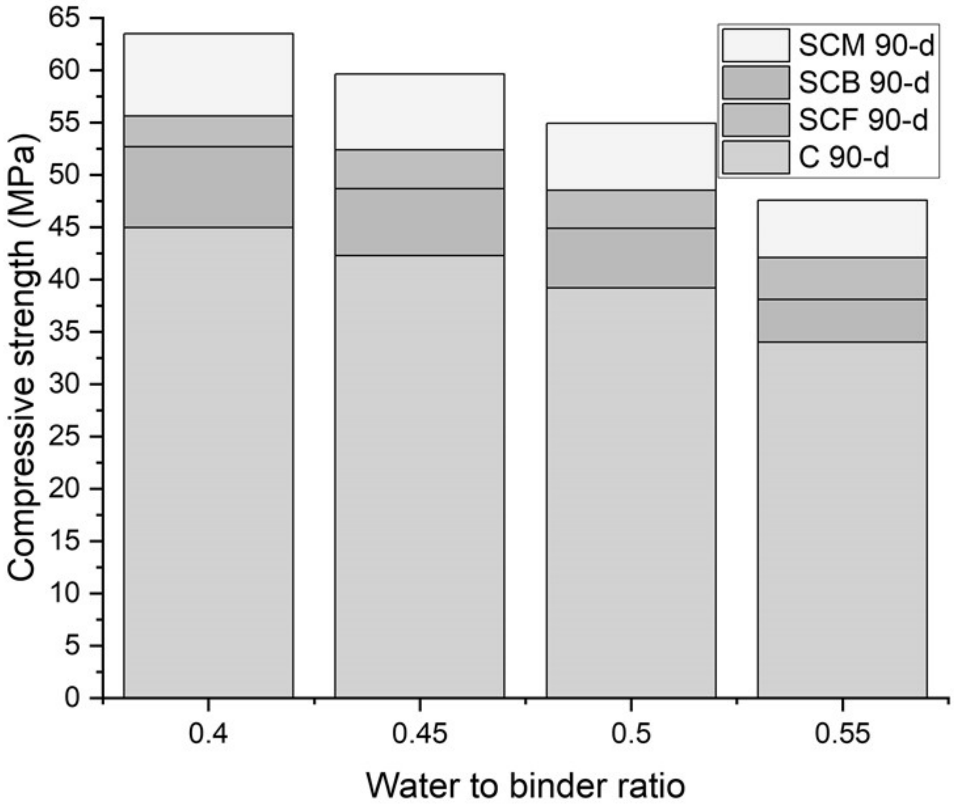

Figure 5.7 Combined effect of SP and mineral admixture on CS at 90 days

5.3 FLEXURAL STRENGTH (FS)

Flexural strength is a measure of the ability of concrete to withstand bending and cracking under load. It is an important mechanical property of concrete, as it directly affects the structural integrity and durability of concrete structures. The flexural strength of concrete is influenced by various factors such as the water-binder ratio, type and percentage of supplementary cementitious materials (SCMs) used, curing conditions, and the age of concrete. In this study, the effects of incorporating various percentages of mineral admixtures on the flexural strength of concrete were investigated. The water-binder ratio was varied to understand its effect on the flexural strength of concrete with these specific SCMs. The samples were tested at 28 days and 90 days to investigate the long-term strength development of the concrete. In this study, the effects of incorporating mineral admixtures, specifically 30% FA, 10% MS and 50% GGBS, as well as the use of superplasticizer on the flexural strength of concrete were investigated. The water-binder ratio was varied to understand its effect on the flexural strength of concrete with these specific mineral admixtures. The synergetic effect of using both mineral admixtures and superplasticizer was also studied. The results of this study will provide valuable insights into the behavior of concrete containing mineral admixtures under flexural loading as shown in Figure 5.8 and given in Table 5.1.

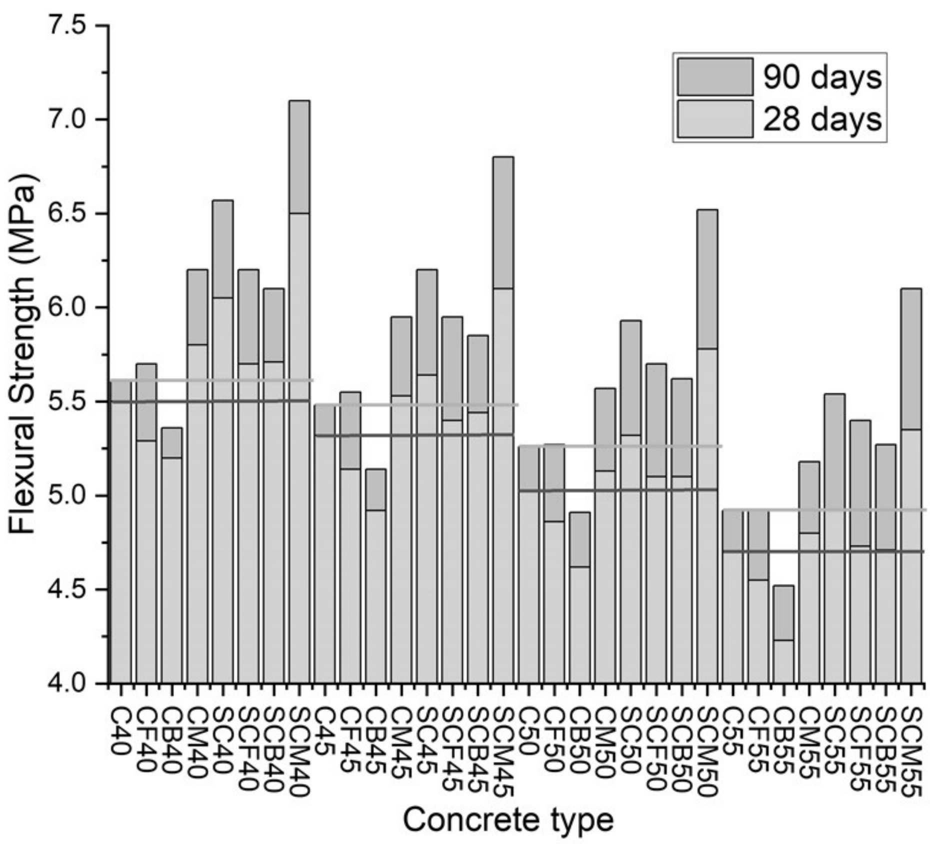

Figure 5.8 Flexural strength of different concrete mix

5.3.1 Effect of w/b

From the test result it can be observed that the samples with a water-binder ratio of 0.4 (C40, SC40, CF40, SCF40, CB40, SCB40, CM40, and SCM40) serve as the reference samples. When comparing the other w/b to this reference group, it can be seen that as the water-binder ratio increases, the flexural strength decreases. Comparing the different groups with a water-binder ratio of 0.45 (C45, CF45, SC45, SCF45, CB45, SCB45, CM45, and SCM45), it can be seen that there is a decrease in flexural strength by approximately 3-6% at both 28 days and 90 days of curing when compared to the reference group at 0.4 w/b ratio as shown in Figure 5.9.

In the group with a water-binder ratio of 0.5 (C50, CF50, SC50, SCF50, CB50, SCB50, CM50, and SCM50), the flexural strength decreases by approximately 6-12% at both 28 days and 90 days when compared to the reference group at 0.4 w/b ratio, highest decrease was observed in CB50 sample as shown in Figure 5.9.

Lastly, in the group with a water-binder ratio of 0.55 (C55, CF55, SC55, SCF55, CB55, SCB55, CM55, and SCM55), the flexural strength decreases by approximately 13-90% at both 28 days and 90 days when compared to the reference group at 0.4 w/b ratio as shown in Figure 5.9. This consistent decrease in flexural strength with an increase in the water-to-binder ratio underscores a clear trend. The effect is indicative of the structural changes in the concrete matrix, potentially attributed to increased porosity, compromising the overall flexural strength performance.

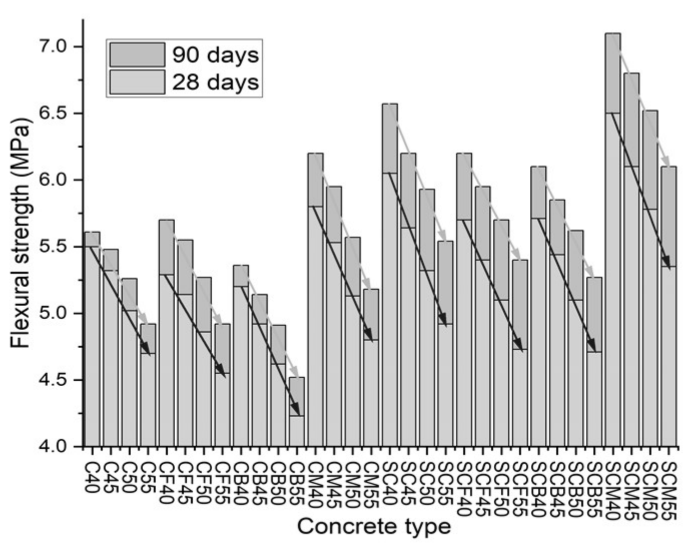

Figure 5.9 Effect of w/b on different concrete types on flexural strength

5.3.2 Effect of Mineral Admixture

The effect of mineral admixture on flexural strength was studied by comparing the FS of concrete samples with different mineral admixtures at different water-binder ratio. The comparison was made between the control group (C) and the groups containing fly ash (CF), ground granulated blast furnace slag (GGBS) (CB), and micro silica (CM).

At a water-cement ratio of 0.4, the addition of fly ash (FA) in concrete results in a decrease in flexural strength by 3.8% 28 days and increase in FS by 1.6% at 90 days respectively compared to control concrete (C40). On the other hand, the addition of ground granulated blast furnace slag (GGBS) in concrete results in a decrease in flexural strength by 5.5% and 4.5% at 28 days and 90 days respectively compared to control concrete. The addition of MS (CM) in concrete results in an increase in flexural strength by 5.5% and 10.5% at 28 days and 90 days respectively compared to control concrete.

At a water-cement ratio of 0.45, the addition of fly ash in concrete results in a decrease in flexural strength by 3.4% and 1.3% at 28 days and 90 days respectively compared to control concrete (C45). The addition of GGBS in concrete results in a decrease in flexural strength by 7.5% and 6.2% at 28 days and 90 days respectively compared to control concrete. The addition of MS in concrete results in an increase in flexural strength by 3.9% and 5.6% at 28 days and 90 days respectively compared to control concrete as shown in Figure 5.8 and Table 5.6.

At a water-cement ratio of 0.5, the addition of FA in concrete results in a decrease in flexural strength by 3.2% at 28 days and increase in FS by 0.2% at 90 days respectively compared to control concrete (C50). The addition of GGBS in concrete results in a decrease in flexural strength by 8% and 6.6% at 28 days and 90 days respectively compared to control concrete. The addition of MS in concrete results in an increase in flexural strength by 2.2 and 5.9% at 28 days and 90 days respectively compared to control concrete as shown in Figure 5.8, Figure 5.10, and Table 5.6.

At a water-cement ratio of 0.55, the addition of FA in concrete results in a decrease in flexural strength by 3.2% and 0% at 28 days and 90 days respectively compared to control concrete (C55). The addition of GGBS in concrete results in a decrease in flexural strength by 10.1% and 8.1% at 28 days and 90 days respectively compared to control concrete. The addition of MS in concrete results in an increase in flexural strength by 2.1 and 5.3% at 28 days and 90 days respectively compared to control concrete Figure 5.8, Figure 5.10, and Table 5.6. Similar trend also observed in SP concrete mix as shown in Figure 5.8, Figure 5.11 and given in Table 5.7.

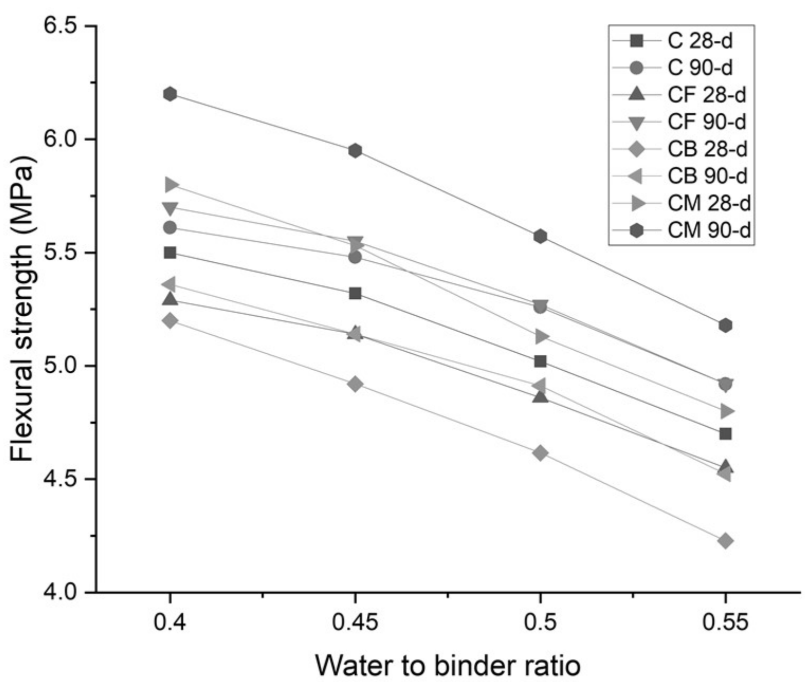

Figure 5.10 Comparison of FS of MA admixed concrete with plain concrete with varying w/b and curing age

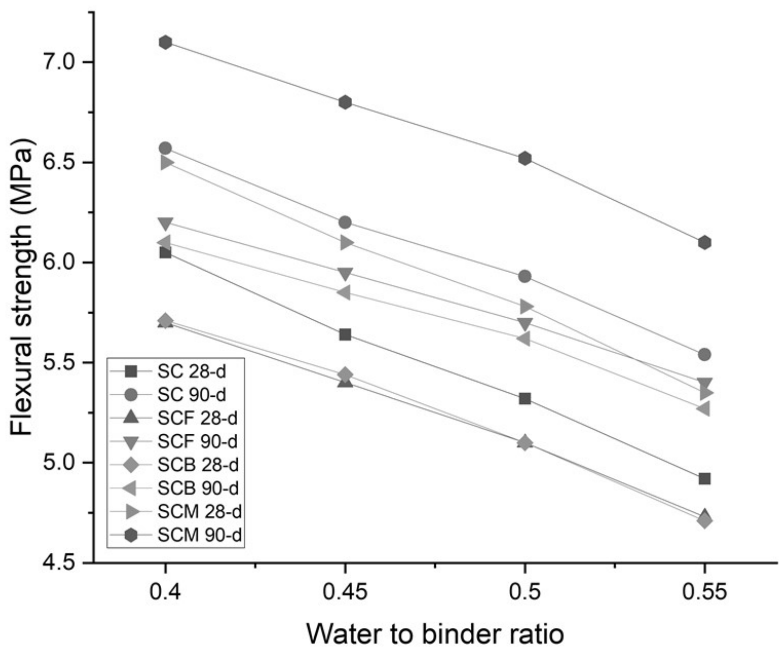

Figure 5.11 Comparison of FS of MA and SP admixed concrete with SP concrete with varying w/b and curing age

It can be concluded that the addition of micro silica alone has a positive effect on the flexural strength of concrete, while the addition of FA and GGBS has a negative effect on the flexural strength of concrete at 28 days. Possibly due to GGBS and FA are pozzolanic materials, which means they react with calcium hydroxide to form cementitious compounds such as C-S-H gel. On the other hand, the decrease in flexural strength with the addition of GGBS may be attributed to the lower early-age strength gain and slower hydration process of GGBS particles. However, the reaction between GGBS and FA with calcium hydroxide is not as efficient as the reaction between MS and calcium hydroxide. MS has a higher surface area and reacts more efficiently with calcium hydroxide to form more C-S-H gel, leading to an increase in flexural strength. It is also possible that the presence of other compounds in GGBS and FA such as iron oxide and alumina may interfere with the formation of C-S-H gel and thus lead to a decrease in flexural strength.

Table 5.6 Change in FS of MA admixed concrete w.r.t control concrete without SP at different curing age

w/b ↓ Age →	Control Concrete (C)		Concrete with FA (CF)		Concrete with GGBS (CB)		Concrete with MS (CM)	
	FS (MPa)		% Change in FS With Respect to control concrete (C)					
	28d	90d	28d	90d	28d	90d	28d	90d
0.4	5.50	5.61	-3.8	1.6	-5.5	-4.5	5.5	10.5
0.45	5.32	5.48	-3.4	1.3	-7.5	-6.2	3.9	8.6
0.5	5.02	5.26	-3.2	0.2	-8.0	-6.6	2.2	5.9
0.55	4.70	4.92	-3.2	0.0	-10.1	-8.1	2.1	5.3

Table 5.7 Change in FS of MA and SP admixed concrete w.r.t control concrete with SP at different curing age

w/b ↓ Age →	Control Concrete with SP (SC)		Concrete with FA and SP (SCF)		Concrete with GGBS and SP (SCB)		Concrete with MS and SP (SCM)	
	FS (MPa)		% Change in FS w.r.t control concrete with SP (SC)					
	28d	90d	28d	90d	28d	90d	28d	90d
0.4	6.05	6.57	-5.79	-5.6	-5.6	-7.2	7.4	8.1
0.45	5.64	6.20	-4.26	-4.0	-3.5	-5.6	8.2	9.7
0.5	5.32	5.93	-4.1	-3.9	-4.1	-5.2	8.6	9.9
0.55	4.92	5.54	-3.9	-2.5	-4.3	-4.9	8.7	10.1

5.3.3 Effect of Superplasticizer

At a water-binder ratio of 0.4, it can be seen that the addition of superplasticizer improves the flexural strength by approximately 8-12% at 28 days and 9-17% at 90 days in all the sample groups (SC40 vs C40, SCF40 vs CF40, SCM40 vs CM40, and SCB40 vs CB40) as shown in Table 5.8. At a water-binder ratio of 0.45, the improvement in flexural strength due to the addition of superplasticizer is, at approximately 5-10% at 28 days and 7-14% at 90 days in all the sample groups (SC45 vs C45, SCF45 vs CF45, SCM45 vs CM45, and SCB45 vs CB45). At a water-binder ratio of 0.5, the improvement in flexural strength due to the addition of superplasticizer is, at approximately 6-12% at 28 days and 8-17% at 90 days in all the sample groups (SC50 vs C50, SCF50 vs CF50, SCM50 vs

CM50, and SCB50 vs CB50) as shown in Table 5.8. Lastly, at a water-binder ratio of 0.55, the improvement in flexural strength due to the addition of superplasticizer is nearly same as 0.5, at approximately 4-11% at 28 days and 10-17% at 90 days in all the sample groups (SC55 vs C55, SCF55 vs CF55, SCM55 vs CM55, and SCB55 vs CB55).

Table 5.8 Change in FS of SP concrete with respect to without SP concrete

Type	Concrete without SP		Concrete with SP		% change in FS w.r.t. without SP concrete	
	C		SC			
w/b	**28d**	**90d**	**28d**	**90d**	**28d**	**90d**
0.4	5.50	5.61	6.05	6.57	10.0	17
0.45	5.32	5.48	5.64	6.2	6.0	13.1
0.5	5.02	5.26	5.32	5.93	6.0	12.8
0.55	4.70	4.92	4.92	5.54	4.7	12.6
FA	**CF**		**SCF**		**% change in FS**	
w/b	**28d**	**90d**	**28d**	**90d**	**28d**	**90d**
0.4	5.29	5.70	5.70	6.20	7.75	8.8
0.45	5.14	5.55	5.40	5.95	5.06	7.2
0.5	4.86	5.27	5.10	5.70	4.9	8.2
0.55	4.55	4.92	4.73	5.40	4.0	9.8
GGBS	**CB**		**SCB**		**% change in FS**	
w/b	**28d**	**90d**	**28d**	**90d**	**28d**	**90d**
0.4	5.20	5.36	5.71	6.10	9.8	13.8
0.45	4.92	5.14	5.44	5.85	10.6	13.8
0.5	4.62	4.91	5.10	5.62	10.5	14.4
0.55	4.23	4.52	4.71	5.27	11.4	16.5
MS	**CM**		**SCM**		**% change in FS**	
w/b	**28d**	**90d**	**28d**	**90d**	**28d**	**90d**
0.4	5.80	6.20	6.50	7.10	12.07	14.52
0.45	5.53	5.95	6.10	6.80	10.31	14.29
0.5	5.13	5.57	5.78	6.52	12.67	17.02
0.55	4.80	5.18	5.35	6.10	11.46	17.77

Overall, it can be concluded that the addition of superplasticizer improves the flexural strength of the concrete, but the improvement is more pronounced at lower water-binder ratio. This is because the addition of superplasticizer in the concrete mixture improves the workability of the concrete by reducing the optimal water-binder ratio, which in turn increases the packing density of the mixture. This results in better particle-to-particle contact and a more homogeneous distribution of the cement paste throughout the mixture. Additionally, superplasticizers are surface-active agents that change the surface charges of cement particles, causing them to disperse into smaller agglomerates, which improves the flow ability and reduces the segregation of the concrete mixture. This improves the quality of the concrete and results in higher flexural strength.

5.3.4 Combined Effect of Superplasticizer and Mineral Admixture

The effect of combining mineral admixtures (fly ash, GGBS, and micro silica) with superplasticizer on flexural strength is analyzed. By comparing the C group to the SCF, SCM, and SCB groups, it can be observed that the addition of superplasticizer improves the flexural strength of concrete when combined with mineral admixtures. When comparing the C40 sample with the SCF40 sample, it can be seen that there is a 3.64 % increase in flexural strength at 28 days and a 10.52% increase at 90 days. Similarly, when comparing the C50 sample with the SCF50 sample, there is a 1.59% increase in flexural strength at 28 days and an 8.38% increase at 90 days.

In case of MS, when comparing the C40 sample with the SCM40 group, it can be seen that there is an 18.18% increase in flexural strength at 28 days and a 26.56% increase at 90 days. Similarly, when comparing the C50 with the SCM50 group, there is a 15.14% increase in flexural strength at 28 days and a 23.97% increase at 90 days. Lastly, when comparing the C40 sample with the SCB40 sample, it can be seen that there is a 3.82% increase in FS at 28 days. Similarly, when comparing the C50 sample with the SCB50 sample, there is a 1.59% increase in flexural strength at 28 days and a 6.86% increase at 90 days as shown in Figure 5.12, Figure 5.13, and Table 5.9.

This synergistic effect can be explained by the fact that the mineral admixtures and superplasticizer work together to enhance the hydration of the cement, resulting in the formation of more and denser hydration products. The mineral admixtures, such as FA, MS and GGBS, react with the calcium hydroxide produced during the hydration of cement to form additional C-S-H gel, which is responsible for the strength development of concrete. On the other hand, superplasticizer improves the workability of the concrete by reducing the water demand, which in turn leads to a higher packing density of the paste and a more efficient use of the cement.

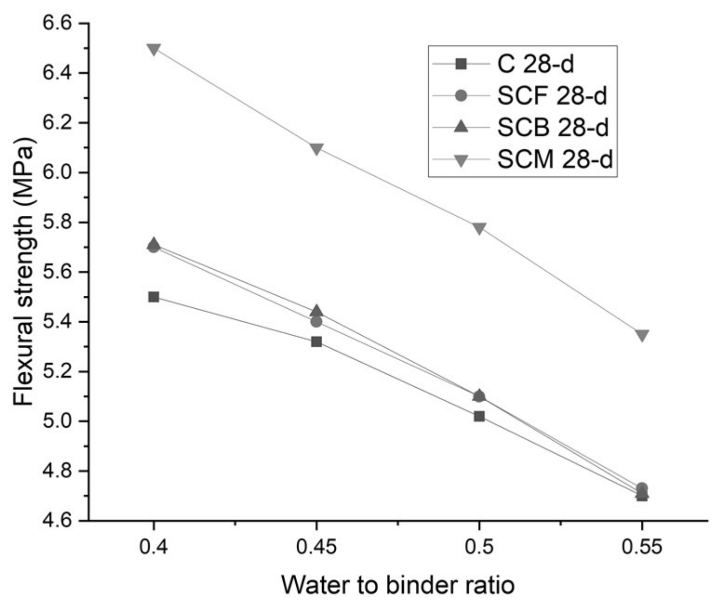

Figure 5.12 Combined effect of SP and mineral admixture on FS at 28 days

Table 5.9 Change in FS of with MA and SP admixed concrete w.r.t. control concrete without SP at different curing age

w/b ⇓ Age ⇒	Control Concrete without SP (C)		Concrete with FA and SP (SCF)		Concrete with GGBS and SP (SCB)		Concrete with MS and SP (SCM)	
	FS (MPa)		% Change in FS w.r.t control concrete without SP (C)					
	28d	90d	28d	90d	28d	90d	28d	90d
0.4	5.50	5.61	3.64	10.52	3.82	8.73	18.18	26.56
0.45	5.32	5.48	1.50	8.58	2.26	6.75	14.66	24.09
0.5	5.02	5.26	1.59	8.38	1.59	6.86	15.14	23.97
0.55	4.70	4.92	0.64	9.76	0.21	7.11	13.83	23.98

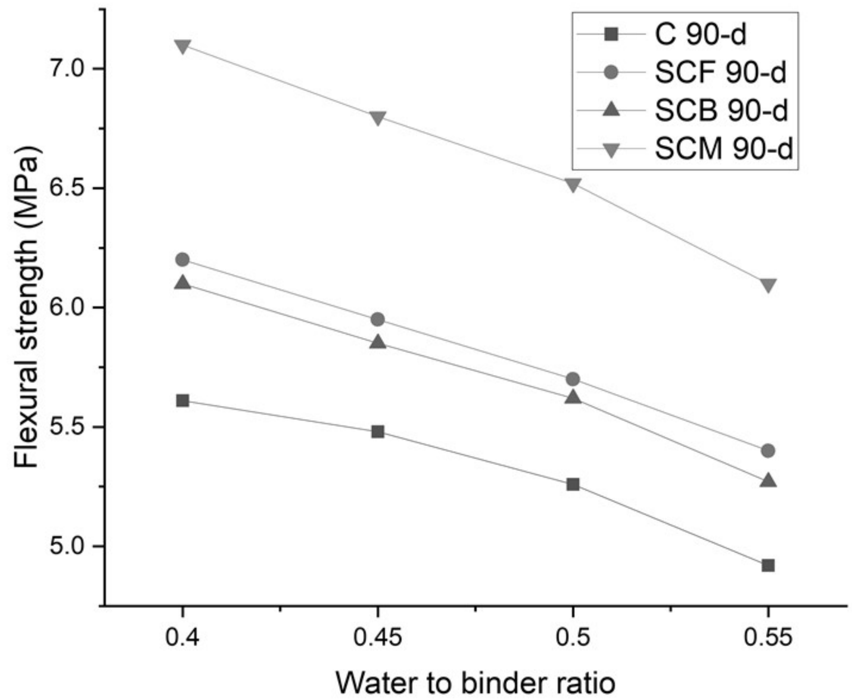

Figure 5.13 Combined effect of SP and mineral admixture on FS at 90 days

5.4 SPLITTING TENSILE STRENGTH (STS)

The ability of concrete to resist cracking under tensile stress is crucial for its structural integrity and durability. Unlike compressive strength, which is relatively high in concrete, tensile strength is relatively low. It is generally accepted that concrete's tensile strength is approximately 10% of its compressive strength. However, with the use of appropriate techniques such as the addition of steel reinforcement or mineral admixtures, the tensile strength of concrete can be enhanced. One of the key techniques for measuring concrete's tensile strength is by using the splitting tensile test, which simulates the cracking behavior of concrete under direct tension. It is an important property for the design and evaluation of concrete structures. STS of different concrete mix is given Table 5.1 in and shown in Figure 5.15 for better understanding

5.4.1 Effect of w/b

The test results for splitting tensile strength (STS) show a similar trend as the flexural strength data, with the samples at a water-binder ratio of 0.4 (C40, CF40, CB40, CM40, SC40, SCF40, SCB40, and SCM40) serving as the reference group. As the water-binder ratio increases, the STS decreases. A comparison of the different groups at a water-binder ratio of 0.45 (C45, CF45, CB45, CM45, SC45, SCF45, SCB45, and SCM45) shows a decrease in STS by approximately 3-8% at both 28 days and 90 days when compared to the reference group at 0.4 w/b. Similarly, the group at a water-binder ratio of 0.5 (C50, CF50, CB50, CM50, SC50, SCF50, SCB50, and SCM50) shows a decrease in STS by approximately 8-12% at both 28 days and 90 days, and the group at a water-binder ratio of 0.55 (C55, CF55, CB55, CM55, SC55, SCF55, SCB55, and SCM55) shows a decrease in STS by approximately 15-23% at both 28 days and 90 days when compared to the reference group at 0.4 w/b as shown in Table 5.1 and Figure 5.15. The addition of mineral admixtures and superplasticizer in the concrete mixture improves the STS of the concrete. It can be explained that as the water-binder ratio increases, the water content in the concrete mixture also increases. This excess water can lead to a reduction in the number of bonds between the cement particles and the aggregate, leading to a decrease in the overall strength of the concrete. The increased water content can also lead to an increase in porosity, which also weakens the concrete. Additionally, the increased water content can lead to a reduction in the density of the concrete, which also contributes to the decrease in strength.

5.4.2 Effect of Mineral Admixture

Similar to flexural strength results at a water-cement ratio of 0.4, the addition of FA in concrete results in a decrease in STS by 4.4% at 28 days and increase in STS by 5.7% at 90 days respectively compared to control concrete (C40). On the other hand, the addition of ground granulated blast furnace slag (GGBS) in concrete results in a decrease in flexural strength by 11.2% and 8.6% at 28 days and 90 days respectively compared to control concrete. The addition of MS (CM) in concrete results in an increase in flexural strength by 4.1% and 9.7% at 28 days and 90 days respectively compared to control concrete.

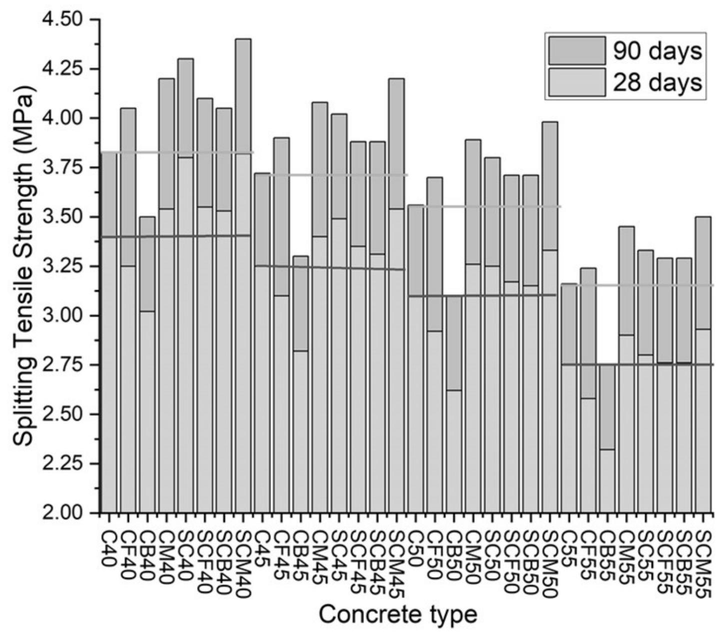

Figure 5.14 Splitting tensile strength of different concrete mix

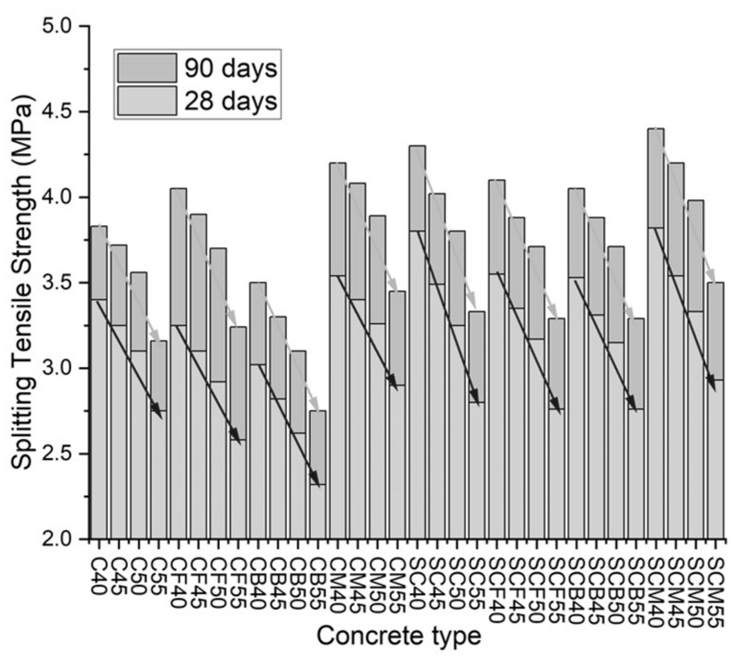

Figure 5.15 Effect of w/b on different concrete types on splitting tensile strength

At a water-cement ratio of 0.45, the addition of FA in concrete results in a decrease in STS by 4.6% and increase of 4.8% at 28 days and 90 days respectively compared to control concrete (C45). The addition of GGBS in concrete results in a decrease in STS by 13.2% and 11.3% at 28 days and 90 days respectively compared to control concrete. The addition of MS in concrete results in an increase in STS by 4.6% and 9.7% at 28 days and 90 days respectively compared to control concrete as shown in Figure 5.15, Figure 5.16, and Table 5.10.

At a water-cement ratio of 0.5, the addition of FA in concrete results in a decrease in STS by 5.8% at 28 days and increase in FS by 3.9% at 90 days respectively compared to control concrete (C50). The addition of GGBS in concrete results in a decrease in STS by 11.2% and 8.6% at 28 days and 90 days respectively compared to control concrete. The addition of MS in concrete results in an increase in STS by 5.2 and 9.3% at 28 days and 90 days respectively compared to control concrete

At a water-cement ratio of 0.55, the addition of FA in concrete results in a decrease in STS by 6.2% and increase by 2.5% at 28 days and 90 days respectively compared to control concrete (C55). The addition of GGBS in concrete results in a decrease in STS by 15.6% and 13% at 28 days and 90 days respectively compared to control concrete. The addition of MS in concrete results in an increase in STS by 5.5% and 9.2% at 28 days and 90 days respectively compared to control concrete.

Also, similar trend can be observed for SP admixed concrete as given in Table 5.11 and shown in Figure 5.16 and Figure 5.17.

It can be concluded that the addition of MS alone has a positive effect on the STS of concrete, while the addition of FA and GGBS has a negative effect on the STS of concrete at 28 days. This can be because GGBS and FA are pozzolanic materials, which means they react with calcium hydroxide to form cementitious compounds such as C-S-H gel. On the other hand, the decrease in STS with the addition of GGBS may be attributed to the lower early-age strength gain and slower hydration process of GGBS particles. However, the reaction between GGBS and FA with calcium hydroxide is not as efficient as the reaction between MS and calcium hydroxide. MS has a higher surface area and reacts more efficiently with calcium hydroxide to form more C-S-H gel, leading to an increase in STS. It is also possible that the presence of other compounds in GGBS and FA such as iron oxide and alumina may interfere with the formation of C-S-H gel and thus lead to a decrease in STS. As the age of admixed concrete progresses, there is a notable enhancement in Split Tensile Strength (STS). This phenomenon can be attributed to the continued hydration and pozzolanic reactions taking place within the concrete matrix over time. The ongoing chemical processes lead to the development of a more refined and interlocked microstructure, resulting in improved bonding between the cementitious materials and enhanced strength characteristics. The gradual gain in STS with age underscores the long-term performance benefits of mineral admixtures, affirming their positive impact on the mechanical properties of concrete as the material matures over time.

Table 5.10 Change in STS of MA admixed concrete w.r.t control concrete without SP at different curing age

w/b ↓ Age →	**Control Concrete (C)**		**Concrete with FA (CF)**		**Concrete with GGBS (CB)**		**Concrete with MS (CM)**	
	STS (MPa)		**% Change in STS With Respect to control concrete (C)**					
	28d	**90d**	**28d**	**90d**	**28d**	**90d**	**28d**	**90d**
0.40	3.40	3.83	-4.4	5.7	-11.2	-8.6	4.1	9.7
0.45	3.25	3.72	-4.6	4.8	-13.2	-11.3	4.6	9.7
0.50	3.10	3.56	-5.8	3.9	-15.5	-12.9	5.2	9.3
0.55	2.75	3.16	-6.2	2.5	-15.6	-13.0	5.5	9.2

Table 5.11 % change in STS of with MA and SP admixed concrete w.r.t. control concrete without SP at different curing age

w/b ↓ Age →	**Control Concrete with SP (SC)**		**Concrete with FA and SP (SCF)**		**Concrete with GGBS and SP (SCB)**		**Concrete with MS and SP (SCM)**	
	STS (MPa)		**% Change in STS w.r.t control concrete with SP (SC)**					
	28d	**90d**	**28d**	**90d**	**28d**	**90d**	**28d**	**90d**
0.40	3.80	4.30	-6.58	-4.7	-7.1	-5.8	0.5	2.3
0.45	3.49	4.02	-4.01	-3.5	-5.2	-3.5	1.4	4.5
0.50	3.25	3.80	-2.5	-2.4	-3.1	-2.4	2.5	4.7
0.55	2.80	3.33	-1.4	-1.2	-1.4	-1.2	4.6	5.1

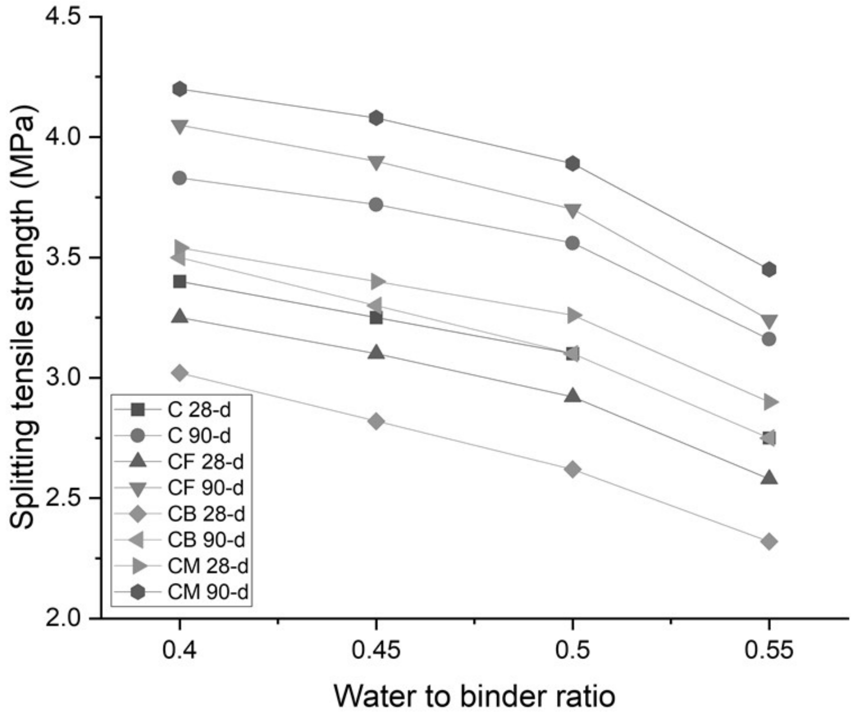

Figure 5.16 Comparison of STS of MA admixed concrete with plain concrete with varying w/b and curing age

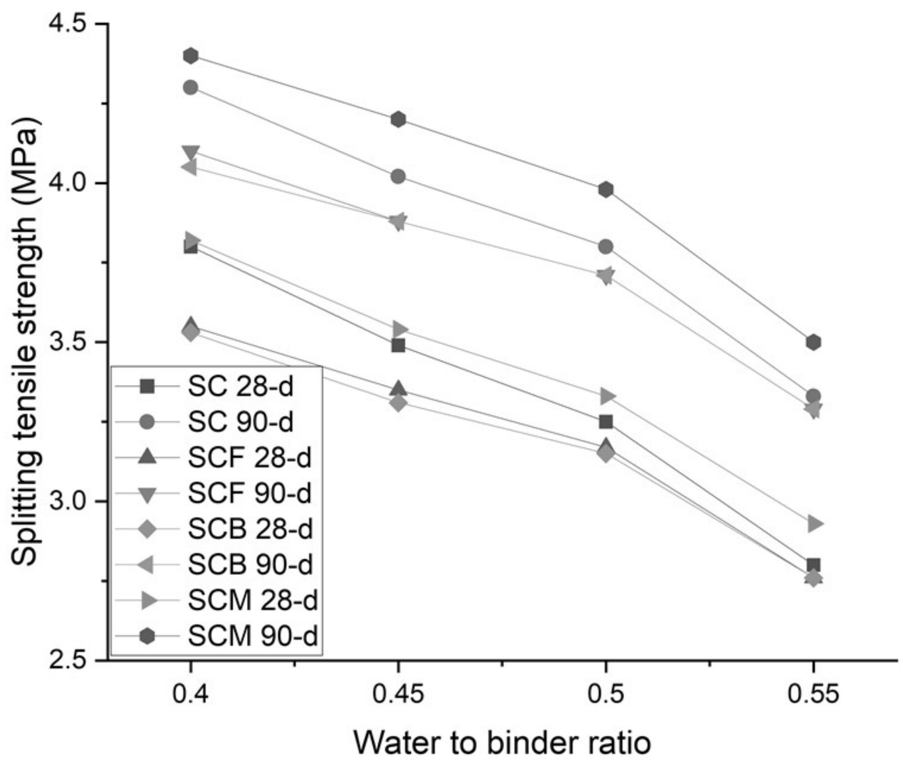

Figure 5.17 Comparison of STS of MA and SP admixed concrete with SP concrete with varying w/b and curing age

5.4.3 Effect of Superplasticizer

5.4.4 Combined Effect of Superplasticizer and Mineral Admixture

It can be observed from the experimental data that the addition of both superplasticizer and mineral admixture has a varying effect on the splitting tensile strength of the concrete samples as given in Table 5.13 and shown in Figure 5.18 and Figure 5.19.

When comparing the sample group C to the sample group SCF, it can be seen that the addition of both SP and FA results in an increase in the splitting tensile strength of the concrete for all water-binder ratios, with the increase ranging from 4.41% at 28 days and 7.05% at 90 days for a water-binder ratio of 0.4, to 0.36% at 28 days and 4.11% at 90 days for a water-binder ratio of 0.55.

Similarly, when comparing the sample group C to the sample group SCM, it can be seen that the addition of both superplasticizer and MS results in an increase in the splitting tensile strength of the concrete for all water-binder ratios, with the increase ranging from 12.35% at 28 days and 14.88% at 90 days for a water-binder ratio of 0.4, to 6.55% at 28 days and 10.76% at 90 days for a water-binder ratio of 0.55. Lastly, when comparing the sample group C to the sample group SCB, it can be seen that the addition of both superplasticizer and GGBS results in an increase in the splitting tensile strength of the concrete for all water-binder ratios, with the increase ranging from 3.82% at 28 days and 5.74% at 90 days for a water-binder ratio of 0.4, to 0.36% at 28 days and 4.11% at 90 days for a water-binder ratio of 0.55 as given in Table 5.13 and shown in Figure 5.18 and Figure 5.19.

In conclusion, it can be seen that the combined effect of superplasticizer and mineral admixture on the splitting tensile strength of concrete is complex and varies depending on the type of mineral admixture used and the water-binder ratio of the mixture. The addition of both superplasticizer and FA, GGBS and MS results in an increase in the STS of the concrete. This can be attributed to the unique properties of each mineral admixture and how they interact with the superplasticizer and the cement paste in the concrete mixture. Additionally, the water-binder ratio of the mixture also plays a significant role in determining the effect of the superplasticizer and mineral admixture on the splitting tensile strength of the concrete.

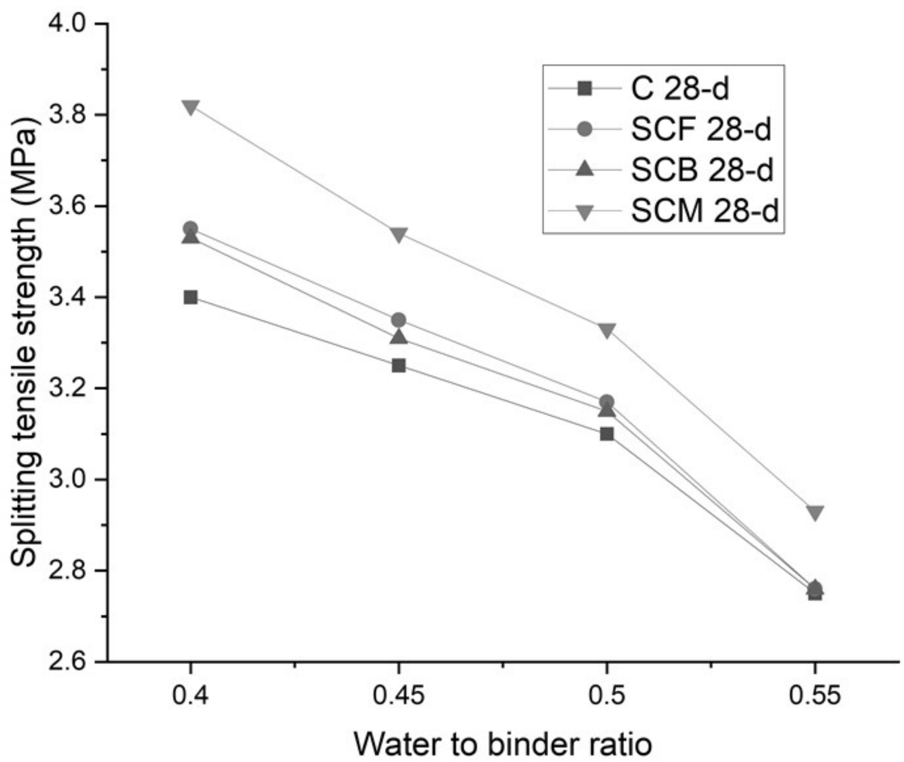

Figure 5.18 Combined effect of SP and mineral admixture on STS at 28 days

Table 5.13 Change in STS of with MA and SP admixed concrete w.r.t. control concrete without SP at different curing age

w/b ↓ Age →	**Control Concrete without SP (C)**		**Concrete with FA and SP (SCF)**		**Concrete with GGBS and SP (SCB)**		**Concrete with MS and SP (SCM)**	
	FS (MPa)		**% Change in FS w.r.t control concrete without SP (C)**					
	28d	**90d**	**28d**	**90d**	**28d**	**90d**	**28d**	**90d**
0.4	3.40	3.83	4.41	7.05	3.82	5.74	12.35	14.88

0.45	3.25	3.72	3.08	4.30	1.85	4.30	8.92	12.90
0.5	3.10	3.56	2.26	4.21	1.61	4.21	7.42	11.80
0.55	2.75	3.16	0.36	4.11	0.36	4.11	6.55	10.76

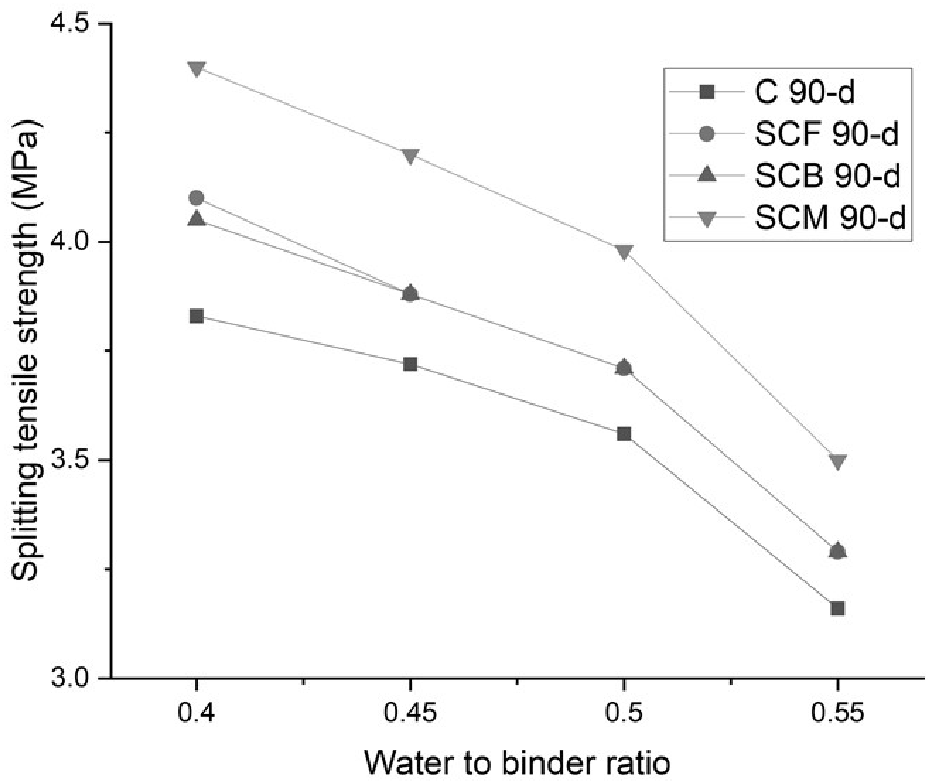

Figure 5.19 Combined effect of SP and mineral admixture on STS at 90 days

5.5 CONCLUSION

The experimental study has demonstrated that the addition of mineral admixtures and superplasticizer can have a positive effect on the strength properties of concrete. The results show that the use of fly ash, GGBS, and micro silica as mineral admixtures, as well as the use of superplasticizer, can result in an increase in the compressive strength, flexural strength, and splitting tensile strength of concrete. The improvement in strength properties was observed at all water-binder ratios and testing ages. Furthermore, the combination of mineral admixtures and superplasticizer was found to have a significant effect on the strength properties of concrete. The highest increase in strength properties was observed with the addition of micro silica, followed by fly ash and GGBS. Overall, these findings highlight the potential benefits of using mineral admixtures and superplasticizer in concrete mix designs to improve the strength and durability of concrete structures.