Journal of Advanced Engineering Trends
ISSN : 2682 - 2091

Vol.44, No.1. January 2025

http://jaet.journals.ekb.eg

The Impact of Shrinkage Inhibitors on Self Compacting Concrete

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ABSTRACT

This current paper presents an overview of the influence of adding a shrinkage inhibitors admixtures (SIA) with varying contents (0,1.25, and 2.5 liters/m^3), three types of cement (CEM I 52.5, SRC 42.5, and CEM III 42.5), two types of high range water-reducing and retarding HRWR (Type G), and silica fume from two different sources on early strength self-compacting concrete fresh and hardened concrete properties. 276 cubes (150*150*150mm) containing 23 mixes were cast to investigate the effect of SIA type, Type G, and cement type on fresh concrete properties, mechanical properties especially compressive strength. It was found that concrete cast with CEM III has the largest slump flow diameter, while concrete cast with Sulphate-Resistant Cement SRC gives the least diameter. Sulfate-Resistant Cement has the highest T50 value, while High-Blast Cement CEM III has the lowest T50 value. Using High-Blast Cement decreased the values of compressive strength.

KEYWORD *Shrinkage inhibitors, Cement type, Silica fume source, early strength self compacting concrete*

1. Introduction

Concrete efficiency poses a significant challenge for the concrete engineer. SCC is a highly effective type of concrete when it comes to its fresh features. Referred to as 'silent concrete' or 'noiseless concrete', it possesses the unique characteristic of not needing extra energy for compaction. Instead, it naturally flows and consolidates due to its own weight (Ahmad et al.2023 [1]). The utilization of SCC provides a more mechanized manufacturing process, resulting in enhanced efficiency and excellence by minimizing the risky physical labor for workers, as well as reducing the technical expenses associated with the casting cycle, uniformity, and surface refinement (Kavithaet al.,[2]), (Siddique,[3]). These concretes often exhibit a greater amount of paste and a lower water-to-powder ratio compared to conventional ones. Although SCC has certain benefits, it also presents significant drawbacks. These drawbacks included a significant shrinkage rate and a heightened susceptibility to early-age shrinkage cracking.

In recent years, the duration of the construction process has typically been reduced. As a result, high early-age strength (HES) concrete has become an effective material for achieving fast production cycles (Kumar et al, [4]). High-strength concrete (HSC) is defined by its low water-to-cement w/c ratio, which is less than 0.40, or its compressive strength above 60 MPa (Maia,et al.[5]). A low w/c ratio results in a denser microstructure with smaller holes and reduced overall pore volume. As a result, the permeability of concrete is decreased, and its resistance to ion penetration is enhanced, making certain types of concrete well-known for their enhanced durability. However, the specified pore size may lead to the unwanted outcome of increased shrinkage (Cusson and Hoogeveen [6]).

The primary cause of cracks in concrete prior to loading is differential and excessive shrinkage. The main types of concrete shrinkage include drying shrinkage, thermal shrinkage, chemical shrinkage, plastic shrinkage, autogenous shrinkage, and carbonation shrinkage (Cusson and Hoogeveen [6]; Muthu et al.[7]). The initiation of cracks primarily relies on the correlation between the generation of stress caused by shrinkage and the tensile strength of concrete. The number of cracks is influenced by various factors, including as the composition and nature of the cement, mineral, and chemical additives, the ratio of water to binder (w/b), the size and distribution of aggregates, and the conditions during the curing process. During the process of concrete service, multiple variables contribute to the formation of new cracks and worsen existing ones, leading to the transformation of discontinuous cracks into a continuous network [8]. Cracks in concrete are well recognized as significant channels for the infiltration of toxic substances into the concrete, resulting in increased permeability and reduced durability, which visibly deteriorates the concrete's qualities [8,9]

Shrinkage can be reduced by employing several techniques such as modifying cement, using mineral additives, including chemical admixtures, adding fibers, controlling curing conditions, and implementing sophisticated internal curing processes.Traditional curing methods, such as water pounding, may not be efficient for curing large cross-section elements due to the restricted water penetration from the externally battered surface. Shrinkage Reducing Admixtures (SRA) have been developed over the past twenty years. The primary mode of action for these products is the decrease in surface

Revised:15 January , 2024, Accepted:21 July , 2024

tension of the liquid within the interstitial pores of the concrete. This method is also efficient in decreasing autogenous shrinkage in cases where self-desiccation is significant [10,11,12]

The use of shrinkage-reducing admixture is identified as the high-efficiency methodology. This reduces the surface tension of the liquid in the capillary pore, resulting in a 20–50% drying shrinkage reduction when applied with a dosage up to 3%. It can achieve even greater efficiency by combining the admixture with expansive agents to provide synergistic effects, giving mitigation of drying shrinkage of up to 80%. Replacing cement with supplementary cementitious materials, up to 35%, is also an effective approach to mitigate drying shrinkage, giving a reduction between 5–42%. [13]

Utilizing a shrinkage-reducing chemical is a critical method for mitigating concrete cracking [13,14,15]. Surfactant, which are organic chemicals, belong to a category of compounds that can reduce the surface tension of a solution in concrete capillaries [Kioumarsi, et al [16,17]. This reduction in surface tension helps to decrease the negative pressure in the capillary pores, ultimately resulting in a reduction in the dry shrinkage value that occurs during the hardening process of concrete [18,19]. Reducers also postpone the occurrence of the maximum heat generated during the hydration process of the cement, which is highly advantageous in mitigating shrinkage cracks caused by temperature variations [20,21].

Several findings indicate that SRA has a heightened impact on the maneuverability of concrete. In their study, Yoo et al. [22] discovered that the slump of ultra-high-performance fiber-reinforced concrete (UHPFRC) with 0, 1, and 2% SRA was measured at 235 mm, 245 mm, and 240 mm, respectively. This indicates that the inclusion of SRA somewhat enhanced the workability of UHPFRC while maintaining the same water-to-binder ratio and water reducer. This finding aligns with the outcomes documented in a separate investigation [23].

Contrary to the aforementioned advantages, the SRA entails adverse effects typically seen as unfavorable. Several studies by Zhan and He [24], Yoo,[25] Quangphu et al [26] Güneyisi et al [27], and Yoo et al [28] have noticed decreases in the hydration level of cement and the rate at which concrete gains strength. During the early stages, there were notable decreases in mechanical strength, as shown in studies [29-32]. Moreover, other investigators by Gencel et al [33]; Anshuang et al [34]; Riaan and Boshoff-[35] noted substantial delays in setting times when compared with reference specimens.

Ribeiro et al. [36] conducted an experiment to achieve a greater decrease in shrinkage by testing the combined effect of two distinct SRAs. The results showed a cumulative effect on shrinkage reduction. Prior to the introduction of shrinkage-reducing admixtures, expansive cements were employed for more than four decades to mitigate the impact of drying shrinkage [37-39]. This approach has demonstrated favorable outcomes in enhancing joint space and restricting curing. However, its implementation necessitates specific care [40].

In their study, Quangphu et al. [41] examined how the inclusion of SRA (Shrinkage-Reducing Admixture) affects the mechanical properties of high-performance concrete. The findings indicated that the compressive strengths of concrete, which included 1, 2, and 4% SRA, were cured for 90 days at a w/b of 0.4 (or 0.22), a temperature of 20 °C, and relative humidity of 100%, noticed a reduction of 4, 5, and 14% (2, 11, and 12% for the w/b of 0.22), respectively.

Oliveira, et al.[39] provided experimental findings regarding the autogenous shrinkage of self-compacting concrete. The evaluation focused on the effectiveness of various shrinkage-compensating materials, considering the inherent high autogenous shrinkage of concrete mixtures with low w/c ratio. The study focused on two shrinkage-reducing admixtures and one expanding binder. The results demonstrate the effectiveness of using each product individually and highlight a synergistic effect on lowering autogenous shrinkage when a shrinkage-reducing admixture and expanding agent are combined. Moreover, the outcomes demonstrate the possibility of attaining a predetermined range of shrinkage by utilizing the combined influence of a set retarder and an expanding admixture.

The present work conducted by Kalkan, et al.[42] aims to examine the impact of SRA on the mechanical characteristics of SCC. For this objective, the compressive and flexural strength values of SCC samples with SRA and other chemical additions were compared to the corresponding values of samples without any additives. The test results showed that the inclusion of SRA had minimal to negligible impact on the compressive and tensile strength of the concrete mixture after 28 days, regardless of the presence of other additives in the mixture alongside SRA.

Rizzuto,J .P et al.[43] investigated the effect of self-curing admixture on concrete properties in hot climate Conditions. They found that adding admixtures affects the slump flow diameter.

2. Research Significant

A series of tests were conducted to examine the impact of shrinkage inhibitors (SIA) on the mechanical characteristics of both fresh and hardened self compacting concrete. To achieve this objective, a total of twenty-five distinct concrete mixtures were produced and examined, each including various combinations of concrete additives. This experimental program investigated the impact of using various types of cement, specifically high-range water-reducing and retarding types, with two different contents of supplementary cementitious materials, as well as the inclusion of silica fume, on the properties of both fresh and hardened concrete. Significant findings were derived from conducting several tests on fresh and hardened concrete mixtures.

3.Experimental Program

3.1 Constituent Ingredients

The component mixtures employed throughout the experiment included Portland cement CEM I, sulphate-resistant cement SRC, high blast furnace cement CEM III, silica fume from two sources, crushed pure dolomite aggregate, natural siliceous sand, two types of high-range water reducing and retarding (HRWR) and shrinkage inhibitors admixtures SIA, and water. The following sections describe the characteristics of these materials.

3.1.1. Cement and cement replacement substances

Three types of cement were employed in preparing the specimens: Portland cement (grade 52.5) CEM I 52.5, sulfate-resistant-cement (SRC 42.5), and blast furnace cement CEM III 42.5 with a blast furnace proportion of 50%. The ingredients were provided by an Egyptian manufacturer and corresponded to European Cement Standard EN 197-1 [44]. The physical and mechanical characteristics of the cement are listed in Table 1. Moreover, two types of silica fume were used, produced by two different companies. The first type was a light gray color from source 1 with a specific gravity of 2.35 as shown in Figure 1, while the second type from source 2 was dark gray with a specific gravity of 2.3 as shown in Figure 2. The silica fume was utilized as a partial substitute for cement based on weight. The silica fume that was utilized complied with the specifications given in ASTM C 1240 [45]. Table 1, sourced from the provider, outlines the attributes of silica fume.

Table 1 : Physical and chemical characteristics of cement and SF

property	**OPC 52.5**	**SRC 42.5**	**CEM III 42.5 (50% blast)**	**SF Source1**	**SF Source 2**
Fineness(cm2/g)	3260	3358	4350	20000	20000
Specific gravity	3.15	3.15	3.15	2.35	2.3
Soundness (expansion)	0.5mm	1mm	1mm	-	-
Silica dioxide (SiO2)	21.45%	20.4	30.27	89.25	91.96
Aluminum oxide (Al2O3)	5.8%	4.1	8.45	0.12	0.1
Iron oxide (Fe2O3)	3.6%	4.78	2.39	1.0	1.68
Calcium oxide (CaO)	63.63%	62.9	49.7	0.2	0.91
Magnesium oxide (MgO) %	1.4%	1.21	3.85	0.15	0.15
Sulphur trioxide (SO3) %	3.17%	1.73	1.47	0.1	0.1
Loss due to ignition	4.1	3.5	1.3	0.2	0.2
colour	Dark Grey	Dark Grey	Dark Grey	Light Grey	Dark Grey
Compressive strength at 28 days	56.8 Mpa	44.5 Mpa	47.7 Mpa	-	-
Bulk Density(t/m^3)	1.98	1.95	1.85	0.355	0.35

Figure 1: Silica fume source1

Figure 2: .Silica fume source2

3.1.2 Aggregate

The coarse materials utilized were crushed pure dolomite with a maximum dimension of 19 mm and a specific gravity of 2.66. The aggregate used for the sample preparation was natural siliceous sand with a particle size smaller than 5 mm and a specific gravity of 2.5. Fine aggregate was devoid of contaminants and organic substances with a fineness modulus of 2.25. The results of the sieving analysis test conducted in line with ESS No. 1109/2002 [46] and the data are provided in Figure3.The chemical analysis of sand and coarse aggregates was recorded in Table2.

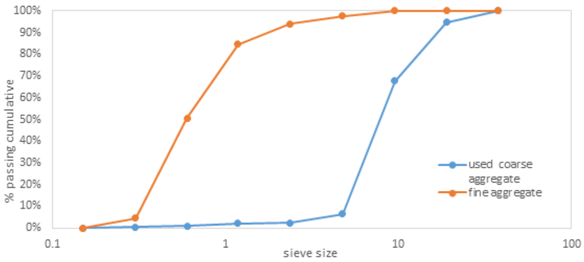

Figure 3: Gradation curve of fine and coarse aggregates

3.1.3 Water

The tested specimens were mixed and cured using potable tap water. Table 3 indicates the results of tests conducted on water

3.1.4 Chemical admixtures

Two types of chemical admixtures were used : first was shrinkage Inhibitors admixtures SIA (and the second was Type G (high water reducing and retarding).

Table 3: Water test results.

Test	Result	Egyptian Code Limits
Chloride (Cl^-)	107	< 500 ppm
Sulphates (SO_3)	103	< 300 ppm
TDS	390	< 2000 ppm
pH	7.01	$\geq$ 7

3.1.4.1 The Shrinkage Inhibitors Admixtures SIA

The used shrinkage Inhibitors admixtures (SIA) which is a light brown turbid liquid. It exhibits compatibility with water in any proportion and can also be incorporated into a pumping superplasticizer. It is highly convenient for usage in building applications and exhibits a shrinkage rate ranging from 50 to 80%. The dosage explored in this study ranged from 0.5% to 2.0% of the total mass of the cementitious materials.Table 4 illustrates the performance data of SIA.

3.1.4.2 High range water reducing and retarding HRWR

Two types of high-range water reducing and retarding (Type G) named Optima (A1) and (A2) were used . Table 8 concluded the performance test data.

The three types were compliant with BS EN 934-2 [46], the performance test data was recorded in Table 4.

Table 2: Chemical analysis of fine and coarse aggregate

Compound	Fine aggregate	Coarse aggregate	Limits	Specifications
Chlorides (%)	0.05	0.02	< 0.06%	BS 812 part 117
Sulphates (%)	0.17	0.01	< 0.3%	BS 812 part 1178
PH	7.75	7.3	----	
Soundness (Na_2SO_4)	2.18%	1.8	< 10%	ASTM C88

Table 4: Performance test data of chemical admixtures.

Aspect	SIA	HRWR -Type G A1	HRWR -Type G A2
Relative Density	0.97	1.08	1.055
pH	8.4	4	7.2
Chloride Ion content	----	---	< 0.2%
Colour	Light brown	Light yellow	Light green

3.2 Mixing process and specimen preparation.

Egyptian code, and ASTM standards were used to design the mixes and test program. Twenty-five mixes of ESSCC were used to cast the specimens. Mixes containing different types of chemical admixtures (SIA with varying contents) and different types of cement, with adding two different sources of silica fume.The mix mainly consists of a cement content of 475 kg/m^3, water content of 175 liters/m^3, fine and coarse aggregates each of 821 kg/m^3, a silica fume content of 25 kg/m^3, and (W/C+sf) = 0.420. admixtures differs in content and type according to mix design. For each mix, 12 cubes (150x150x150 mm) were prepared as shown in Figure 4. The details of the mixed ingredients will be shown in Table 5.

Each batch's were weighed and blended using a mechanical concrete mixer. To ensure the homogeneity of the ingredients, the water was combined with the additives and cement or cement filler for 30 seconds. Simultaneously, sand was added to the mixer and mixed for 30 seconds, followed by dolomite aggregate and another 2 minutes of mixing. Fresh concrete for SCC was evaluated for slump flow (flowability), passing ability, and propensity for segregation by using the slump flow experiment of the freshly mixed SCC (ECCS,2020). [47]

Figure 4:Specimen after pouring

3.2.2 Slump flow test

The slump flow test measures the ability of SCC to flow. The assessment of the deformability of SCC horizontal free flow (slump flow) is conducted when there are no obstacles present. The process is analogous to the one used to ascertain the slump of concrete. The key difference lies in the fact that slump flow is quantified by measuring the diameter of the concrete spread in two perpendicular directions rather than assessing the decrease in height. Concrete exhibits a higher ability to occupy form-works when the slump flow is increased. The duration required for the concrete to reach a diameter of 50 cm during a slump flow test is indicative of the concrete's viscosity and stability. It was conducted according to BS-EN-12350-8 [48]. A shorter duration indicates improved fluidity or reduced loss of workability. The slump T50 test, which measures the consistency of concrete without any separation of aggregates along the edges, yields results in the range of 2.2–3.5 s and slump flow widths of 600–700 mm.

Standard slump cone (200 x 100 x 300 mm) was filled with cement and the time (T50 cm) for concrete to achieve a 500 mm slump flow radius and the mean diameters D of the spread lifting the cone, as seen in Figure 5. The average measured slump flow diameter was recorded in Figure 7.

3.3 Hardened concrete tests

3.3.1 Compression test

Compression tests were carried out according to ECCS 203-2003 appendix 3, parts 7-2 and 7-3 [49] to check the hardened concrete. The hardened concrete samples were continuously stored in clear water (20 ± 2 oC) until the days of testing. The used cubes were standardized steel cubes (150 x 150 x 150 mm) of the concrete mixture that were made to assess compressive strength at ages 1, 3, 7, and 28 days.

Figure 5: Slump Flow Experimental work

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4. Results and Discussion

4.1 Fresh concrete

The self compacting concrete characteristics, such as flowability, passing ability, and segregation resistance, have been determined by slump flow. Generally, it was investigated that adding SIA increases the T50 and decreases the diameter D. The results was represented in figure 6.

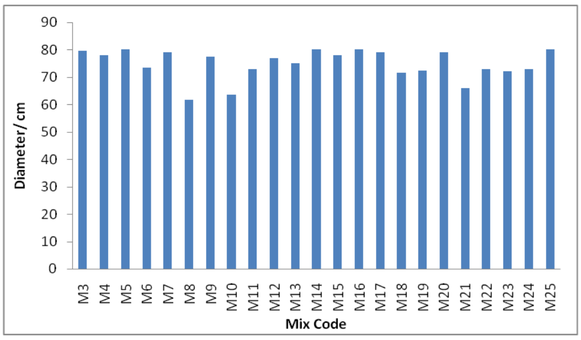

Figure 6: Slump flow diameter of concrete

From figure 6, it was observed that the slump flow diameters ranged between 600 and 800 mm. That satisfy the limits of self-compacting concrete.

The utilization of SIA leads to a marginal or consistent rise in the diameter of the concrete slump flow, as depicted in Figure 7. The likely reason is that when there is sufficient free water in the specimen, the SI reduces the tensile stress between water and concrete paste, resulting in an increase in slump quantity compared to the control specimen. However, with time, the decrease in available water causes the disappearance of this phenomenon and diminishes the slump in comparison to the control sample. Overall, the mentioned findings indicate that the utilization of SIA initially enhances the fluidity of the concrete, but with time, the fluidity decreases, compared to the control sample. Mountaser et al, found that self compacting concrete with compressive strength 65 Mpa achieved 69 cm slump flow diameter and T50 was3.8 seconds [50]

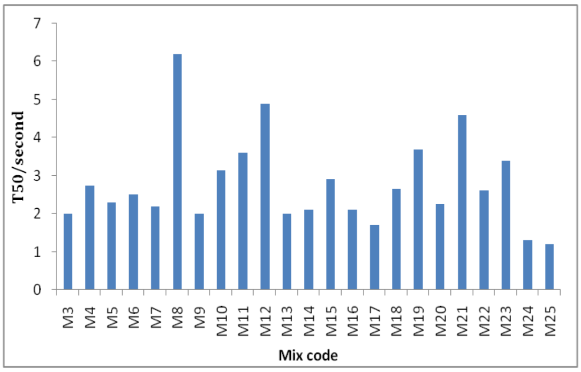

Figure7: Time that Concrete Reach T50

From experimental tests recorded in figure 7, it was found that T50 (the time that concrete mix reaches 50 cm) was not recorded in mixes M9, M17, M24, and M25. They recorded a time of T50 less than two seconds because M9 and M25 were cast with high blast furnace cement CEM III,while M17, M24were cast using sulphate-resistant cement SRC. Time increased to more than 5 seconds in M8, which was cast using SRC cement and SIA of 2.5 liters /m^3 of concrete mixture and a Type G (HRWR) decreased to 8.5 liters/m^3. It was found that the maximum T50 was obtained in mixes M8, M12, M21, and M11.Due to the presence of SIA. Mix M3 has the greatest compressive strength at any age.

4.2. Hardened concrete

4.2.1Compressive Strength Results

Table 6 illustrated the compressive strength values and values of standard deviation at different ages 1,3,7,and 28 days. The standard deviation of compressive strength at 1 day ranged from 0.87 in M10 to 2.7 in Mix3. it ranged at 3 days from 0.89 to 2.3, while the range was from 0.678 to 3.12 at 7days. At 28 days the standard deviation of compressive strength was ranged from 0.2 to 3.75.

Figures 8 to11 illustrate the results of the compressive strength test after 1, 3, 7, and 28 days. It was found that Mix M3 and M25 at 7days, M3 and M24 at 28days, M6 and M23 at 3days have the highest compressive strength.

Table 5: Experimental concrete mixtures

Mix code	**Cement Type**	**Mineral admixtures**		**Aggregate**		**water**	**Chemical admixtures**		
		Content (kg/m^3)	**source**	**Fine (kg/m^3)**	**Coarse (kg/m^3)**	**L/m^3**	SIA (l/m^3)	**Type G (l/m^3)**	
M3	٥٢.٥CEMI	25	1	٨٢١	٨٢١	١٧٥	٠	١١	A1
M4	٥٢.٥CEMI	25	1	٨٢١	٨٢١	١٧٥	١.٢٥	٩.٧٥	A1
M5	٥٢.٥CEMI	25	1	٨٢١	٨٢١	١٧٥	٢.٥	٨.٥	A1
M6	SRC 42.5 N	25	1	٨٢١	٨٢١	١٧٥	٠	١١	A1
M7	SRC 42.5 N	25	1	٨٢١	٨٢١	١٧٥	١.٢٥	٩.٧٥	A1
M8	SRC 42.5 N	25	1	٨٢١	٨٢١	١٧٥	٢.٥	٨.٥	A1
M9	CEM III	25	1	٨٢١	٨٢١	١٧٥	٠	١١	A1
M10	CEM III	25	1	٨٢١	٨٢١	١٧٥	١.٢٥	٩.٧٥	A1
M11	٥٢.٥CEMI	25	1	٨٢١	٨٢١	١٧٥	١.٢٥	11	A1
M12	٥٢.٥ CEMI	25	1	٨٢١	٨٢١	١٧٥	٢.٥	١١	A1
M13	CEM III	25	1	٨٢١	٨٢١	١٧٥	١.٢٥	١١	A1
M14		25	1	٨٢١	٨٢١	١٧٥	٢.٥	١١	A1
M15		25	1	٨٢١	٨٢١	١٧٥	٢.٥	٨.٥	A1
M16	SRC 42.5 N	25	1	٨٢١	٨٢١	١٧٥	١.٢٥	١١	A1
M17	SRC 42.5 N	25	1	٨٢١	٨٢١	١٧٥	٢.٥	١١	A1
M18	٥٢.٥CEMI	25	2	٨٢١	٨٢١	١٧٥	٠	١١	A1
M19		25	2	٨٢١	٨٢١	١٧٥	١.٢٥	١١	A1
M20		25	2	821	821	١٧٥	٢.٥	١١	A1
M21	SRC 42.5 N	25	2	821	821	١٧٥	١.٢٥	١١	A1
M22	CEM III	25	2	821	821	١٧٥	١.٢٥	١١	A1
M23	٥٢.٥CEMI	25	1	821	821	١٧٥	١.٢٥	١١	A2
M24	SRC 42.5 N	25	1	821	821	175	١.٢٥	١١	A2
M25	CEM III	25	1	821	821	175	١.٢٥	١١	A2

Table 6: Compressive strength and standard deviation at different ages

Mix code	**Cement type.**	**Average diameter (cm)**	**T50 (second)**	**SIA content %**	**HRWR type**	**HRWR Content L/m^3**	**SF source**
M3	CEM I52.5	79.5	4.5	zero	1	11	1
M6	SRC 42.5	73.5	3.5			11	
M9	CEM III	77.5	4			11	
M4	CEM I52.5	78	2.75	1.25	1	9.75	1
M7	SRC 42.5	79	2.2			9.75	
M10	CEM III	63.5	3.15			9.75	
M5	CEM I52.5	80	2.3	2.5	1	8.5	1
M8	SRC 42.5	61.5	6.2			8.5	
M15	CEM III	78	2.9			8.5	
M11	CEM I52.5	73	2.56	1.25	1	11	1
M16	SRC 42.5	80	2.1			11	
M13	CEM III	75	2			11	
M12	CEM I52.5	77	4.9	2.5	1	11	1
M17	SRC 42.5	79	1.7			11	
M14	CEM III	80	2.1			11	
M19	CEM I52.5	72.5	3.7	1.25	1	11	2
M21	SRC 42.5	66	4.6			11	
M22	CEM III	73	2.62			11	
M23	CEM I52.5	72	3.4	1.25	2	11	1
M24	SRC 42.5	73	1.3			11	
M25	CEM III	80	1.2			11	

Table 7: Slump flow diameter and T50 results

Mix code	1day- SD	3days-SD	7days-SD	28 days-SD
M3	20 [2.6]	33 [2.1]	54.7 [3.1]	63 [3.75]
M4	29.3 [2.7]	35 [2.2]	39 [1.7]	44 [2.75]
M5	20 [1.8]	30 [1.78]	39 [2.1]	48 [1.77]
M6	26.7 [1.87]	38 [1.8]	48 [1.6]	51[2.1]
M7	18 [1.3]	22 [1.66]	36 [1.67]	38 [1.27]
M8	24.4 [0.89]	20 [1.2]	38 [1.9]	45[0.2]
M9	28.2 [1.08]	31 [2.2]	39 [1.1]	44.7 [0.567]
M10	30.5 [0.87]	37 [0.98]	36.5 [0.678]	45 [0.356]
M11	28.8 [2.1]	32 [2.9]	42 [1.57]	47 [2.86]
M12	29.3 [1.9]	29 [2.15]	37 [2.31]	37 [2.82]
M13	18 [2.1]	28 [1.1]	44 [1.63]	50 [1.92]
M14	15 [0.615]	22 [0.89]	31.5 [0.89]	36 [1.3]
M15	19.2 [1.23]	23[1.15]	33 [1.55]	41 [1.7]
M16	26.7 [1.66]	35 [1.65]	48.3 [2.12]	51 [2.18]
M17	19.3 [3.1]	23 [[1.23]	32 [1.67]	35 [4.24]
M18	31 [2.1]	35 [1.23]	36 1.89]	46 [2.78]
M19	18.7 [1.9]	22 [2.0]	20 [1.76]	33 [2.2]
M20	19.2 [2.21]	25[1.6]	30.5 [1.67]	39 [1.8]
M21	19 [1.89]	27 [2.4]	34.7 [2.97]	42 [1.78]
M22	15 [1.9]	24 [2.3]	35 [2.1]	46.8 [2.1]
M23	27 [0.89]	39 [1.1]	40.7 [2.2]	52.5 [1.789]
M24	23.7 [1.16]	31 [1.73]	30.3 [1.87]	62 [2.1]
M25	19.3 [0.98]	23 [1.62]	50 [3.21]	60.7 [2.6]

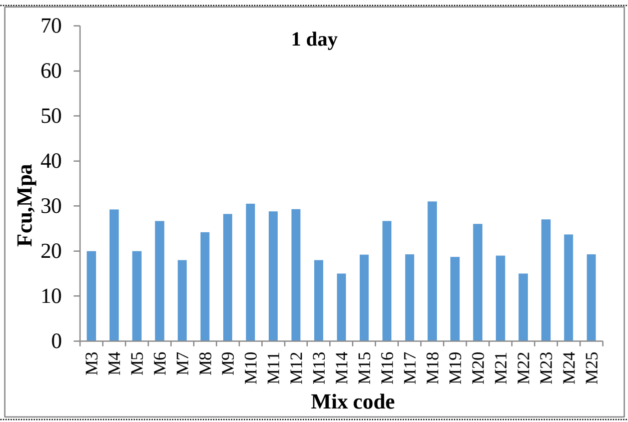

Figure 8. Compressive strength results after one day.

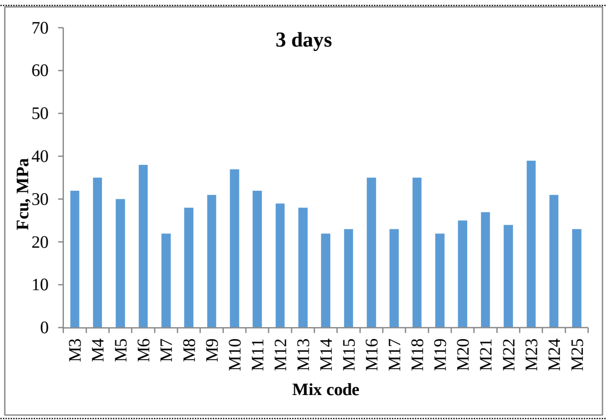

Figure 9 : Compressive strength results after 3 days

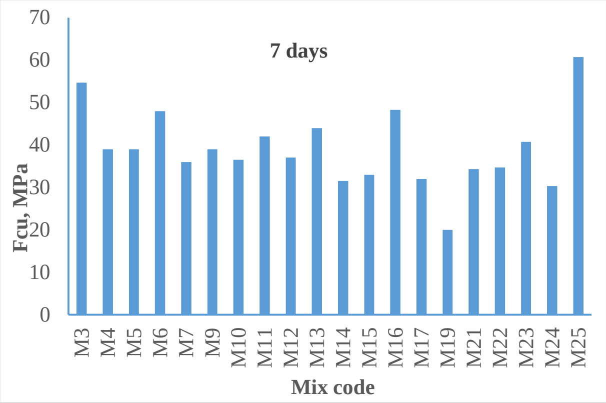

Figure 10: Compressive strength results after 7 days

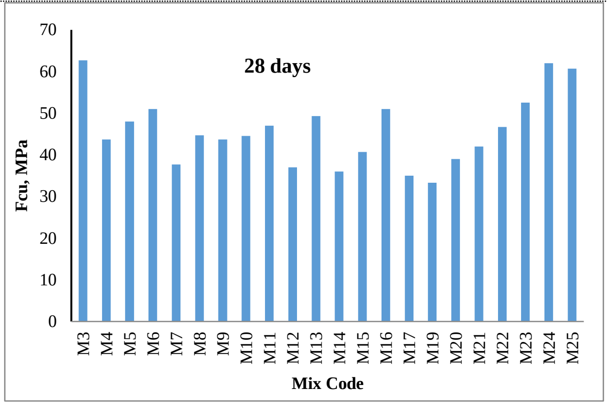

Figure 11: Compressive strength results after 28 days

5. **Studied Factors**

Four factors were studied and their effect on fresh concrete (mainly T50 and slump flow diameter) and on hardened concrete, mainly compressive strength. First: effect of cement type, effect of silica fume source, and adding SIA with two percentages (1.25 % and 2.5%, in addition to chemical admixtures source.

5.1 Results for fresh concrete

5.1.1. Effect of cement type on fresh concrete

To study effect of three different types of cement CEM I, SRC, CEM III , the results were represented in table 7. Table 7 illustrated the slump flow test results of early strength self consolidation concrete mixes. It was found that the maximum slump flow diameter was in CEM III, while SRC achieved the lowest slump flow diameter. Maximum T50 was gained in SRC results, while minimum T50 was found in CEM III mixes.

5.1.2 Effect of SIA dosage

Effect of SIA on compressive strength was investigated for three types of cements. Table 8 illustrated the results of compressive strength as the SIA content changed from zero to 1.25 and 2.5%.

According to table 8. Using SIA content ranging from zero to 1.25 liters /m^3, and 2.5 liters /m^3 decreased the T50 and but increased the average slump flow diameter compared to the reference concrete mix without SIA, when using CEM I or SRC.

Increasing SIA leads to an increase in slump flow diameter, and T50 decreases. For SRC concrete, increasing SIA content from 1.25 to 2.5 l/m^3 increased slump flow diameter by 1.3% and T50 decreased by 35.7%. In CEM I 52.5 and CEM III concrete mixes, the decrease in T50 was 10.2% and 2.3%, the increment in diameter was 9% and 6%.

The findings corroborated the research conducted by Tao and Lei [51], which demonstrated that the inclusion of a 2.5% shrinkage-reducing chemical is advantageous in mitigating the shrinkage of concrete T500. At first, the shrinkage diminishes and then stabilizes as the amount of the SRA increases. When the content of SRA is 0.5, 1, and 1.5%, the concrete T500 drops by 0, 33.3, and 33.3%, respectively, compared to the benchmark mixture ratio.

Xi et al.[52] concurred with findings that including an SRA enhances the workability of concrete and augments its slump.

5.1.3 Effect of HRWR type

Table 9 illustrated the effect of using two different types of high range water reducer HRWR on T50 and average diameter of slump flow test. It was found that HRWR type 2 has the least T50 and average slump flow diameters when using any type of cement.

5.1.4. Effect of Mineral Admixture Type.

Effect of adding silica fume with two different sources was recorded in table 10. Two sources of silica fume with fixed content of 25kg/m^3 were used to cast early strength self-compacting concrete mixes using three types of cement: CEM I, SRC, and CEM III, and Type G source 1. It was found that silica fume from source 2 recorded highest T50 and average slump flow diameter.

5.2. Results for hardened Concrete

5.2.1 Effect of cement type

Figures 12 to 18 show the effect of cement types on the compressive strength of early-strength self consolidation concrete when cast with different chemical admixtures and silica fume from two sources. All concrete specimens improved with age, as predicted.

At 1.25% SIA, it was found that using SRC cement resulted in the highest compressive strength values compared to CEM III and CEM I. After one day, a slight reduction in compressive strength appeared, while increases of 9.5%, 20%, and 10.6% appeared when changing cement type from CEM I to SRC after 3, 7, and 28 days.

For Silica fume source 2 and 1.25% SIA, it was found that using SRC cement resulted in the highest compressive strength values in the early ages of 1 and 3 days compared to CEM III and CEM I. However, at 7 and 28 days, the highest compressive strength was found in the CEM III.

According to SIA content 1.25% and HRWR 9.75l/m^3 , changing cement type from CEM I to SRC decreased the compressive strength at any age. The reduction was 36.6%, 28%, 5%, and 13.73% after 1,3,7, and 28 days, respectively while changing cement type from CEM1 to CEM III led to increase by 4.5% , 5.7%, 2.5% and 11.3%, respectively.

For silica fume source 2 and HRWR type 2, at 1.25% SIA, it was found that using CEM I 52.5 cement resulted in the highest compressive strength values in the early ages of 1 and 3 days compared to CEM III and SRC 42.5. After that, the highest compressive strength was found in SRC concrete mixes compared to CEM I and CEM III. Results showed that in the case of using 2.5% SIA and 11 liters of HRWR source 1, the highest compressive strength was found in CEM I.

According to the Figures, the results indicate that the compressive strength of early strength self-compacting concrete decreases with increasing the dosage of SIA. According to the concrete which was cast using

CEM I, increasing SIA from zero to 1. 25 l/m^3 decreased compressive strength by 37.7%, 37%, 40% and 22.5% at ages 1, 3, 7, and 28 days. While increasing to 2.5 l/m^3 leads to a decrease of 29, 28, 18.6 and 18.6% at ages 1, 3, 7, and 28 days. The rate of decrease was high in the early ages until 7 days.

Table 8 :Effect of SIA on slump flow diameter and T50.

Mix code	Cement type	SF source	HRWR	SIA content	Average diameter (cm)	T50 (sec)
M18	CEM I 52.5	1	Type G source 1	0	71.5	2.26
M19				1.25%	72.5	2.56
M20				2.5%	79	2.3
M6	SRC 42.5	1	Type G source 1	0	73.5	2.48
M16				1.25%	79	2.8
M17				2.5%	80	1.83
M9	CEM III	1	Type G source 1	0	77.5	1.68
M13				1.25%	75	2.78
M14				2.5%	80	2.1

Table 9 : Effect of HRWR type on T50 and average slump flow diameters

Mix code	Cement type.	Average diameter (cm)	T50	SIA%	HRWR type
M11	CEM I52.5	73	3.56	1.25	1
M16	SRC 42.5	80	2.1		
M13	CEM III	75	2		
M23	CEM I52.5	72	3.4	1.25	2
M24	SRC 42.5	73	1.3		
M25	CEM III	80	1.2		

Table 10 : Effect of silica fume source on T50 and average slump flow diameter

Mix code	Cement type.	Average diameter (cm)	T50	SIA%	S.F
M11	CEM I52.5	73	3.56	1.25	1
M16	SRC 42.5	80	2.1		
M13	CEM III	75	2		
M19	CEM I52.5	72.5	3.7		2
M21	SRC 42.5	66	4.6		
M22	CEM III	73	2.62		

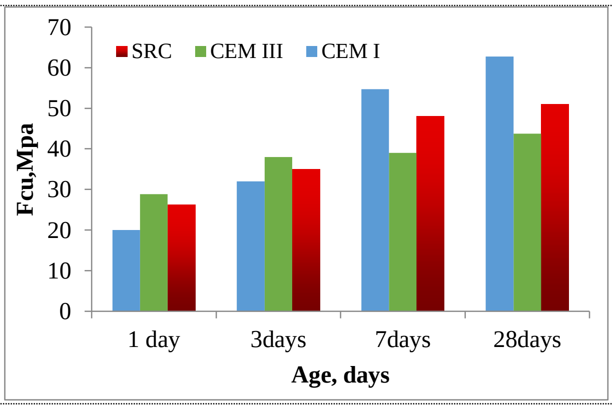

Figure 12:Influence of cement type on compressive strength results for SIA content 0%

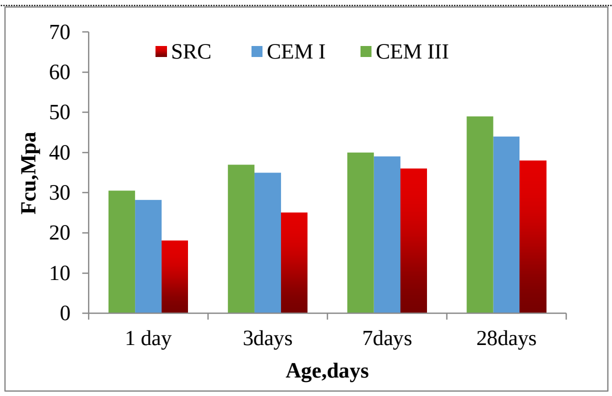

Figure 13:Influence of cement type on compressive strength for SIA content 1.25%

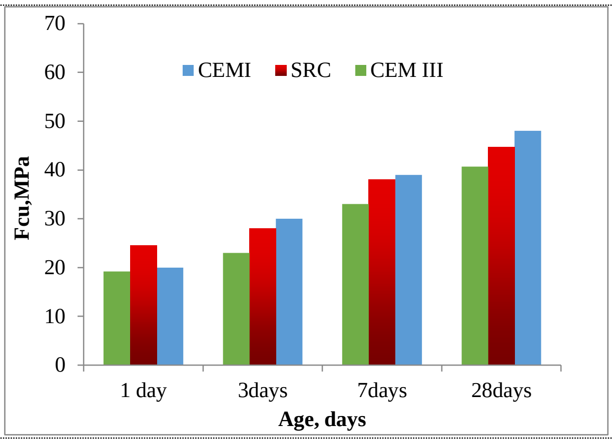

Figure14:Influence of cement type on compressive strength for SIA content 2.5%

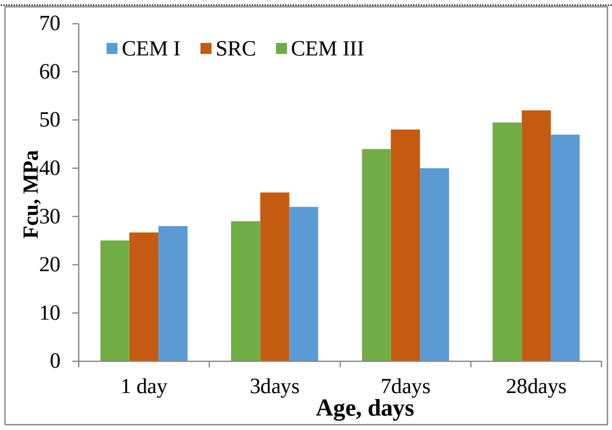

Figure15:Influence of cement type on compressive strength for SIA content 1.25%

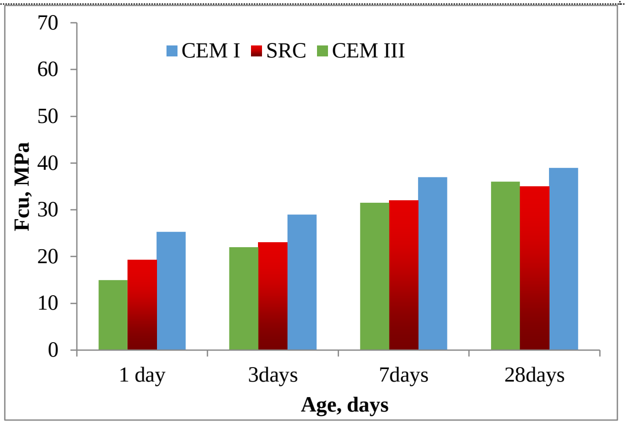

Figure 16 : Influence of cement type on compressive strength for SIA content 2.5%

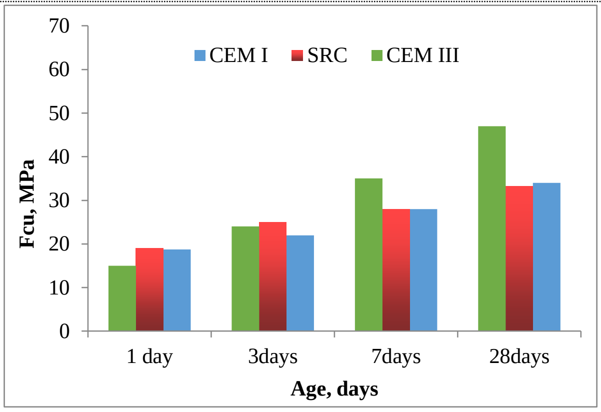

Figure17: Influence of cement type on compressive strength for SIA content 1.25%

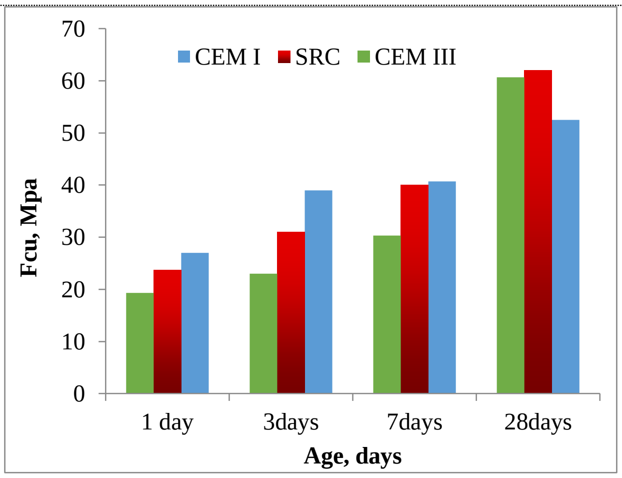

Figure 18 :Influence of cement type on compressive strength for SIA content1.25%

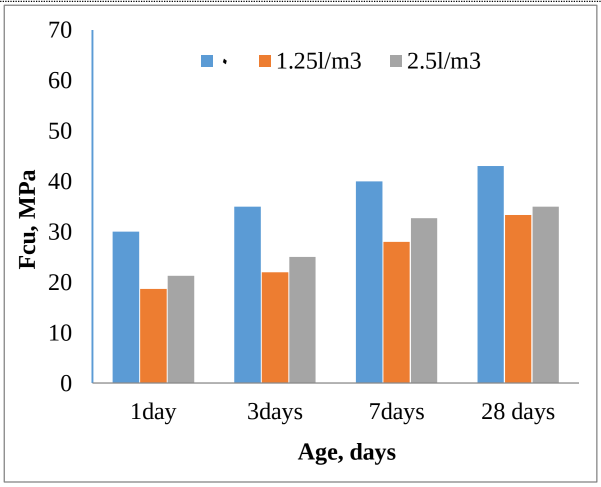

Figure 19 : Effect of SIA content on compressive strength of CEM I concrete

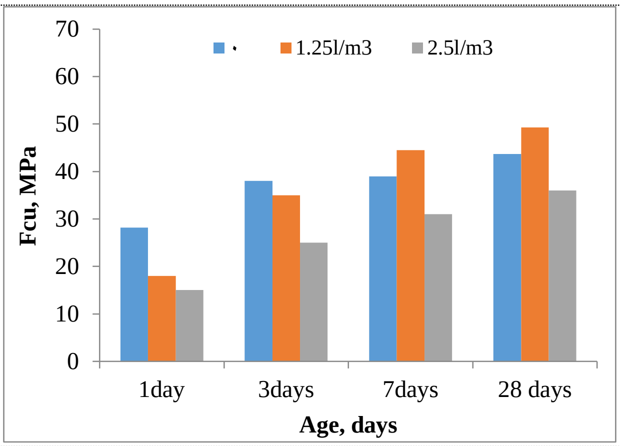

Figure 20: Effect of SIA content on compressive strength of SRC concrete.

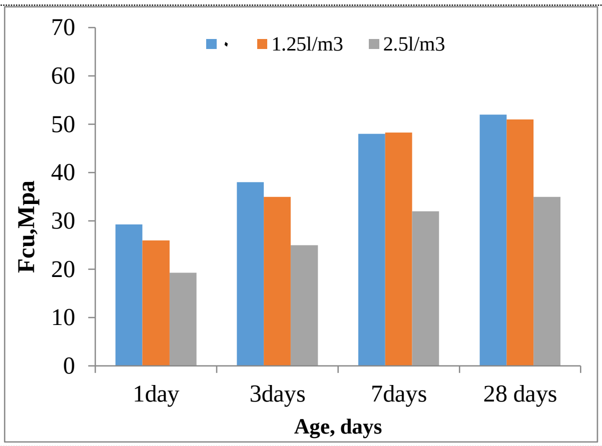

Figure 21: Effect of SIA content on compressive strength of CEM III concrete.

5.2.2. Effect of SIA dosage.

To study the effect of SIA content on the early strength of self-compacting concrete containing three different cement, namely CEM I, SRC, and CEM III. Three SI contents were investigated (zero, 1.25 liters/m^3, and 2. 5 L/m^3 were examined, and the results are illustrated in Figures 19 , 20, and 21.

According to SRC concrete, the decrement in compressive strength values was high in the early stages. It was 9%, 8.5%, 3.2%, at 1,3, and 28 days, when increasing SIA to 1.25 L/m^3. While increasing it to 2.5L/m^3 decreased the compressive strength values by 10.8%, 10%, 31%, and 36.7% at ages 1,3,7, and 28 days. The decrease was highest on day 7 and day 28.

According to CEM III concretes M9, M13, and M14, the decrease in compressive strength values was high in the early stages. It was 36% and 2% at age 1 and 3 days, while it increased by 14.4%, 13.8% at 7 and 28 days, respectively when increasing SIA to 1.25 L/m^3. While increasing SIA to 2.5L/m^3 decreased the compressive strength values by 46.8, 44, 15.4, and 17.6% at 1, 3, 7, and 28 days. The decrease was highest on ages 1 and 3 days.

The findings were consistent with Anshuang et al. [53] who demonstrated that the introduction of SRA at a 2% dosage resulted in a loss of 24.4% in 7-day compressive strength to 86.7 MPa and a decrease of 17.8% to 109.4 MPa in 28-day compressive strength. The SIA had a greater impact on the 7-day strength of ultra-high performance concrete (UHPC), resulting in a more pronounced drop. This suggests that the SRA had a more noticeable influence on the strength of UHPC at an early stage [54-59].

The results corroborated the conclusions of Tao and Lei [51], who observed that the use of SRA diminishes the 28-day compressive strength of concrete. However, it effectively mitigates concrete shrinkage and enhances the overall performance of the concrete mixture. Considering that the concrete mixture meets the technical standards, the optimal dose of the shrinkage-reducing agent is 1.5%. This dosage results in a shrinkage rate of 1 for the concrete mixture after 28 days.

Oliveira, et al. [39] discovered that the use of SRAs has a notable impact on decreasing concrete shrinkage. However, their tests revealed that incorporating this material leads to a reduction in the compressive strength of the concrete [55,56,57]. The strength-depleting impact of SRA material is more pronounced in the early phases and diminishes over time. Nevertheless, the inclusion of SRA in concrete results in a reduced compressive strength compared to concrete without SRA, even when subjected to identical conditions [60,61].

The use of a shrinkage reduction agent resulted in a more pronounced decrease in the strength of the concrete. Furthermore, when the amount of the agent increased, the fall became even more serious. The initial decline in strength exceeded 10%, and the negative effects continued to worsen with age without any improvement. When the maintenance period reached 90 days, the concrete's compressive strength decreased by 18.4%, and its flexural strength decreased by 12.5% when a 0.5% SRA was used. This mostly arose from two factors [52].

The compressive strength was reduced by 20.8, 31.2, and 41.0%, respectively, while the 28-day compressive strength declined by 18.9, 28.6, and 37.1%, respectively, as the dosage of SRA was increased from 0.0 to 2.0% when comparing the curing duration of 3 to 28 days [61].

5.3.2 Effect of Mineral Admixture type on compressive strength

To study the effect of silica fume source. Concrete mixes were cast using two different sources of silica fume. Two concrete mixes were cast for each cement type, and the results were illustrated in figure23.

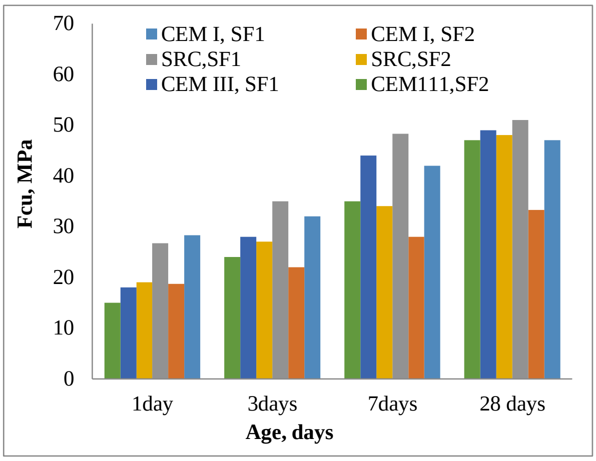

Figure 22. Effect of silica fume source on compressive strength

Figure 22 showed relation between the age and the early strength of self-compacting concrete compressive strength at 1, 3, 7,and 28 days. It was found that silica fume source 1 was the best. Using silica fume source 2 leads to a decrease in compressive strength of about 51.3%, 31.25%, 33.3%, 29.3% , respectively at concrete ages of 1,3,7, and 28 days for CEM I concrete.

According to the concrete cast with SRC, there were reductions in compressive strength at different ages.a 8%, 22.89%,29.6% and 29% at 1,3,7, and 28-day, respectively.

CEM III concrete compressive strength decreased by 28.7%, 14.3%, 20.4% and 4% at 1,3,7, and 28 days, respectively. The lowest decrement was in CEM III concretes.

Silica fume can significantly reduce the shrinkage of concrete. The ultra fine particles of silica fume can effectively fill in the spaces between cement particles, reducing the amount of free water and thereby limiting shrinkage [62,63,64].

Saif,M. S. et al found that adding silica fume by 10% as cement replacement can be classified as as excellent concrete even after exposure to 300 °C[65].

5.2.4 Effect of HRWR type on compressive strength

Two types of HRWR were used in casting early strength self-compacting concrete mixes with three types of cement. Figure illustrates the results.

According to CEM I early strength self-compacting concrete, type G 1 was better than Type G2. Changing type G1 to type G2 decreased the compressive strength by 15.7 % and 10% at concrete age of 7 and 28 days.

In SRC and CEM III concretes: type G 2 was better than Type G1 at 28 days. While at 1,3, and 7 days, the compressive strength was better in Type G1. The difference in compressive strength values was about 10%.

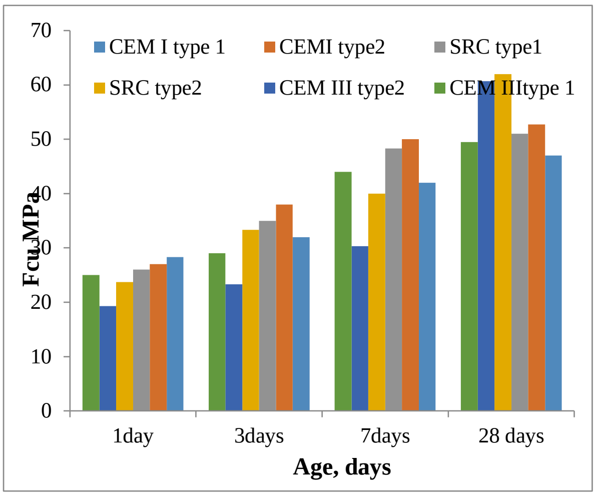

Figure 23. Effect of type G on compressive strength

Rizzuto,et al found that using self curing admixtures affects the slump flow test of self compacting concrete [43].

An experimental study was conducted on the influence of SI admixtures (SIA) on the mechanical properties of fresh and hardened concrete if SI is used in combination with different chemical additives in concrete mixes cast with three different cement types.

6 .CONCLUSIONS

From this study program, research outcomes may be derived.

1-According to effect of cement used:

A -CEM III has the largest slump flow diameter, while sulphate-resistant cement SRC gives the least diameter.

Sulfate- resistant cement has the highest T50 value, while high-blast cement CEM III has the lowest T50 value.

B-Using high-blast cement decreased the values of compressive strength at 1,3,7, and 28 days by 11%, 12%, 12%, and 3%, respectively, compared to ordinary Portland cement CEM I52.2.

C-Comparing the compressive strength of CEM I 52.5 by 5 concrete cast with sulfate-resistant cement showed a 6% reduction in 28-day compressive strength.

2-According to shrinkage inhibitors content

D-Increasing SIA leads to an increase in slump flow diameter, and T50 decreases.
E- The results indicate that the compressive strength of early strength self-compacting concrete decreases with an increase in the dosage of SRA.
F- SIA content 1.25liter/m^3 decreased compressive strength by 5%.12.5%,13%, and 11% at concrete age 1,3,7,28 days.
I- Adding SIA content of 2.5 liter/m^{3}decreased the compressive strength values by 15%,17%, 25%, 20% at concrete ages of 1,3,7,28 days.

3-According to silica fume source
J-Silica fume source 1 gives higher slump flow diameter compared to silica fume source2. K-Silica fume source 1 gives higher compressive strength values at concrete age 1,3,7 days. While silica fume source 2 has higher compressive strength values at 28 days.

4-According to HRWR sources
K-concrete cast with Type G source 1 has low slump flow diameter compared to concretes with source2.

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