Study on Strength and Durability Properties of Self-Compacting Mortar using different Mineral Admixtures and Macro-Synthetic Fibers

Ashwini Ramesh Patil[1], S. Bhavanishankar[2]

[1]PG Student, Dept. of Civil Engineering, University Visvesvaraya College of Engineering, Bengaluru, India
[2]Associate Professor, Dept. of Civil Engineering, University Visvesvaraya College of Engineering, Bengaluru, India

---

Abstract – *An experimental study has been conducted to examine the characteristics of self-compacting mortar (SCM). Employing macro-synthetic fibers as well as mineral admixtures like fly ash and silica fume, SCM have been investigated for fresh, hardened and durability properties. A standard SCM mix i.e., 100% cement is developed in the current study while maintaining good flowability. 16 SCM mortar mixes with varying percentages of Fly ash and Silica fume, with and without adding Macro-synthetic fibers, are designed in order to evaluate the effects of mineral admixture and Macro-synthetic fibers on SCM. Self-compacting mortar's fresh properties, such as mini-slump flow and mini-v-funnel flow time, are studied both with and without the addition of macro-synthetic fibers and hardened Properties like compressive and flexural strength as well as durability property such as drying shrinkage are studied. The self-compacting mortar mix specimens with and without the addition of macro-synthetic fibers are cast, cured and tested for 7 days and 28 days in order to assess the compressive strength and flexural strength. The self-compacting mortar specimens with and without the addition of macro-synthetic fibers are cast, cured in water for three days and then air-dried for the remaining days. The test is repeated every five days up to thirty days to determine drying shrinkage. Conclusions are drawn based on the results obtained from the investigation.*

Key Words: Self Compacting Mortar, Macro-synthetic fibers, Fresh Properties, Compressive Strength, Flexural Strength, Drying Shrinkage.

1. INTRODUCTION

Self-compacting concrete (SCC) has been in use for the past two decades. SCC was first discovered in 1986 by Japanese researchers to increase concrete durability by increasing the workability of concrete and hence by increasing the building quality. SCC is defined as concrete with very high flowability coupled with good stability. These two characteristics allow the concrete to fill every corner of the formwork by its own weight without the requirement of any external vibrators. Another quality that is always needed for SCC is its passing ability that is needed for filling extremely congested areas of reinforced concrete constructions.

The standard technique to produce self-compatibility is to minimize the coarse aggregate content and use an appropriate mortar. Therefore, mortar plays a very important role on the workability characteristics of SCC and these properties might be investigated by examining the self-compacting mortar (SCM). In fact, examining the qualities of SCM is an inherent aspect of SCC design.

On the other hand, use of finely divided mineral admixtures in SCC reduces the cost of SCC. As most of the mineral admixtures available in the market are generally, by-products obtained from manufacturing industries. Mineral admixtures replace cement without compromising the properties of concrete. Moreover, the mineral admixtures will also boost the strength and durability properties of concrete.

2. OBJECTIVES OF PRESENT STUDY

- In the lab, mixes for self-compacting mortar (SCM) are being developed.
- The Mini-slump flow diameter tests and Mini V-funnel tests (with and without fibers) are used to analyze the properties of fresh mortar.
- To determine the hardened properties of SCM mortar, compressive strength and flexural strength tests (with and without fibers) are carried out.
- To determine the durability properties of SCM, drying shrinkage tests (with and without fibers) were performed.
- Conclusions are drawn based on the results obtained.

3. METHODOLOGY

- The use of mineral admixtures like fly ash and silica fume to replace cement in SCM mixes is examined in several literature reviews.
- Prior to casting, calculate the material requirements for various mix proportions and carry out various preliminary material tests.
- Cement mortar with mix ratio 1:2 is being taken into consideration for the current investigation. Fly ash and Silica fume are used as mineral admixtures, along with M sand as a fine aggregate and macro-synthetic fibers as a fiber.

- Materials physical attributes are assessed.
- The Mini-Slump flow diameter tests and compressive strength are used to determine the optimum quantity of fibers added in the mixture.
- The marsh cone test is used to determine the proper amount of superplasticizer (Master Glenium 8233) for cement paste.
- For all mortar mix, the rheological characteristics of SCM are determined using a mini-slump flow diameter and a mini v-funnel flow time.
- The hardened characteristics of each SCM combination, including compressive and flexural strengths are assessed after 7 days and 28 days of curing.
- A 30 day drying shrinkage test is carried out on all SCM combinations to examine their durability characteristics.

4. MATERIALS

- Ordinary Portland cement
- Fine Aggregate
- Water
- Superplasticizer (Master Glenium SKY 8233)
- Macro-synthetic fiber
- Fly Ash
- Silica Fume

Table -1: Physical Characteristics of Materials

Materials	Test conducted	Results	Code Specifications
Cement	Specific gravity	3.14	3.15 (IS 4031 Part11:1988)
	Normal consistency (%)	33	25%-35% (IS 4031 Part4:1988)
	Initial setting time (min)	75	Min 30 (IS 4031 Part5:1988)
	Final setting time (min)	330	Max 600 (IS 4031 Part5:1988)
	Fineness (Dry Sieving) (%)	5	Max 10 (IS 4031 Part1:1996)
Fly Ash	Specific gravity	2.13	-
Silica Fume	Specific gravity	2.2	-
Fine aggregate	Specific gravity	2.67	2.75 (IS2386 Part3:1963)
	Sieve Analysis	Zone II	1250 (IS383:2016)

5. MIX PROPORTIONING

1:2 cement mortar ratio is being considered for the present experiment and 480 samples are cast from 16 SCM mixes in the laboratory. In addition, M sand as the fine aggregate, mineral admixtures like FA, silica fume and macro-synthetic fibers are used.

Table -2: Mix Proportions

SL. NO.	Mix notation	Mix proportions
1	M0	100% C
2	M1	80%C + 20%FA
3	M2	70%C + 30%FA
4	M3	50%C + 50%S
5	M4	95%C + 5%SF
6	M5	90%C + 10%SF
7	M6	85%C + 15%SF
8	M7	80%C + 15%FA + 5%SF
9	M8	80%C + 10%FA +10%SF
10	M9	80%C + 5%FA + 15%M
11	M10	70%C + 25%FA + 5%S
12	M11	70%C + 20%FA +10%S
13	M12	70%C + 15%FA + 15%S
14	M13	50%C + 45%FA + 5%S
15	M14	50%C + 40%FA +10%S
16	M15	50%C + 35%FA +15%S

6. RESULTS AND DISCUSSION

The current study aims to determine the characteristics of SCM mixes, without and with macro-synthetic fibers. SCM mixes are developed without altering the amount of water and total powder content (Portland cement and mineral admixtures). Mini-V-funnel and mini-slump flow tests are done to determine the workability of fresh mortar. Strength properties such as compressive strength, flexural strength, and durability property such as drying shrinkage of all blends are measured.

6.1 Fresh Properties

The SP content is varied in each SCM mix for the determination of flow characteristics. Because of this, every combination has slump flow diameters between 240 and 260 mm and mini-V funnel flow times between 7 and 11 seconds that satisfy the EFNARC standards.

Table -3: Fresh Properties of SCM Mixes (without fibers)

SL. NO.	Mix Notation	W / P	SP (%)	Mini Slump Flow Dia (mm)	Mini V-funnel flow time (sec)
1	M0	0.39	0.7	254	9.4
2	M1	0.39	0.8	252	9.1
3	M2	0.39	0.8	249	10
4	M3	0.39	0.8	246	10
5	M4	0.39	0.8	247	9
6	M5	0.39	0.9	244	9.8
7	M6	0.39	0.9	242	10.7
8	M7	0.39	0.9	250	8
9	M8	0.39	0.9	247	9
10	M9	0.39	0.9	243	10
11	M10	0.39	0.8	248	9
12	M11	0.39	0.9	244	9.4
13	M12	0.39	0.9	243	10
14	M13	0.39	1	245	10
15	M14	0.39	1	242	10.6
16	M16	0.39	1	241	11

Table -4: Fresh Properties of SCM Mixes (with fibers)

SL. NO.	Mix Notation	W / P	SP (%)	Mini Slump Flow Dia (mm)	Mini V-funnel flow time (sec)
1	M0	0.40	0.8	250	7.4
2	M1	0.40	0.8	248	7.6
3	M2	0.40	0.8	246	9
4	M3	0.40	0.8	243	11
5	M4	0.40	0.8	247	9
6	M5	0.40	0.9	244	10
7	M6	0.40	0.9	241	11
8	M7	0.40	0.9	252	7.8
9	M8	0.40	0.9	249	7.9
10	M9	0.40	0.9	245	10
11	M10	0.40	0.9	246	9.8
12	M11	0.40	0.9	243	10.7
13	M12	0.40	1	241	11
14	M13	0.40	1.1	244	10
15	M14	0.40	1.1	242	10.8
16	M16	0.40	1.1	240	11

- All of the combinations consequently have slump flow diameters and mini-V funnel flow rates that satisfy the EFNARC criteria.
- Standard SCM mix (M0) with 0.39 w/c and 0.7 percent SP results in a 254 mm Mini-slump flow diameter and a 9.4 sec mini-V-funnel flow time that satisfies EFNARC criteria.
- Because the particle size of mineral additives is smaller than that of cement, so it takes more water to hydrate them, in order to achieve the same workability as the standard mortar mix.
- In comparison to FA and SF requires a greater amount of superplasticizer. Finer the material the more SP required.
- Higher SP (1% SP and 0.39 w/p) is needed in SCM mixes with cement replacement levels of 45% FA, 5% SF (M13), 40% FA, 10% SF (M14), and 35% FA, 15% SF (M15), respectively, to give workability that satisfies EFNARC criteria.

- The Mini-V funnel flow duration increased and the Mini-slump flow diameter reduced as the amount of fiber increased.
- Standard SCM mix (M0) with 0.40 w/p and 0.8% SP produces flow parameters that meet EFNARC standards, including a mini-slump flow diameter of 250 mm and a mini-V funnel flow duration of 7.4 sec.
- For SCM mixes containing 45% FA, 5% SF (M13), 40% FA, 10% SF (M14), and 35% FA, 15% SF (M15), more SP (1.1% SP and 0.40 w/p) is needed to achieve workability that satisfies EFNARC criteria.

6.2 Hardened Properties

The compressive strength, flexural strength, and drying shrinkage of SCM mixes using mineral admixtures like FA and SF, with and without macro-synthetic fibers at various ages are determined.

6.2.1 Compressive Strength

The graph shows the compressive strength of self-compacting mortar at 7 days and 28 days after curing with varied degrees of cement replacement with FA and SF, with and without macro-synthetic fibers. To cast SCM cubes for compressive strength, a cube with the dimensions 70.6 x 70.6 x 70.6 mm was used. The mortar cube's compressive strength was assessed in accordance with IS: 4031 (Part 6) of 1988.

6.2.1.1 Compressive Strength without fibers

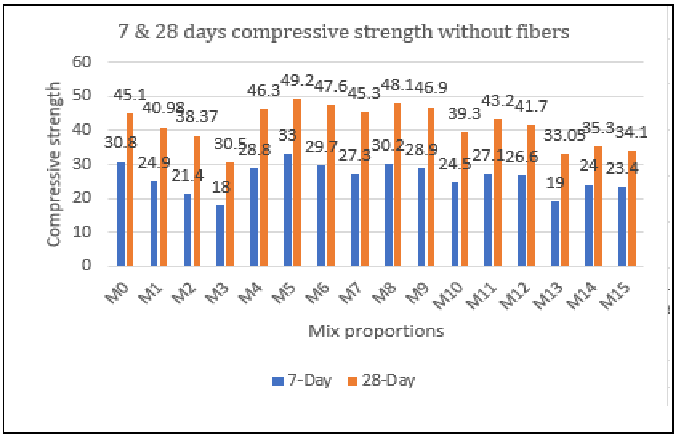

Chart -1: Compressive Strength vs 7&28 Days

- Standard SCM mix has a compressive strength of 45.1 MPa after 28 days.
- The binary mixes of SCM, with fly ash has a smaller early strength development than the standard mix (M0).
- The SCM mix with 10% SF has a higher compressive strength of 49.2 MPa after 28 days, which is 9.09% greater than the standard SCM mix (M0).
- According to the findings, the produced SCM mix (M4) with a cement replacement level of 50% FA has the lowest compressive strength of 30.5 MPa after 28 days, which is 32.37 percent lower than the standard SCM mix (M0).
- Binary SCM mixes with 5% SF (M4), 10% SF (M5), and 15% SF (M6) cement replacement levels exhibit better compressive strengths than the standard SCM mix (M0).
- The SCM mix with 10% FA and 10% SF (M8) produces good compressive strength in ternary SCM mixes containing FA and SF.
- In binary mixtures of SCM, the compressive strength increases as the SF replacement level increases up to a certain point, after which it falls if the replacement level is increased further, and it also decreases when the FA replacement level increases.

6.2.1.2 Compressive Strength with fibers

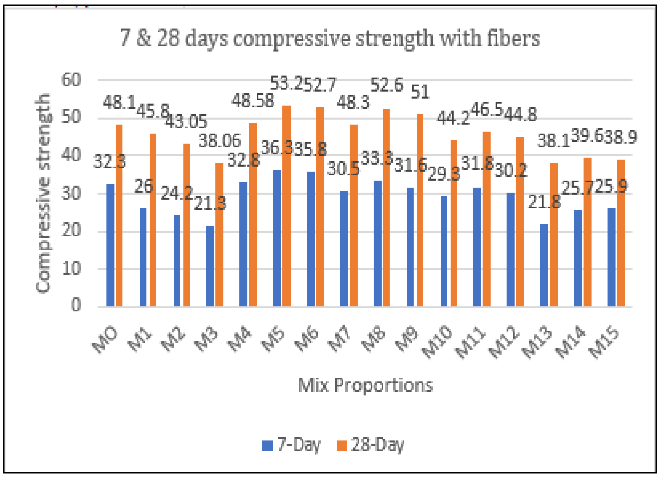

Chart -2: Compressive Strength vs 7&28 Days

- The standard SCM mix has a compressive strength of 48.1 MPa after 28 days.
- Adding macro-synthetic synthetic fibers weighing 4 kg/m3 can slightly improve compressive strength by 4 to 8%.
- The initial strength development of a binary SCM mix consisting of silica fume is greater than that of a standard mortar (M0).
- After 28 days, the 10% SF SCM mix has a highest compressive strength of 53.2 MPa, which is 10.6% more than the standard SCM mix(M0).
- The developed SCM mix with a cement replacement level of 50% FA (M3) has the lowest compressive strength of 38.06 MPa after 28 days, which is 20.87 percent lower than the standard SCM mix (M0).
- In comparison to the standard SCM mix (M0), binary SCM mixes with cement replacement levels of 5% SF (M4), 10% SF (M5), and 15% SF (M6) have higher compressive strengths.
- A 10% FA and 10% SF (M8) cement replacement level offers good compressive strength in tertiary SCM mixes that contain FA and SF.

6.2.2 Flexural Strength

The graph at 7 days and 28 days after curing depicts the flexural strength of self-compacting mortar with various levels of cement replacement with FA and SF, with and without macro-synthetic fibers. SCM mixes are cast using prisms with dimensions of 40*40*160 mm. The mortar sample's flexural strength has been evaluated in line with ASTM C 34802.

6.2.2.1 Flexural Strength without fibers

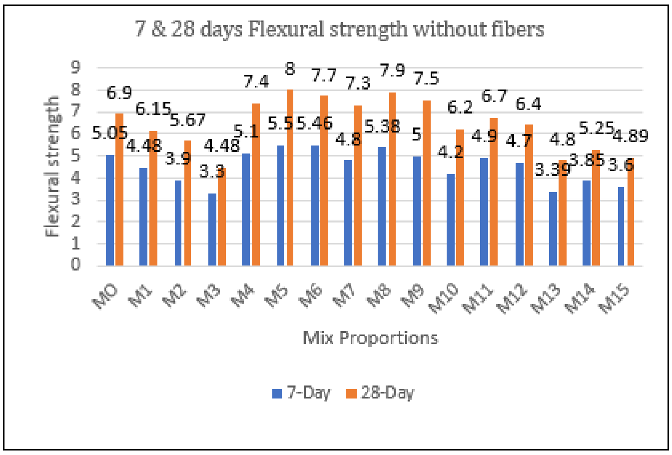

Chart -3: Flexural Strength vs 7&28 Days

- The standard SCM mix's flexural strength is 6.9 MPa after 28 days.
- The initial strength development of a binary SCM mix including silica fume is greater than that of a standard mortar (M0).
- The SCM mix with 10% SF has a maximum flexural strength of 8 MPa after 28 days, which is 15.94% more than the standard SCM mix (M0).
- The generated SCM mix with a cement replacement level of 50% FA (M4) has the lowest flexural strength of 4.48 MPa after 28 days, which is 35.07% less than the standard mix (M0), according to the results.
- Binary SCM mixes with 5% SF (M4), 10% SF (M5), and 15% SF (M6) cement replacement percentages exhibit higher flexural strengths than the standard mix (M0).
- A cement replacement level of 10% FA and 10% SF (M8) produces good flexural strength in tertiary SCM mixes incorporating FA and SF.

6.2.2.2 Flexural Strength with fibers

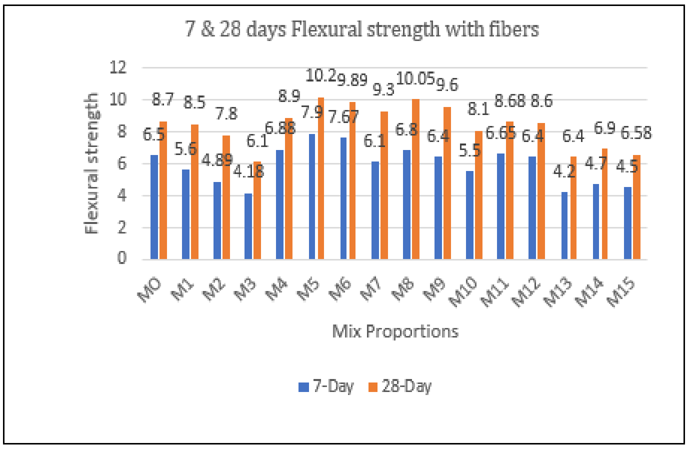

Chart -4: Flexural Strength vs 7&28 Days

- The standard SCM mix has a flexural strength of 8.7 MPa after 28 days.
- Adding 4 kg/m3 of macro-synthetic fibers enhances the flexural strength by 20 to 30 percent as a result of the bridging action of the macro-synthetic fibers.
- The SCM mix with 10% SF has a maximum flexural strength of 10.2 MPa after 28 days, which is 17.24% more than the standard SCM mix (M0).
- According to the study's results, the produced SCM mix (M4), which has a cement replacement level of 50% FA, has the lowest flexural strength of 6.1 MPa after 28 days, which is 29.89% lower than the standard SCM mix (M0).
- A cement replacement level of 10% FA and 10% SF (M8) produces good flexural strength in tertiary SCM mixes containing FA and SF.

6.2.3 Drying Shrinkage Strength

The graph illustrates the drying shrinkage of self-compacting mortar using mineral admixtures such as FA and SF, with and without macro-synthetic fibers. The specimens were cured in water for the first three days before being dried by air for the remaining days. For a total of thirty days, the test is administered at intervals of five days. The dimensions of the rectangular prism used to cast the SCM specimens were 285*25*25mm. The drying shrinkage of the mortar sample was determined in accordance with ASTM C 596-01 or IS 4031 Part 10 of 1988.

6.2.3.1 Drying Shrinkage Strength without fibers

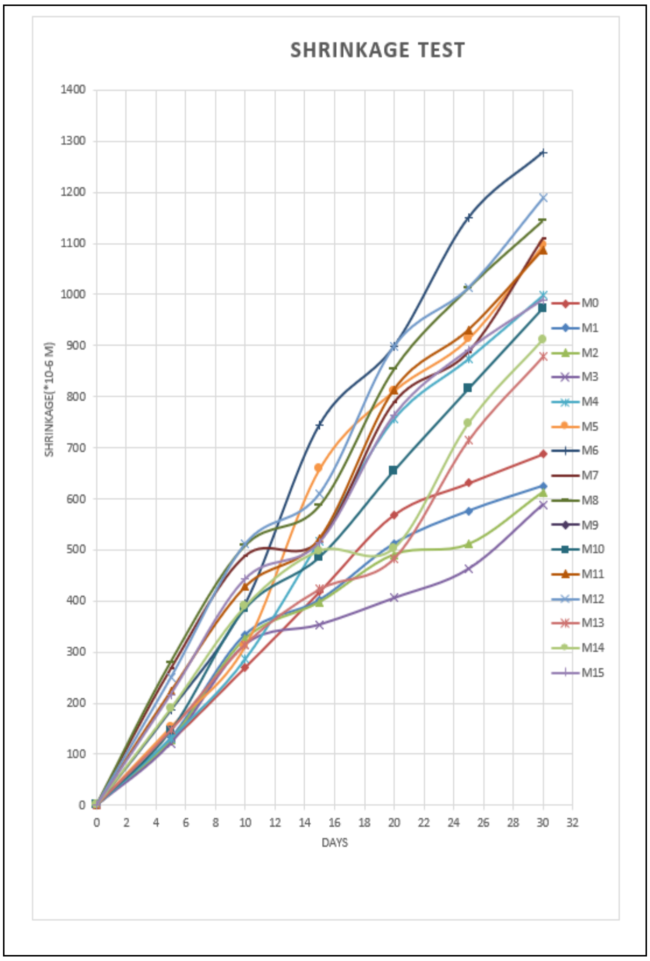

Chart -5: Drying Shrinkage vs Days

- After 30 days, the standard SCM mix (M0) exhibited a drying shrinkage of 688 mm.
- According to the findings, the SCM mix with a cement replacement level of 50% FA (M3) had a lower drying shrinkage (589 m) at 30 days than the standard SCM mix (M0).
- The maximum drying shrinkage after 30 days is reported to be 1278 m for the SCM mix with a cement replacement level of 15% SF (M6).
- According to the findings, all SCM mixes, including 5%, 10%, and 15% SF, noticed more drying shrinkage of 998 mm, 1096 mm, and 1278 mm than the standard SCM mix (M0).
- Compared to the standard SCM mix (M0), SCM mixes containing 20% FA (M1), 30% FA (M2), and 50% FA (M3) as cement substitutes showed decreased drying shrinkage of 625 mm, 613 mm, and 589 mm, respectively.
- Because SF has a higher fineness than cement, drying shrinkage increases as the degree of silica fume replacement increases.

6.2.3.2 Drying Shrinkage Strength with fibers

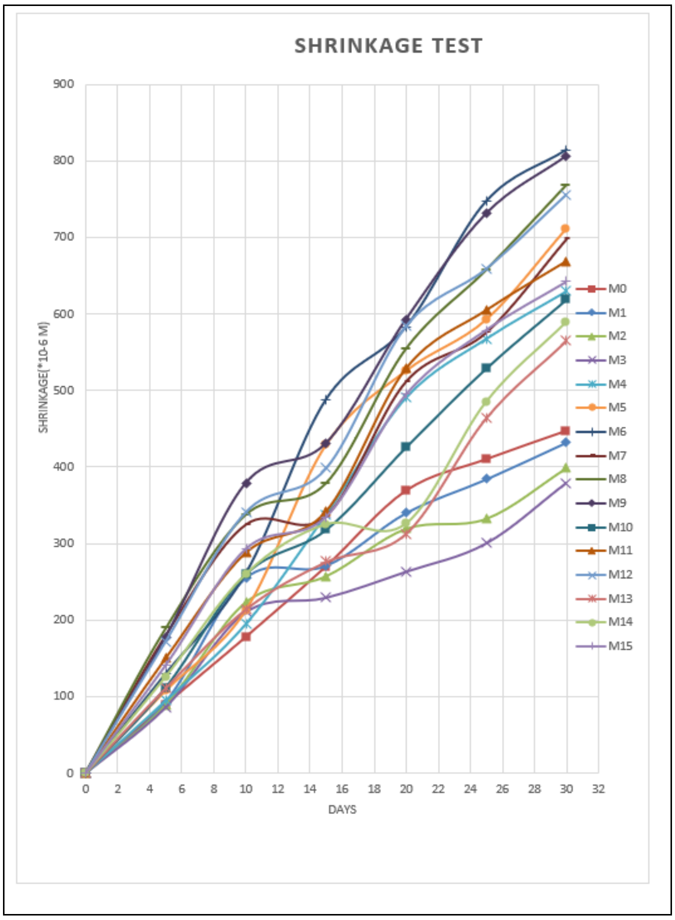

Chart -6: Drying Shrinkage vs Days

- After 30 days, it was observed that the standard SCM mix (M0) showed a drying shrinkage of 447 mm.
- Macro-synthetic fibers with a density of 4 kg/m3 reduce drying shrinkage by up to 50%.
- According to the results, the SCM mix with a cement replacement level of 50% FA (M3) had a lower drying shrinkage (379 m) at 30 days than the standard SCM mix (M0).
- According to the results, the SCM mix with a 15% SF cement replacement level (M6) exhibits a maximum shrinkage of 814 m after 30 days.
- According to the results, all SCM mixes containing 5%, 10%, and 15% SF noticed more drying shrinkage than the standard SCM mix (M0), measuring 630 mm, 712 mm, and 814 mm, respectively.

- Compared to the standard SCM mix (M0), SCM mixes containing 20% FA (M1), 30% FA (M2), and 50% FA (M3) as cement substitutes showed lower drying shrinkage of 432 mm, 398 mm, and 379 mm, respectively.

7.CONCLUSIONS

- In comparison to the standard mix (M0), FA and SF necessitates a greater amount of superplasticizer. Finer the material the more SP required.
- In comparison to the standard mix (M0), When the fibers amount is increased, the Mini-slump flow diameter decreased and Mini-V funnel flow time increased, it is because the workability of mortar has decreased due to addition of fibers.
- The binary SCM mix with 10% silica fume is superior to all other mixes in terms of compressive strength and flow properties when compared to the standard mix (M0), but it has been noted that drying shrinkage is higher in this mix. This is because silica fume has a larger surface area than all other mineral admixtures.
- Because of the fineness of the silica fume, it has been found that the binary SCM mix containing 5% SF (M4), 10% SF (M5), and 15% SF (M6) has higher flowability and hardened properties such as compressive strength and flexural strength but slightly increased drying shrinkage when compared to the standard mix (M0).
- In contrast to the standard mix (M0), the tertiary SCM mix consisting of 10% FA and 10% SF (M8) gives good compressive strength, flexural strength, and flow properties but enhanced drying shrinkage due to fly ash and silica fume's fineness.
- By Comparing all the Mixes, it has been observed that, the Binary Mixes of SCM containing SF, the compressive strength and Flexural strength increases up to 10 %, thereafter it decreases as the content of SF is increased.
- By Comparing all the Mixes, it has been observed that, the Binary Mixes of SCM containing FA, the Flow Properties and Strength Properties decreases, as the content of FA is increased.
- In comparison to all the SCM mixes without fibers, on adding 4 Kg/m^3 of Macro-synthetic fibers to all the mixes increases Compressive strength, Flexural strength and decreases Drying Shrinkage, because of proper binding between matrix and fibers.

REFERENCES

[1] Soma Prasanth Reddy et.al. “A study on the performance of self-compacting concrete with fly ash and alccofine” EPRA International Journal of Multidisciplinary Research (IJMR) -Volume: 7, Issue: 9, September 2021.

[2] Sanjay Thakur et.al “research on effect of silica fume and fly ash with partial replacement of cement and fine aggregate” *International Journal of Civil Engineering and* Technology (IJCIET) Volume 9, Issue 8, August 2018, pp. 113–119.

[3] Arda Mohan and K.M.Mini. “Strength and durability studies of SCC incorporating silica fume and ultra-fine GGBS” ELSEVIER -*Construction and Building Materials* 171 (2018) 919–928.

[4] Ahmet Benli b. et.al “An experimental study of different curing regimes on the mechanical properties and Soraptivity of self-compacting mortars with fly ash and silica fume” ELSEVIER-*Construction and Building Materials* 144 (2017) 552–562.

[5] Mohamed Saafi et.al “Enhanced properties of graphene/fly ash geopolymeric composite cement” *Cement and Concrete Research* 67 (2015) 292–299.

[6] Assem A.A. Hassan et.al. “Effect of metakaolin and silica fume on the durability of self-consolidating concrete” Cement & Concrete Composites 34 (2012) 801–807.

[7] El-Hadj Kadri et.al. “Influence of metakaolin and silica fume on the heat of hydration and compressive strength development of mortar” ELSEVIER-Applied Clay Science 53 (2011) 704–708.

[8] Genesis, Erhan, et al. “Strength and Drying Shrinkage Properties of Self-Compacting Concretes Incorporating Multi-System Blended Mineral Admixtures.” ELSEVIER Construction and Building Materials, vol. 24, no. 10, 2010.

[9] B. Rongbing et.al. “Synthesis and evaluation of shrinkage-reducing admixture for cementitious materials” Cement and Concrete Research 35 (2005) 445 – 448.