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MECHANICAL AND TIME-DEPENDENT BEHAVIOR OF FIBER REINFORCED SELF-COMPACTED CONCRETE

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ملخص البحث

يهدف هذا البحث إلى دراسة لسلوك الانكماش اللدن والجاف للخرسانة ذاتية الدمك المسلحة بالألياف. لدراسة هذا الهدف تم استخدام نوعين من الأسمنت (الأسمنت البورتلاندى العادى وأسمنت الحجر الجيرى). تم استخدام نوعين من الألياف (ألياف الصلب والألياف البولي بروبلين). وقد تم استخدام الياف الصلب بنسب (٠,٥، ٠,٧٥ ٠,٢ %) من الحجم الكلى للخرسانة. كما تم استخدام ألياف البولي بروبلين بنسب (٠,٠٥، ٠,٢ ٠,١ %) من الحجم الكلى للخرسانة. تم دراسة الظروف المناخية المحيطة بالخرسانة وتأثيرها على الانكماش اللدن والجاف لهذا النوع من الخرسانة. كما تم دراسة الخواص الميكانيكية ومقاومة الضغط - مقاومة الشد- معايير المرونة).

ABSTRACT

This research was conducted to evaluate the shrinkage behavior of fiber Self-Compacting Concrete (SCC) mixes. As the cement content in SCC mixes is usually high compared to normal concrete, the shrinkage is usually higher and the resistance against the development of induced cracks tends to be lower. The investigated mixes were fiber-reinforced utilizing steel and polypropylene fibers. The main parameters taken into consideration were the cement type, fiber type, volume fraction of fibers and different exposure conditions. Three types of fibers were used including hooked end steel fibers, cramped steel fibers and polypropylene fibers. The properties of fresh SCC were evaluated in terms of the slump, J-ring and V-funnel tests. The mechanical properties including the compression, splitting tensile, flexural strength as well as the modulus of elasticity were measured. Also; the time-dependent deformations in terms of plastic and dry shrinkage were evaluated.

Keywords: Self-compacting Concrete, Plastic Shrinkage, dry shrinkage, Fibers, Mechanical Properties.

1. Introductions

Cement-based materials are the most abundant of all man-made materials and are among the most important construction materials. It is most likely that they will continue to have the same importance in the future. However, such traditional construction and engineering materials are needed to meet new and higher demands. When facing issues of productivity, economy, quality and environment, they have to comply with other construction materials such as plastic, steel and wood. One of the recent advances in concrete technology is the evolution of SCC. Self-compacted concrete is a new category of concrete that, without additional compaction energy, flows and consolidates under the influence of its own weight [1]. The use of SCC offers a basis for more industrialized production. Not only will it reduce the unhealthy tasks for workers, it can also reduce the technical costs of in situ cast concrete, due to the improved casting cycle, quality, durability, surface finish, increased reliability of concrete structures and eliminating some of the potential human errors. However, SCC mixes are sensitive, strongly dependent on the composition and the characteristics of the constituents SCC mixes should possess the incompatible properties of high flow ability together with high segregation resistance. This balance is made possible by the dispersing effect of high-range water reducing admixtures combined with the cohesiveness produced by the high concentration of fine particles in additional filler material [2]. The main mechanisms controlling this fine balance are related to surface physics and chemistry, hence, SCC is strongly dependent on the activity of the admixture, as well as on the large surface area generated by the high content of fines [3]. Since the ratio of surface area to volume increases exponentially with particle irregularity and decreased size, this area has a predominant effect on fresh and hardened concrete [4 - 7]. In almost all reinforced concrete structures, concrete is subjected to sustained stresses, and the load-dependent strains, as well as shrinkage strains, has profound effects on the structural behavior. The consequences are the excessive deflection of the structural members, wide cracks in the concrete subjected to tensile stresses and redistribution of stresses with time. Moreover, the complexity of structures and their size have continued to increase, and this has resulted in a greater importance of their strain characteristics and deformation. The reinforced concrete designers possibly encounter far more problems. They need to know the creep and shrinkage properties of concrete and must be able to consider them in the analysis of concrete structures. Usually, shrinkage occurs simultaneously with creep, which is defined as deformation occurring under a constant sustained stress [8]. The common practice for many years has been to consider these two phenomena to be additive. The overall increase in strain of a stressed and drying member is thus assumed to consist of plastic shrinkage and creep. This approach is simple and suitable for the many practical applications where creep and shrinkage occur together. In fact, they are not independent and the principle of superposition cannot be applied [8, 9]. Previous studies have also examined the shrinkage of cement-limestone blends. While Bucher et al. [10] concluded that the fineness of the limestone influenced the shrinkage and stress, it should be noted that the systems evaluated consisted of cement with 10% additions of limestone of various sizes. As such, the cement-limestone blends were not interground and were not designed to have similar performance like those typical of Portland Lime Stone Cements (PLCs) and those used in the present study. When interground PLC mortar systems were evaluated, [11], and it was found that PLC systems were had similar or slightly less shrinkage than the Ordinary Portland Cement (OPC) systems. The PLC systems also had no increased tendency to crack. The purpose of the current study is to continue this work and investigate the shrinkage of interground PLCs containing up to 15% limestone and to better understand why these engineered PLCs do not appear to exhibit increased shrinkage with increased Blaine fineness [11]. In this study, the effect of adding randomly distributed short fibers to improve the shrinkage and toughness of cementitious matrices of SCC by preventing or controlling the initiation and propagation of cracks was studied. Twenty self compacting concrete mixtures were designed. Three types of fibers were used. Hooked end steel, cramped steel and polypropylene fibers were applied. Fly ash is used as mineral addition in order to achieve high powder content. Fresh properties of SCC were investigated (slump flow, viscosity and plastic shrinkage). In addition, the mechanical properties of the different mixes were tested (compressive strength, splitting tensile strength, flexural strength, elastic modulus and drying shrinkage).

2. Experimental program

To achieve the aim of the research, twenty mixes were prepared from FSCC. Two types of cement (Portland cement and lime stone cement) were used. Two types of steel fibers (cramped and hooked end) were used with different volume fractions of 0.2, 0.75 and 1 %. Polypropylene fibers were used at 0.05, 0.1 and 0.2 % volume fraction. A total of 60 cylinders of 200 mm height and 100 mm diameter were tested in the fresh state to examine the plastic shrinkage of FSCC. A total of 120 cubes 100×100×100 mm were tested to determine the compressive strength of the mixes at 7 and 28 days. A total of 180 cylinders of 300 mm height and 150 mm diameter were tested to determine the indirect tensile strength and modules of elasticity at 28 days. A total of 60 prisms 70×70×300 mm were tested to determine the drying shrinkage of hardened concrete.

2.1 Materials

Two types of cement were used; ordinary portland cement (CEM I 42.5 N) and portland limestone cement (CEM II/B-L 32.5 N). Ordinary portland cement conformed with the requirements of E.S.S. **4765-1/2009** [12] with a specific gravity of 3.16 and Blain fineness of 3994 cm^2/gm. Portland limestone cement conformed also with the requirements of E.S.S. **4765-1/2009** [12] with specific gravity of 3.15 and Blain fineness of 4850cm^2/gm. Crushed dolomite was used as a coarse aggregate with a maximum nominal size of 12 mm, a specific gravity of 2.75, absorption of 2.1% and a crushing modulus of 18.5%. Well, graded siliceous sand was used with a specific gravity of 2.60, absorption of 0.81%, and a fineness modulus of 2.55. Class (F) flay ash meeting the requirements of ASTM C618 [13] with a specific gravity of 2.1 was used. The cement content was 400 kg/m^3 in all mixes and the water per binder (flay ash+ cement) ratio (w/b) was 0.4. Tap water was used for mixing the concrete. A high range water reducer (HRWR) was used as superplasticizer meeting the requirements of ASTM C494 (type A and F) [14]. The admixture is a brown liquid having a density of 1.18 kg/liter at room temperature. The amount of HRWR was 1.5% of the binder (flay ash + cement) weight. The steel fibers used were either hooked end or cramped with a length of 25 mm, 1 mm in diameter and 7.85g/cm^3 density. The polypropylene fibers were fibrillated with 15 mm length and 0.9 g/cm^3 density.

2.2 Casting and testing procedures

Cement and both coarse and fine aggregate were mixed for one minute then, the slurry of water, fly ash, and HRWR was added and mixing continued for four minutes to ensure full mixing. The properties of fresh self-compacted concrete were determined by different methods that included the slump, V-funnel and J-ring tests. For examining the effect of test variables on the plastic shrinkage of FSCC, plastic shrinkage tests commenced 15 min after water was first added to the mix. The early-age deformation of fresh concrete was measured by means of an optical apparatus, which is shown schematically in Figures (1 and 2). The details of the apparatus calibration method and procedure for the test were in accordance to ASTM C 827-82[15]. During the tests, the measurements were recorded at regular intervals of time; the final reading was taken 240 min after starting the test. The test samples were left in the moulds to harden overnight and a final measurement was taken 24h after casting. The deformations were converted to shrinkage strain using the expression: $\varepsilon = X/ML$ Where: ε = plastic shrinkage strain, X = deformation (mm), M = magnification factor and L = height of the specimen (200 mm).

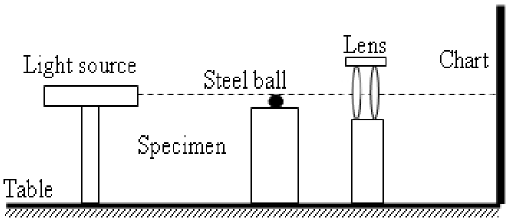


Figure [1] layout of plastic shrinkage apparatus

Figure [2] apparatus for measuring plastic shrinkage

Testing of FSCC drying shrinkage was carried out according to ASTM C 157 [16]. Three Prismatic specimens of 70×70×300 mm were prepared for each mixture. As the length of the specimen was much larger than the cross-sectional dimensions, then shrinkage was assumed to take place only in the longitudinal direction. The measurement of shrinkage with time can then provide a measure of one–dimensional shrinkage of the tested material. A mechanical gage was used to measure the change in the length of the test specimens at proper time intervals. Figure (3) shows the apparatus of drying shrinkage measurement.

Figure [3] apparatus for measuring dry shrinkage

The shrinkage at Time (t) is calculated by the following equation:

Drying shrinkage $=\Delta L/ L_o$; Where: ΔL is the measured change in the length and Lo is the original length measured at the start of measurements.

After 24 hours of casting, the specimens were removed from the molds and submerged in water at 20°C until testing. A 2000 KN capacity compressive strength testing machine was used to determine of the compressive strength and splitting tensile strength and modules of elasticity. Mixes features are reported in Table (1). In this table, mixture code gives information on the component of the mixes in the concrete. Test specimens were designated by letter C1 or C2 for type of cement used (C1: for cement CEMI 42.5 N) (C2: for cement CEMII/B-L 32.5 N) followed by (H): hooked fibers, (C) for cramped fibers and (P) polypropylene fibers. The basic requirements of flow ability of FSCC are specified by local technical specification for SCC [17].

Table (1): Mix proportions by weights (Kg/m^3)

Type of cement	Mix code	Vf %*	Cement	Sand	Dolomite	F.A	HRWR	W
Portland cement (CEM I 42.5 N)	C1	0	400	996	871	٤٠	6	160
	C1H1	0.75		940	770			
	C1H2	0.5		924	758			
	C1H3	0.2		973	798			
	C1CR1	0.75		940	770			
	C1CR2	0.5		924	758			
	C1CR3	0.2		973	798			
	C1P1	0.2		993	815			
	C1P2	0.1		995	816			
	C1P3	0.05		995	815			
limestone cement (CEM II/B-L 32.5 N).	C2	0	400	996	871	40	6	160
	C2H1	0.75		940	770			
	C2H2	0.5		924	758			
	C2H3	0.2		973	798			
	C2CR1	0.75		940	770			
	C2CR2	0.5		924	758			
	C2CR3	0.2		973	798			
	C2P1	0.2		993	815			
	C2P2	0.1		995	816			
	C2P3	0.05		995	815			

C1: CEMI 42.5 N C2: CEMII/B-L 32.5 N H: hooked steel fibers CR: cramped steel fibers P: polypropylene fibers (*) Fiber volume fraction F.A.: Fly ash

Table (2): Properties of fresh concrete.

Type of cement	Mix code	Vf %*	result of fresh properties						
			Slump test			J- Ring		V-Funnel	
			$D_{ave.}$ (mm)	T (sec)	T_{50}	$D_{avr.}$ (mm)	H_{in}-H_{out} (cm)	T. (sec)	velocity (mm/sec)
Portland cement (CEM I 42.5 N)	C1	0	780	6.35	3	730	0.4	6.5	10
	C1H1	0.75	680	7.50	3.5	650	0.7	9.2	7.065
	C1H2	0.5	730	7.25	3.25	680	0.6	8	8.125
	C1H3	0.2	750	7.08	3.15	700	0.5	7.3	8.904
	C1CR1	0.75	650	7.45	4	650	0.8	10	6.5
	C1CR2	0.5	750	7.30	3.5	690	0.6	8.5	7.647
	C1CR3	0.2	770	6.55	3.45	710	0.5	7.2	9.027
	C1P1	0.2	700	7.45	3.2	690	0.8	9.1	7.142
	C1P2	0.1	730	7.1	3.05	700	0.6	8.3	7.831
	C1P3	0.05	750	6.55	2.50	730	0.5	7.4	8.78
limestone cement (CEM II/B-L 32.5 N).	C2	0	750	6.25	2.5	750	0.5	6.5	10
	C2H1	0.75	650	8.37	3.25	650	0.8	10.3	6.310
	C2H2	0.5	700	7.40	3.11	700	0.7	10	6.5
	C2H3	0.2	730	6.35	2.35	720	0.6	8.3	7.831
	C2CR1	0.75	660	8.45	3.2	660	0.8	11	5.909
	C2CR2	0.5	690	8.2	3.05	690	0.75	9.5	6.842
	C2CR3	0.2	720	6.5	2.5	710	0.6	7.5	8.67
	C2P1	0.2	690	7.5	2.50	670	0.75	10.4	6.25
	C2P2	0.1	720	6.5	2.45	690	0.6	8.4	7.73
	C2P3	0.05	750	6.25	2.35	720	0.5	6.25	10.4

C1: CEMI 42.5 N C2: CEMII/B-L 32.5 N H: hooked steel fibers CR: cramped steel fibers P: polypropylene fibers (*) Fiber volume fraction

3. RESULTS AND DISCUSSIONS
3.1 FRESH CONCRETE
Table (1) summarizes the results of testing the properties of fresh SCC mixes. The slump flow ranged from 650 to 780 mm for all mixes. The effect of fiber inclusion on the flow ability of SCC was noticed in decreasing the final diameter compared with that of the control mix. The T_{50} value ranged from 2.5 to 3 seconds for the mixes without fibers and from 2.5 to 4 seconds for those with fibers. The results show that, the fibers have noticeable effect in restricting the flow of FSCC concrete. Figure (4) shows the slump flow diameter of SCC mixtures. The original application of the ring test was in conjunction with the slump flow. However, this combination provides a much more powerful tool for the assessment of the fresh properties of fiber self-compacting concrete. For the concrete mixes containing fibers, the difference between the height of the concrete inside and outside the j- Ring was 0.8 cm. While the difference was only 0.45 cm for those without fibers. Both Types of fibers, steel and polypropylene, seem to have a regular influence on the blocking criteria of SCC. The basic requirements of flow ability were specified by technical specification for SCC [18].

3.1.1 Effect of the cement type on the properties of fresh FSCC

Figures (4 to 9) show the effect of the cement type on the flow diameter of the different mixes. It is noticed that the mixes cast with ordinary Portland cement are more flowable than those with limestone cement by 4% in term of the flow diameter. The effects of percentage of fiber volume fraction are illustrated in Figures (4 to 9). As shown in these figures, the flow diameter decreases as the percentage of volume fraction increased. For example, the mixes cast with ordinary Portland cement and hooked steel fiber had a flow diameter that ranged from 680 to 750 mm. The percentage of reduction ranged from 4 % to 14%. The percentage of reduction for the mixes with polypropylene fibers and the ordinary Portland cement ranged from 4% to 10%. The percentage of reduction for the mixes with cramped steel fibers and the ordinary Portland cement ranged from 4% to 17%.

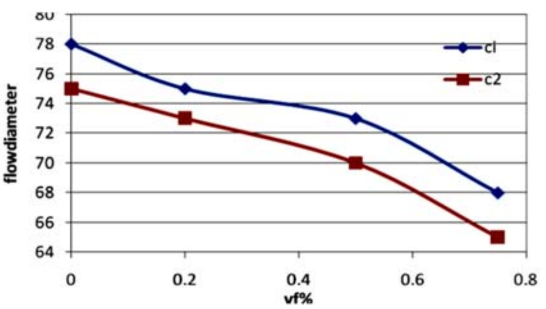


Figure (4) relationship between volume fraction of hooked end steel fiber and the flow diameter using different types of cement.

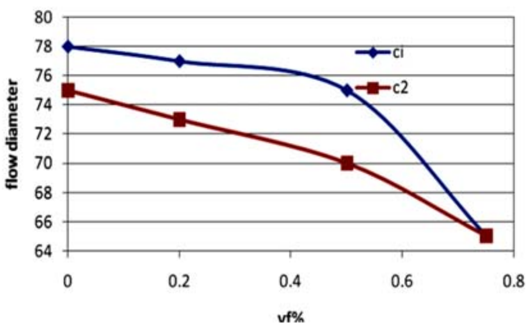


Figure (5) relationship between volume fraction of cramped steel fiber and flow diameter using different types of cement.

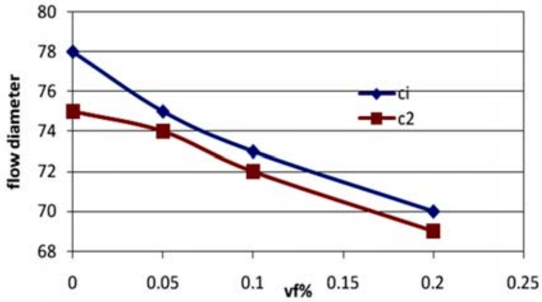


Figure (6) relationship between the volume fraction of polypropylene fiber and the flow diameter using different types of cement.

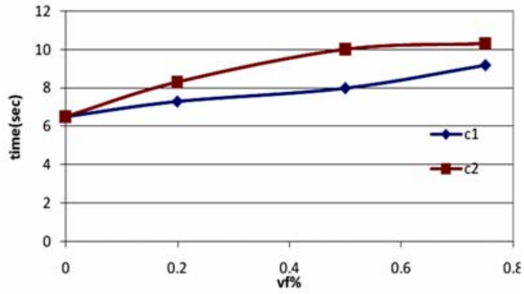


Figure (7) effect of type of cement 0f mixes with different ratio of Vf% on the time 0f V-Funnel Test for hooked end steel fiber..

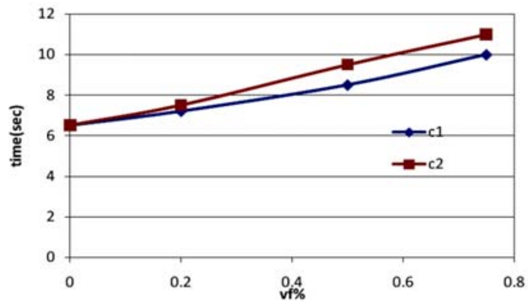


Figure (8) effect of type of cement 0f mixes with different ratio of VF% on the time 0f V-Funnel Test for cramped steel fiber.

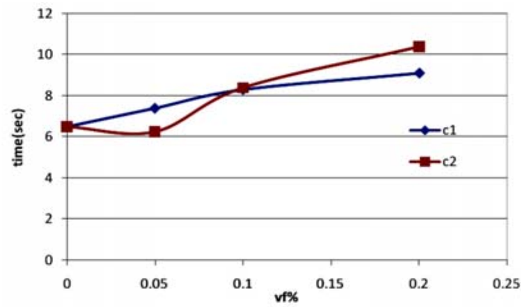


Figure (9) effect of type of cement 0f mixes with different ratio of vf% on the time 0f V-Funnel Test for polypropylene

3.1.2 Effect of the fibers type on the properties of fresh FSCC

Figures (10 to 13) show the relation between the volume fraction for different types of fibers and the flow diameter. These figures indicate that the flow diameter for the mixes containing cramped steel fibers is larger than the flow diameter of the mixes with hooked steel fibers and those with polypropylene fibers. For examples; at 0.05 V_f the flow diameters were (770, 780 and 750 mm) for the mixes with hooked end steel fibers, cramped steel fibers and polypropylene fibers, respectively. These values were decreased by (1 %, 3.8%, and 10.2%), respectively from the control mix when using ordinary portland cement as shown in Figure (12). In Figure (11), it can be seen that the flow diameter were (720, 710 and 690 mm) at 0.2 V_f for the mixes with hooked end steel fibers, cramped steel fibers and polypropylene fibers, respectively. These values were decreased by (4 %, 5.3%, and 10.6%), respectively from the control mix when using lime stone cement. At 0.75% V_f the flow diameter decreases by (12% and 16.6%) for hooked end steel fibers and cramped steel fibers, respectively compared the control mix with ordinary Portland cement. At 0.75% V_f the flow diameter decreases by (13%, 12%) for hooked end steel fibers and cramped steel fibers, respectively compared the control mix with ordinary limestone cement. Similar trends were observed from the J-Rring test results as illustrate in Figures (12 and 13) and for V-funnel test results in Figures (14 and 15).

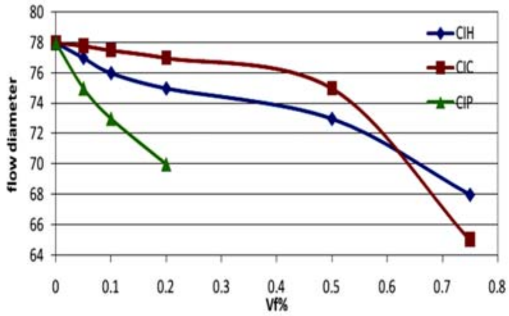


Figure (10) relationship between the volume fraction of fiber and the flow diameter for the mixes using ordinary Portland cement.

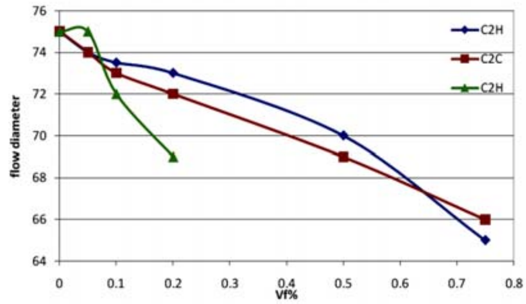


Figure (11) relationship between the volume fraction of fiber and the flow diameter using lime stone cement.

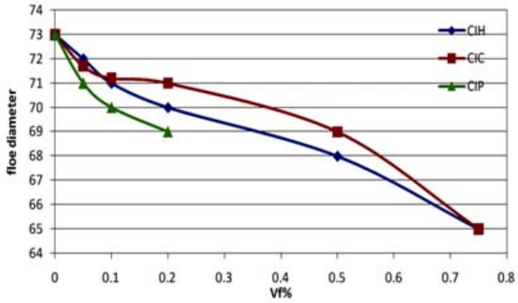


Figure (12) relationship between volume fractions of different types of fibers and the flow diameter of J-Ring test using ordinary Portland cement.

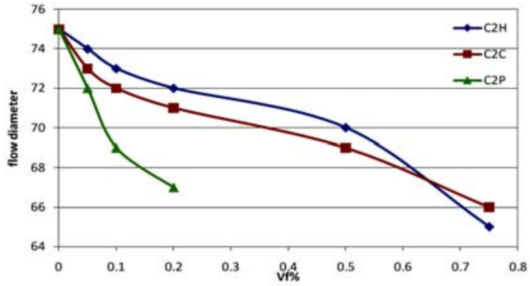


Figure (13) relationship between the volume fraction of fiber and the flow diameter for J-Ring test using lime stone cement

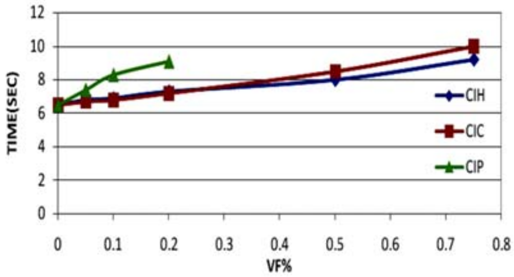


Figure (14) effect of type of fiber with different ratio of VF% on the time 0f V-Funnel test using ordinary Portland cement.

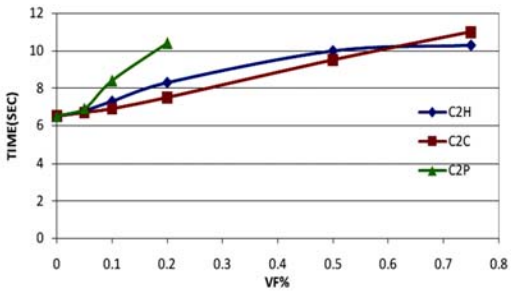


Figure (15) effect of type of fiber with different ratio of VF% on the time 0f V-Funnel test using lime stone cement.

3.1.3 Effect of cement type on the plastic shrinkage

Figure (16) shows the relationship between the plastic shrinkage and time for the control mixes tested in the laboratory at 58% relative humidity. This figure illustrates that the plastic shrinkage for the C1 mixes is more than the plastic shrinkage for the corresponding C2 mixes. For example, the shrinkage for C1 was 0.00148 mm after one hour and the shrinkage for the mix with C2 was 0.00075 mm. Thus, the reduction in the plastic shrinkage for the C2 mix compared with that of C1 mix was 49 %. After 24 hours, the reduction in the plastic shrinkage for the mix C2 is less than that mix of C1 by 7%.

This result is supported by a previous study conducted by Timothy Barrett [19]. The reasons for the difference in the plastic shrinkage is attributed to the interground materials in limestone cement are slightly finer that the ordinary cement. Also, limestone cement has fewer particles above 30 microns in size [19-20].

3.1.4 Effect of fiber types on the plastic shrinkage

Figures (17 to 19) show the relationship between the plastic shrinkage and elapsed time for the different mixes containing different types of fibers with the same percentage of volume fraction compared to the control mixes without fibers. Figure (19) shows that the plastic shrinkage of the mixes with polypropylene fibers was more than the plastic shrinkage for those with hooked end and cramped circular section steel fiber at 0.2% V_f. It was noticed that, the plastic shrinkage wasn't improved at this percentage of all types of fiber compared to the control mix with ordinary Portland cement. Generally, the plastic shrinkage for the mixes with these percentage polyproblen fibers was larger than that of the control mix. For example, the plastic shrinkage at one hour for the mix with polypropylene fiber was equal to 0.00185 mm, while the shrinkage for the mix with hooked end and crimped circular section steel fiber was 0. 0.0011, 0.0014 mm; respectively. The maximum plastic shrinkage was 0.00281, 0.00248, and 0.00252 mm for the mixes with polypropylene, hooked end and crimped steel fibers; respectively. The maximum plastic shrinkage for the mixes with polypropylene fiber increased by 4%, while the maximum plastic shrinkage for the mixes with hooked end steel fiber and cramped steel fiber was decreased by 8.15% and 6.7%; respectively. The plastic shrinkage of the mix with crimped steel fibers and hooked end steel fibers was improving compared to the control mix, while it didn’t improve due to the polypropylene fibers. For example, at 0.2 % Vf, the plastic shrinkage at one hour for the mix with polypropylene fiber, was 0.0016 mm; while the shrinkage of that with hooked end and crimped circular section steel fibers was 0.00054 and 0.00135 mm, respectively. The maximum plastic shrinkage for the mixes with cramped steel and hooked steel fiber decreased by 0% and 8%, respectively while the maximum plastic shrinkage for the mixes with polypropylene fibers was increased by 10% compared to the control mix with lime stone cement.

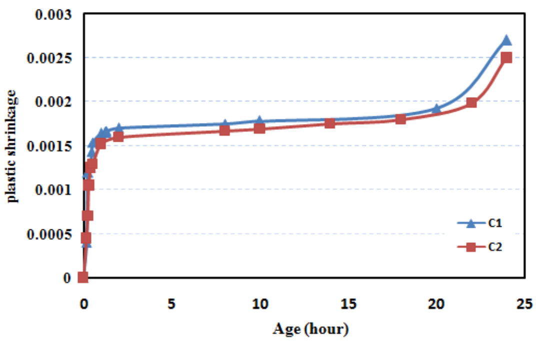


Figure (16) relationship between plastic shrinkage and ages (hours) for control mixes.

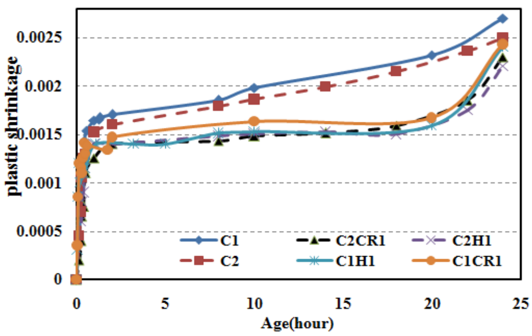


Figure (17) relationship between plastic shrinkage and ages (hour) for mixes with 0.75 % volume fraction for different types of steel

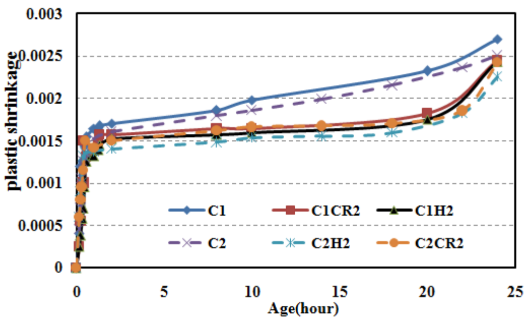


Figure (18) relationship between plastic shrinkage and ages (hour) for mixes with 0.5 % volume fraction for different types of steel fiber

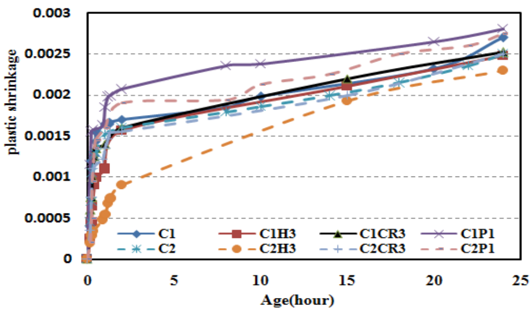


Figure (19) relationship between plastic shrinkage and ages (hour) for mixes with 0.2 % volume fraction for different types of fiber.

3.1.5 Effect of fiber volume fraction on plastic shrinkage

Figure (20) shows the relationship between the max plastic shrinkage and elapsed time for the different mixes containing different types and values of Vf using ordinary Portland cement and limestone cement. It can be seen that as the volume fraction increase the plastic shrinkage decreased. The plastic shrinkage for the mix containing hooked steel fibers at 0.75 Vf is less than the plastic shrinkage for mix with 0.5 Vf and 0.2 Vf. The maximum plastic shrinkage for the mixes with 0.75, 0.5 and 0.2 Vf decreased by 10%, 9.3% and 8%, of the control mix respectively. The same results were noticed for the cramped steel fibers. The maxmum plastic shrinkage for the mixes with 0.75, 0.5 and 0.2 Vf decreased by 10%, 9.3% and 6.7%, of the control mix respectively. The plastic shrinkage for the mixes with polypropylene is more than the plastic shrinkage for control mix. On the other hand the plastic shrinkage decreased as the volume fraction increase. The maximum plastic shrinkage for the mixes with 0.2, 0.1 and 0.05 Vf increased by 4%, 18.5% and 33.3%, of the control mix respectively.

The relationship between the maximum plastic shrinkage and the elapsed time for different mixes containing different fiber contents using limestone cement was showed in the same figure. It can be seen that the plastic shrinkage decreases as the fiber volume fraction increased. The plastic shrinkage for the mixes with polypropylene more than the plastic shrinkage for control mix. It is noticed that, the plastic shrinkage didn’t improved by using the polypropylene fiber compared to the control mix. The maximum plastic shrinkage for the mixes with 0.05Vf, 0.1Vf and 0.2Vf increased by 20%, 12% and 10%, respectively compared with the control mix.

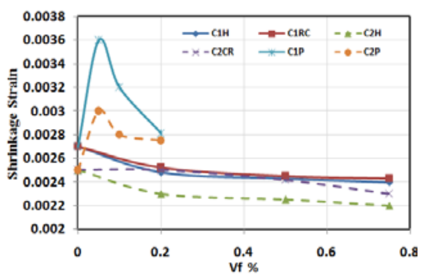


Figure (20) relation between maximum plastic shrinkage Strain and volume fraction percent for mixes with different types of fibers and cement.

3.2 Properties of hardened Fiber self-compacted concrete

From Tables 3 and 4: it was found that fiber addition has a slight effect on the properties of hardened FSCC.

Table [3] Strength results of the mixes with ordinary Portland cement

Mix code	CI	C1H1	C1H2	C1H3	C1CR1	C1CR2	C1CR3	C1P1	C1P2	C1P3
Compressive strength (MPa)	45.0	48.0	49.0	48.0	45.0	44.5	44.0	49.0	49.0	47.0
Indirect tensile strength (MPa)	8.0	8.0	11.0	7.0	10.0	8.0	8.0	10.0	8.0	8.0
Modulus of elasticity (MPa) *10^4	2.38	2.83	3.1	2.78	2.41	2.25	2.32	3.07	3.08	2.69

Table [4] Strength results of the mixes with limestone cement

Mix code	C 2	C2H1	C2H2	C2H3	C2CR1	C2CR2	C2CR3	C2P1	C2P2	C2P3
Compressive strength (MPa)	52.0	59.0	52.0	54.0	52.0	56.0	52.0	56.0	59.0	56.0
Indirect tensile strength (MPa)	8.0	8.0	12.0	9.0	7.0	9.0	8.0	7.0	9.0	7.0
Modulus of elasticity (MPa) *10^4	2.75	3.12	2.88	2.84	2.76	2.91	2.87	2.72	3.2	2.95

3.3 Drying shrinkage:

3.3.1 Effect of cement type:

Figure (21) illustrates the relationship between shrinkage strain and elapsed time for the control mixes at different weather conditions. Generally, the shrinkage strain for the mix with limestone cement is less than the shrinkage for ordinary Portland cement. For example, the shrinkage for the mix with limestone cement was 0.064 at 10 days, while the shrinkage for mix with ordinary Portland cement was 0.1226. On the other hands, the corresponding shrinkage measurements were 0.349 and 0.43 at 100 days. The maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.495 and 0.387 for OPC and L.C, respectively. However, these measurements were reducing to 0.447 and 0.3339, respectively by the end of the experimental at 320 days.

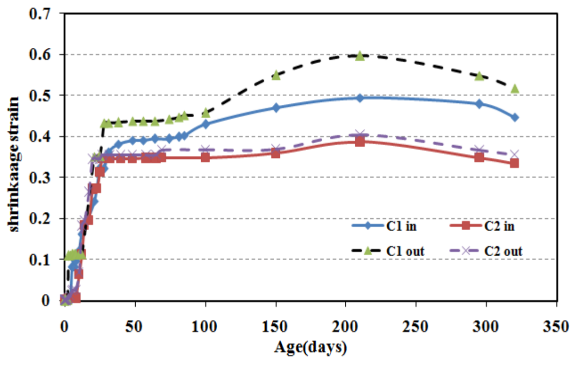


Figure (21) Relationship between shrinkage strain and ages for control mixes in air laboratory and atmosphere

3.3.3 Effect of fiber volume fraction

Figures (22 to 24) show the relationship between the shrinkage strains and elapsed time for different mixes containing different fiber percentage (Vf %) using ordinary Portland cement in the laboratory and open atmosphere. Using fibers decreased the drying shrinkage of the mixes compared to the control mix. As the volume fraction increase the dry shrinkage decreased. These results were supported by a previous study conducted by Özgür Eren; and Khaled Marar [21] and T. Aly et. al. [22] these results were noticed in the laboratory and open atmosphere. The effect of different volume fraction of hooked end steel fiber on the drying shrinkage compared to the control mix without fiber in the laboratory and open atmosphere was explained in Figure (24). The shrinkage strain was 0.00072, 0.0789 and 0.0012 at 10 days for mixes with 0.75, 0.5 and 0.2 Vf% respectively. On the other hands, the corresponding shrinkage measurements were 0.0371, 0.0801 and 0.379 for mixes with 0.75, 0.5 and 0.2 Vf% at 100 days. The maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.0399, 0.0815 and 0.462 for the mixes with 0.75, 0.5 and 0.2 Vf %, respectively. However, these measurements were reduced to 0.0327, 0.08 and 0.33, respectively by the end of the experimental at 320 days. The drying shrinkage for the mixes with 0.75 %, 0.5 % and 0.2 % Vf reduced by 26.2%, 82.1% and 92.6%, respectively compared to the control mix without fibers. These results were in the laboratory. The shrinkage strain was 0.0847, 0.0814 and 0.1344 at 10 days for mixes with 0.75, 0.5 and 0.2 Vf% respectively. On the other hands, the corresponding shrinkage measurements were 0.099, 0.0827 and 0.41 for mixes with 0.75, 0.5 and 0.2 Vf% at 100 days. The maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.112, 0.0832 and 0.4843 for the mixes with 0.75, 0.5 and 0.2 Vf %, respectively. However, these measurements were reduced to after that the shrinkage strain was reduced to 0.1, 0.0826 and 0.355, respectively by the end of the experimental at 320 days. The drying shrinkage for the mixes with 0.75 %, 0.5 % and 0.2 % Vf reduced by 31.5%, 82.1% and 80.7%, respectively compared to the control mix without fibers. These results were in open atmosphere. The same results were noticed and recorded for the cramped steel and polypropylene fibers.

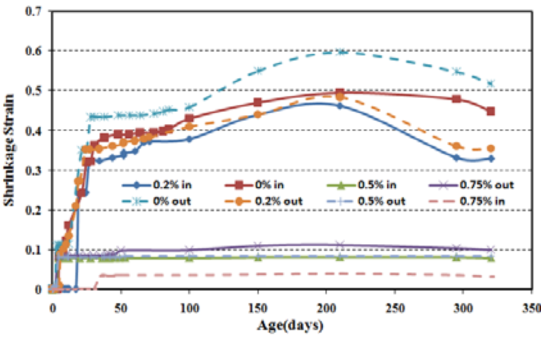


Figure (22) Relation between shrinkage strain and age for mixes with different fiber percentages for hooked end steel fiber using ordinary Portland cement.

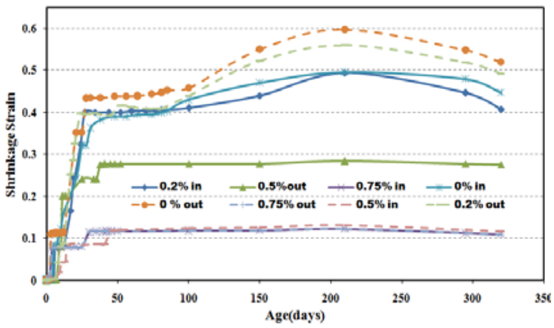


Figure (23) Relation between shrinkage strain and age for mixes with different fiber percentages for cramped steel fiber using ordinary Portland cement.

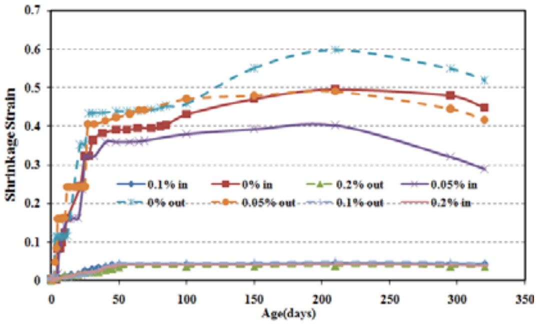


Figure (24) Relation between shrinkage strain and age for mixes with different fiber percentages for polypropylene fiber using ordinary Portland cement.

Figures (25 to 27) show the relationship between the shrinkage strains and elapsed time for different mixes containing different fiber percentages (Vf%) using limestone cement in the laboratory and open atmosphere. The use fibers decreased the drying shrinkage of the mixes compared to the control mix. These results were noticed in the laboratory and open atmosphere. The effect of different volume fraction of hooked steel fiber on the drying shrinkage compared to the control mix without fiber in the laboratory and open atmosphere was explained in Figure (25). This Figure shows that as the volume fraction increase the dry shrinkage decreased. The shrinkage strain was 0.003, 0.00376 and 0.00536 at 10 days for mixes with 0.75, 0.5 and 0.2 Vf%, respectively. On the other hands, the corresponding shrinkage measurements were 0.0045, 0.008and 0.048 for mixes with 0.75, 0.5 and 0.2 Vf % at 100 days. The maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.0051, 0.01 and 0.0511 for the mixes with 0.75, 0.5 and 0.2 Vf %, respectively. However, these measurements were reduced to after that the shrinkage strain was reduced to 0.0042, 0.009and 0.0468, respectively by the end of the experimental at 320 days. The drying shrinkage for the mix with 0.75%, 0.5% and 0.2% Vf reduced by 99%, 97.9% and 89.5%, respectively compared to the control mix without fibers. These results were in the laboratory. The shrinkage strain was 0.004, 0.0032 and 0.08292 at 10 days for mixes with 0.75, 0.5 and 0.2 Vf%, respectively. On the other hands, the corresponding shrinkage measurements were 0.0059, 0.0423and 0.127 for mixes with 0.75, 0.5 and 0.2 Vf % at 100 days. The maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.0069, 0.04364 and 0.1324 for the mixes with 0.75, 0.5 and 0.2 Vf %, respectively. However, these measurements were reduced to after that the shrinkage strain was reduced to 0.0053, 0.0368 and 0.126, respectively by the end of the experimental at 320 days. The drying shrinkage for the mix with 0.75%, 0.5% and 0.2% Vf reduced by 98.9%, 92.9% and 75.7%, respectively compared to the control mix without fibers. These results were in open atmosphere. The same results were noticed and recorded for the cramped steel and polypropylene fibers.

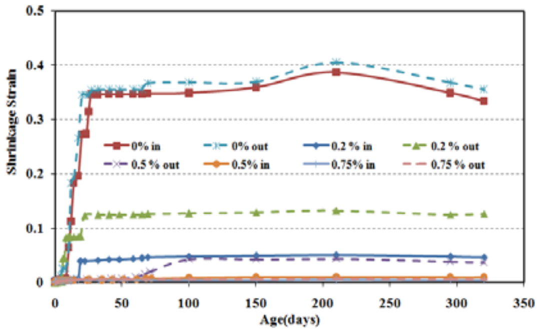


Figure (25) Relation between shrinkage strain and age for mixes with different fiber percentages for hooked steel fiber using limestone cement.

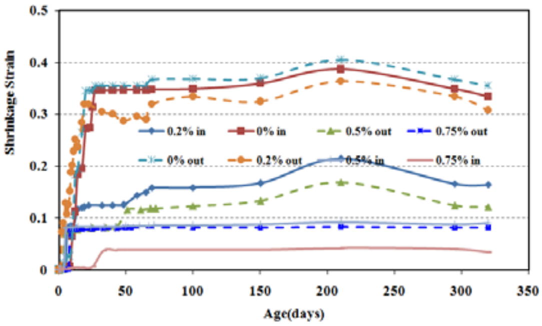


Figure (26) Relation between shrinkage strain and age for mixes with different fiber percentages for cramped steel fiber using limestone cement.

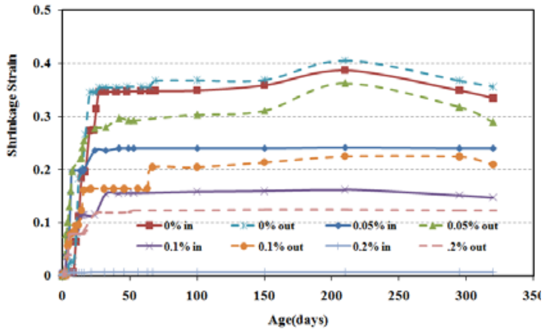


Figure (27) Relation between shrinkage strain and age for mixes with different fiber percentages for polypropylene fiber using limestone cement.

3.3.2 Effect of weather conditions

The effect of weather conditions on the shrinkage strain is shown in Figure (23). The Figure shows that the shrinkage strain for the mixes in the laboratory was less than the shrinkage strain in open atmosphere. For example, the shrinkage strain for the mix with limestone cement in the laboratory was 0.385 at 200 days. This value was less than the shrinkage strain for the mix in open atmosphere by 6.3 %. The change in the shrinkage strain occurred due to the change in the relative moisture content that changes from 34% to 45%, so the higher the relative moisture content caused, the lower the rate of shrinkage. Also, the lower temperature gradient caused the lower rate of shrinkage. The same observations were recorded for the mix with ordinary Portland cement. On the other hand, the effect of using fiber was shown in figures (22 to 24) for the mixes with ordinary Portland cement and figures (30 to 32) for the mixes with limestone cement. For example the shrinkage strain for the mix with 0.75 vf% cramped steel fiber with Portland cement in the laboratory was 0.0434 at 200 days as illustrated in figure (22). This value was less than the shrinkage strain for the mix in open atmosphere by 67.4 %. Also, the shrinkage strain for the mix with 0.75 vf % cramped steel fiber with limestone cement in the laboratory was 0.0398 at 200 days illustrated in figure (25). This value was less than the shrinkage strain for the mix in open atmosphere by 57.4%. The same trends were recorded for the mixes with different values of volume fraction. The change in the shrinkage strain occurred due to the change in the relative moisture content can be eliminated by using the fibers. For example, the maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.4951 for the control mix with ordinary Portland cement. However, these measurements were reduced to after that the shrinkage strain was reduced by 9.6 % by the end of the experimental at 320 days. On the other hand, the maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.0399 for the mixes with 0.75 Vf% hooked steel fibers. However, these measurements were reduced to after that the shrinkage strain was reduced by 18% by the end of the experimental at 320 days.

3.3.4 Influence of the fiber type

Figures (28 to 30) show the relationship between the shrinkage strains and elapsed time for different types of fibers at the same value of Vf% using ordinary Portland cement in the laboratory and open atmosphere. Using polyprobleen fibers decreased the drying shrinkage of the mixes more than steel fibers. Also, Using hooked steel fibers decreased the drying shrinkage compared to the cramped steel fibers. The results were noticed for the laboratory and open atmosphere conditions. For example; Figure (28) shows the relation between the drying shrinkage and ages at 0.2 % volume fraction for different types of fibers. The drying shrinkage for the mixes with hooked steel fiber was less than the drying shrinkage for mixes with cramped steel fibers. Also, the drying shrinkage for steel fibers mixes was less than the drying shrinkage of the control. The maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.4843 and 0.56 for the mixes with hooked steel fiber and cramped steel fibers, respectively. 13.5 percent decreasing in the max drying shrinkage strain for the mix with hooked steel fibers to cramped steel fibers mixes. However, these measurements were reduced to 0.355 and 0.491, respectively by the end of the experimental at 320 days. The same results were noticed and recorded in the open atmosphere. In Figures (28) the drying shrinkage for the mixes with polypropylene fibers was less than the drying shrinkage for the mixes with steel fibers. The maximum shrinkage strain was measured at 210 days and the shrinkage measurements were 0.372. However, the measurements were reduced to 0.348 by the end of the experimental at 320 days. 23.2 percent decreasing in the maximum drying shrinkage for the mixes with polypropylene fibers compared to the steel fibers mixes at 210 days. Also, 29.1 percent increasing in the shrinkage by the end of the experimental at 320 days. The same observations were recorded in the open atmosphere.

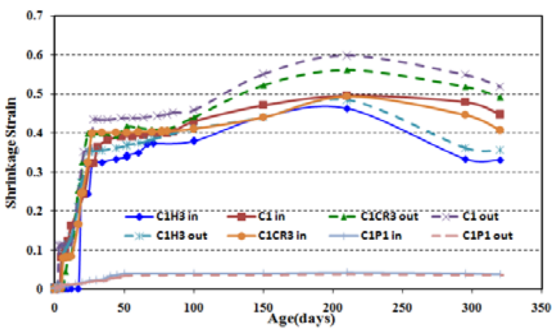


Figure (28) relation between shrinkage strain and age at 0.2 % volume fraction for different types of fibers using ordinary Portland cement.

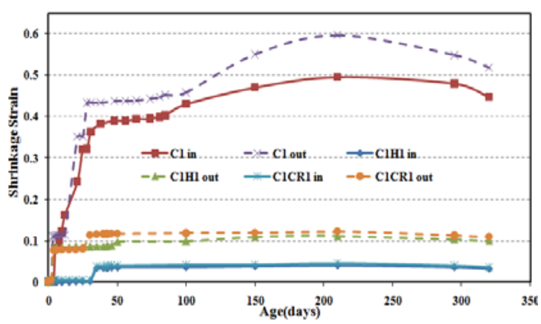


Figure (29) relation between shrinkage strain and age at 0.75 % volume fraction for different types of steel fibers using ordinary Portland cement.

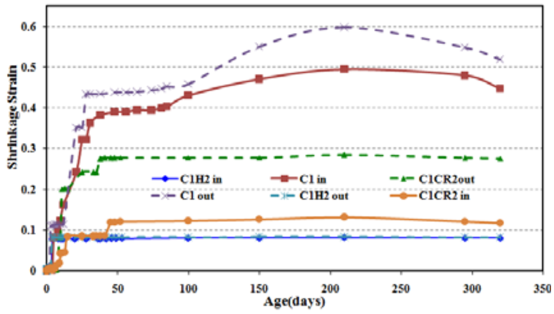
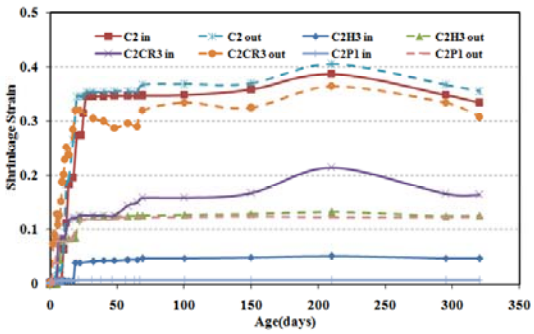


Figure (30) relation between shrinkage strain and ages at 0.5 % volume fraction for different types of steel fibers using ordinary Portland cement.

Figures (31 to 32) show the relationship between the shrinkage strains and elapsed time for different types of fibers at the same value of Vf % using limestone cement in the laboratory and open atmosphere. These figures show that using polypropylene fibers decreased the drying shrinkage of the mixes more than steel fibers. Also, using hooked steel fibers decrease the drying shrinkage more than cramped steel fibers. All types of fibers improved the drying shrinkage compared to the control mix. These results were noticed in the laboratory and open atmosphere conditions. For example; Figure (32) shows the relation between the drying shrinkage and age at 0.75% volume fraction for different types of steel fibers. The drying shrinkage for the mix with hooked steel fiber was less than the drying shrinkage for mix with cramped steel fibers. Also, the drying shrinkage for steel fibers mixes was less than the drying shrinkage of the control. The maximum shrinkage was measured at 210 days and the shrinkage measurements were 0.364 and 0.1342 for the mixes with cramped steel fibers and hooked steel fibers, respectively. However, these measurements were reduced to 0.308 and 0.126, respectively by the end of the experimental at 320 days. The same results were noticed in the open atmosphere. In Figure (31) the drying shrinkage for the mixes with polypropylene fibers was less than the drying shrinkage for the mixes with steel fibers. The maximum shrinkage strain was measured at 210 days and the shrinkage measurement was 0.1236. However this measurement was reduced to 0.1227 at the end of the experimental at 320 days. 66 percent was decreasing in the maximum drying shrinkage for the mix with polypropylene fibers compared to the steel fibers mix. Also, 60.2 percent decreasing in the shrinkage strain at the end of the experimental at 320 days. The same observations were recorded in open atmosphere.



. Figure (31) relation between shrinkage strain and age at 0.2 % volume fraction for different types of fibers using limestone cement.

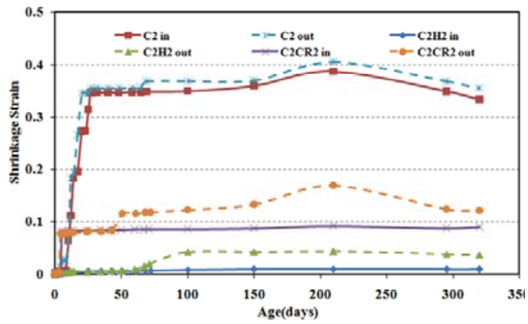


Figure (32) relation between shrinkage strain and ages at 0.5 % volume fraction for different types of steel fibers using limestone cement.

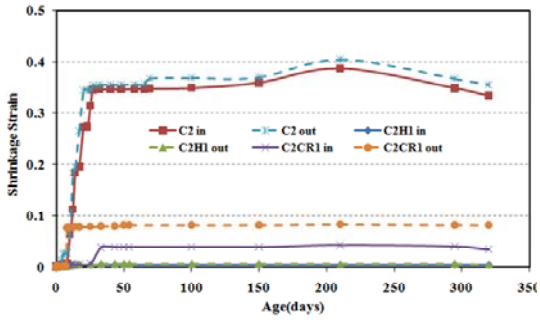


Figure (33) relation between shrinkage strain and age at 0.75 % volume fraction for different types of steel fibers using limestone cement.

3.5 CONCLUSIONS

The following conclusions could be drawn from the results of the research carried out to determine strength and shrinkage of self-compacting fiber reinforced concrete:

1- The mixes cast with ordinary Portland cement yielded higher flowability compared to similar mixes cast with limestone cement by 4% due to the higher finess of ordinary Portland cement.

2- The flow ability of the mixes was reduced due to the use of fibers. In case of Portland cement: the reduction in the flow diameter ranged from (4 % to 11%) for hooked steel fiber; (2.7% to 11%) for cramped steel fibers and (1% to 5.4%). for polypropylene fibers. In case of limestone cement; the reduction in the flow diameter ranged from (4 % to 13.3%) for hooked steel fibers, (5.3% to 12%) cramped steel fibers and (4% to 10.6%) for polypropylene fibers.

3- The plastic shrinkage for the mix with ordinary Portland cement was higher than that for similar mixes with limestone cement. The plastic shrinkage was lower by 7.4% for the mixes with limestone cement compared to the mixes with Portland cement.

4-The plastic shrinkage for the mixes with polypropylene was more than that for both control mixes with ordinary Portland cement and limestone cement. The maximum plastic shrinkage for the mixes with polypropylene fiber increased by 10% and 4 % compared with the control mix with limestone cement and Portland cement and without fibers, respectively.

5- The maximum plastic shrinkage for the mixes with hooked steel fiber and cramped steel fiber decreased by 11% and 10%, respectively compared with the control mix with ordinary Portland cement.

6- The maximum plastic shrinkage for the mixes with cramped steel and hooked steel fiber decreased by 8% and 12%, respectively compared the control mix with limestone cement.

7- The drying shrinkage increased up to 210 days after that the drying shrinkage decreased for all mixes. The average value of decreasing was 9.8% compared to maximum value of drying shrinkage for the mixes.

8- The max drying shrinkage for the mix with limestone cement decreased by 25% compared with the mix with ordinary Portland cement.

9- The max drying shrinkage in the laboratory was less than that in the open atmosphere by 13.7% and 6.0% for the mixes with ordinary Portland and limestone cement, respectively.

10- The use of fibers reduced the drying shrinkage compared to the control mix. Also the drying shrinkage decreased as the volume fraction increases. These results were noticed in the laboratory and open atmosphere.

11-Using poly probleen fibers decreased the drying shrinkage of the mixes more than using steel fibers for two types of cement. The max drying shrinkage for the mix with polypropylene fibers decreased by 91.4% and97.7% compared with the steel fibers mix with ordinary Portland cement and lime stone cement, respectively.

12- Using hooked steel fibers decreased the drying shrinkage more than cramped steel fibers. The max drying shrinkage for the mix with hooked steel fibers decreased by 8.9% and 87.8% compared with the mix with cramped steel fibers with ordinary Portland cement and limestone cement, respectively.

13- The change in the shrinkage strain occurred due to the change in the relative moisture content can be eliminated by using the fibers.

14-Slightly effect on the compressive strength was recorded.

15-Extensive applications could be achieved especially for liquid constrainers and prestressed elements duo to the plastic and dry shrinkage, which was reached by adding different types of fibers to the self-compacted concrete mixes.

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