Effect of internal curing on performance of self-compacting concrete by using sustainable materials

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Abstract. This paper is devoted to investigate the effect of internal curing technique on the properties of self-compacting concrete. In this study, self-compacting concrete is produced by using limestone powder as partial replacement by weight of cement with percentage of (5%), sand is partially replaced by volume with saturated fine lightweight aggregate which is thermostone aggregate as internal curing material in three percentages of (5%, 10%, 15%) for self-compacting concrete, and the use of two external curing conditions which are water and air. The experimental work was divided into three parts: in the first part, the workability tests of fresh self-compacting concrete were conducted. The second part included conducting compressive strength test and modulus of rupture test at ages of (7, 28 and 90) days. The third part included doing the shrinkage test at age of (7, 14, 21, 28) days. The results show that internally cured self-compacting concrete has the best workability and the best properties of hardened concrete which include (compressive strength, modulus of rupture) of externally cured self-compacting concrete with both water and air as compared with reference concretes. Also, the hardened properties of internally cured self-compacting concrete with percentage of (5%) with thermostone aggregate is the best as compared with that of percentages (10% and 15%) in both external curing conditions. In general, the results of shrinkage test have shown reduction in shrinkage of internally cured self-compacting concrete as compared with reference concretes and this reduction increases with increase in the thermostone aggregate content-within-self-compacting-concrete.

1 Introduction

Self-compacting concrete (SCC) is a type of concrete that gets compacted under its self-weight. It is commonly abbreviated as SCC and defined as the concrete that is capable of self-compacting and occupying all the spaces in the formwork without any vibration; purely by means of its self-weight, thereby eliminating the need for either external energy input from vibrators or any type of compacting effort. The use of SCC is spreading worldwide because of its very attractive properties in the fresh state as well as after hardening. The use of SCC will lead to reduce the technical costs of in situ concrete constructions and eliminate some of the potential human error. It will replace manual compaction of fresh concrete with a modern semi-automatic placing technology and in that way, improve health and safety in and around the construction site [22].

Term internal curing means "supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation" according to the definition provided in American Concrete Institute. Also, the hydration of cement continues because of the availability of internal water that is not part of the mixing water, refers to internal curing technique [1].

2 Literature review

The concept of SCC was first proposed by Professor Hajime Okamura, in 1986 in Japan as a solution to concrete's concerns. There are many advantages of using SCC, these include [7] [15]:

- Elimination of the need for vibration.
- Reducing the noise pollution.
- Improving the filling capacity of highly congested structural member.
- Reducing the construction time and labor cost.

Self-compacting concrete (SCC) is characterized by high resistance to segregation that can be cast without compaction or vibration. It flows like honey, de-aerates, self-compacts and has nearly a horizontal concrete level after placing [14]. Internal curing has been discussed as an added advantage in concrete research. It has wider prospect in many countries and it is possible to get benefit from the internal curing instead of traditional external curing. Internal curing has a significant contribution in shrinkage reduction. In the advancement of concrete technology internal curing is found to be beneficial in terms of enhancing concrete performance as well as environment friendly [20].

The main properties of lightweight aggregate (LWA) are its high porosity, high absorption, low specific gravity and cellular structure. These properties make LWA a suitable material for internal curing technique [19].

By replacing a portion of the normal weight aggregates with pre-wetted lightweight aggregates (LWA), additional internal curing water is provided to the concrete mixture. During the hydration of the cement paste within the concrete mixture, this internal curing water will be drawn from the LWA into the hydrating paste, maintaining a high degree of saturation (water-filled pores) in the cement paste and avoiding or at least reducing shrinkage stresses and their accompanying autogenous deformations [9] [6].

3 Expermental work

3.1 Materials

Limestone powder ($CaCO_3$) was used as a filler material and as percentage replacement of cement for producing SCC. The fineness (Blaine specific surface) of the used limestone powder (LSP) is (200 m^2/kg) and the chemical composition of LSP is given in Table (4).

Ordinary Portland Cement (O.P.C) (ASTM Type I). This cement complied with the Iraqi specification [16]. The coarse aggregate was brought from Al-Nibaii region with a nominal size of (14) mm. Al-Ekhaider natural sand is used as fine aggregate in concrete mixes. Table (1) and Table (2) show the sieve analysis and properties for the sand used throughout this work. The grading and properties of the used sand and coarse aggregate satisfies the requirements of the [17].

Glenium 51 (G51) is used in this research as chemical admixture and complies with [5] type F.

Thermostone aggregate is considered as one type of lightweight aggregate and used in this study as internal curing material. Thermostone was gained from Karbala thermostone factory as waste and broken into smaller size particles like sand. Then, the crushed thermostone is washed and cleaned with water afterward dried by spread in air. The crushed particles are sieved and partially replaced by volume with the same size of sand with a certain percentage to have the same grading as the used sand which satisfies the grading requirements of the [17].

Later, the thermostone aggregate is soaked in water for (24) hours to bring the aggregate particles to saturated condition. Table (3) shows the physical properties of the used thermostone aggregate.

3.2 Mix Design and Proportions

The mix design method of the used SCC in this study is according to the European guidelines for SCC [12], and then the proportions of materials were modified after obtaining a satisfactory self-compactability by evaluating through fresh concrete tests. The mix proportions of the SCC which was used throughout this research are shown in Table (5).

3.3 Tests of Fresh Concrete

Slump flow test, T50cm test, V- funnel test and L-box test are used as test methods for workability properties of SCC. These methods are given in the European Federation dedicated to specialist construction chemicals and concrete systems SCC guidelines [12].

3.4 Tests of Hardened Concrete

Tests of hardened concrete in this research are shown below:

- Compressive strength test was conducted according to the British Standard [8] using (Tinius Olsen testing machine) compression device of (1000 kN) maximum capacity. Three cubes (100*100*100) mm were tested for each mix at each age of (7, 28 and 90) days for the determination of compressive strength by using two sets of mixes for SCC, one of these sets is cured in water and the other is cured in air along the test period.
- Modulus of rupture test was performed on two (100x100x400) mm prisms according

to [4] with span of (300) mm at age of (7, 28 and 90) days and the average of two specimens of each mix was adopted.

- Shrinkage test was conducted according to [3]. A micro – meter dial gauge with (0.001) mm reading accuracy was used in this test. Pins were fixed on prisms (100x100x400) mm after casting the specimens. The shrinkage test was conducted by using two sets of prisms specimens for SCC, the first set is cured for 7 days in water, after that it is taken out from water tank and left in air (laboratory conditions) for 21 days, the second set is cured in air along the test period for 28 days. The length change was calculated at age of (7, 14, 21 and 28) days by using the following eq. (1):

$L = [(L_x – L_i)/G]$ …… (1)

where:
L: Shrinkage strain at (x) age.
L_x: Comparator reading of specimen at (x) age minus comparator reading of reference bar at (x) age (mm).
L_i: Initial comparator reading of specimen minus reading of reference bar at that same time (mm).
G: Nominal gauge length (mm).

4 Results and discussion

4.1 Test Results of Fresh Concrete

The results of the slump flow test, V- funnel test and L-box test are shown in Table (6). These results indicate that in general, the workability of fresh SCC improves with increasing thermostone aggregate as partial sand replacement percentage as compared with reference concrete. This is due to that the pre-wetted fine lightweight aggregate (LWA), which provides a set of water-filled reservoirs within the concrete as additional moisture and in turn improves the workability of fresh SCC [13] [22]. These results are within the acceptable criteria for SCC [11] and also indicate excellent deformability and filling ability without any segregation, bleeding and blocking.

4.2 Test Results of Hardened Concrete

The results of the hardened properties which include (compressive strength, modulus of rupture and shrinkage) of SCC in this research are shown in Tables (7) to (12), and represented in Figures (1) to (6). From these results, it can be seen that internally cured SCC with thermostone aggregate has the best hardened properties which include (compressive strength, modulus of rupture) of externally cured SCC with both water and air as compared with reference concretes which didn't contain thermostone aggregate, as a result of internal curing technique. The highest increase in compressive strength reaches 16.72% and 12.67% for SCC internally cured with thermostone aggregate as partial sand replacement with percentage of (5%) and cured in water and air, respectively.

In general, the results of shrinkage test have shown reduction in shrinkage of internally cured SCC with thermostone aggregate as compared with reference concretes which didn't contain LWA.

The increased strength may be due to increase in the degree of cement hydration as a result of internal curing water, which leads to increase the hydration products, improve the interfacial transition zone by filling internal voids of concrete, reduction of shrinkage induced micro cracking and decrease the porosity of SCC. This complies with studies carried out by [18] [10] [2].

5 Conclusions

Depending on the results of this investigation, the following conclusions can be drawn:

1. It is possible to produce self-compacting concrete (SCC) by using thermostone aggregate as partial sand replacement with three different percentages (5%, 10% and 15%) by volume as internal curing material to internal curing technique.
2. It is possible to get benefit from the internal curing instead of traditional external curing because internal curing is easy to use and has a significant contribution to shrinkage reduction, enhancing durability, sustainability and hence, improving overall SCC performance.
3. Improving the workability and the hardened properties which include (compressive strength and modulus of rupture) of internally cured SCC with increasing thermostone aggregate as partial sand replacement as compared with reference concrete.
4. The SCC mixes are internally cured with thermostone aggregate and externally cured in both water and air exhibit very low shrinkage as compared with reference concrete.

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Table 1. Sieve analysis of sand and thermostone aggregate

Sieve size (mm)	Percent passing (%)	I.Q.S.45: 1984 Limits Zone (2)
10	100	100
4.75	99.8	90 - 100
2.36	84.4	75 - 100
1.18	65.6	55 - 90
0.60	41.8	35 - 59
0.30	11	8 - 30
0.15	2.2	0 - 10
Fineness modulus = 2.95		

Table (2): Physical and chemical properties of sand

Property	Test result	I.Q.S.45: 1984 Limits
Apparent specific gravity	2.55	------
Absorption, %	2.95	------
Bulk density (kg/m3)	1710	------
Sulphate content (SO3)	0.19%	0.50% (max)

Table (3): Physical properties of thermostone aggregate

Property	Test result
Shape	Crushed
Apparent specific gravity	1.14
Bulk density (kg/m^3)	675
Absorption, %	48

Table (4): Chemical composition of limestone powder

No.	Constituents	Quantity (%)
1	CaO	56.21
2	SiO_2	----
3	Al_2O_3	----
4	Fe_2O_3	----
5	L.O.I	43.78
6	SO_3	----
7	MgO	----

Table (5): Mix proportions of SCC mixes*

Thermostone Aggregate (fine) kg/m^3			Coarse Aggregate kg/m^3	Sand kg/m^3	Limestone Powder (5%) kg/m^3	Cement kg/m^3	Index of Mixes
15%	10%	5%					
---	---	---	850	825	25	475	Mix-R
---	---	16.3	850	783.75	25	475	Mix-T5%
---	32.6	---	850	742.5	25	475	Mix-T10%
48.9	---	---	850	701.25	25	475	Mix-T15%

*Water (kg/m^3) = 185
Glenium 51 (liter per 100kg of cementitious materials) = 1.1

Table (6): The results of the slump flow test, V- funnel test and L-box test

Mixes	Compressive strength (MPa)		
	7 days	28 days	90 days
Mix-R	40.76	42.88	45.71
Mix-T5%	44.04	47.66	53.35
Mix-T10%	41.98	45.98	50.82
Mix-T15%	37.84	40.73	42.04

Table (7): Test results of compressive strength of SCC internally cured with thermostone aggregate and externally cured with water

Index of Mixes	Slump flow		V-Funnel		L-Box	
	D (mm)	T50cm (sec)	TV (sec)	TV5min (sec)	Blocking Ratio (H2/H1)	T40cm (sec)
Mix-R	736	3.5	10	12	0.9	3.5
Mix-T5%	747	3.3	9.5	11.6	0.91	3.4
Mix-T10%	760	3.1	8.5	10.5	0.92	3.2
Mix-T15%	772	2.8	7.2	9.3	0.93	3

Table (8): Test results of compressive strength of SCC internally cured with thermostone aggregate and externally cured with air

Mixes	Compressive strength (MPa)		
	7 days	28 days	90 days
Mix-R	38.27	40.22	42.63
Mix-T5%	40.21	43.48	48.03
Mix-T10%	38.96	41.92	45.95
Mix-T15%	35.13	37.83	40.89

Table (9): Test results of modulus of rupture of SCC internally cured with thermostone aggregate and externally cured with water

Mixes	Modulus of rupture (MPa)		
	7 days	28 days	90 days
Mix-R	5.66	5.87	6.04
Mix-T5%	5.98	6.31	6.65
Mix-T10%	5.80	6.04	6.28
Mix-T15%	5.63	5.75	5.88

Table (10): Test results of modulus of rupture of SCC internally cured with thermostone aggregate and externally cured with air

Mixes	Modulus of rupture (MPa)		
	7 days	28 days	90 days
Mix-R	5.32	5.51	5.65
Mix-T5%	5.57	5.85	6.07
Mix-T10%	5.45	5.66	5.86
Mix-T15%	5.31	5.43	5.52

Table (11): Test results of volume change of SCC internally cured with thermostone aggregate and externally cured with water for 7 days and with air until 21 days

Mixes	Shrinkage × 10^{-6}					
	Water curing			Air curing		
	1 day	4 days	7 days	14 days	21 days	28 days
Mix-R	0	+20	+25	-40	-135	-180
Mix-T5%	0	+30	+35	-30	-40	-50
Mix-T10%	0	+35	+40	-20	-30	-35
Mix-T15%	0	+40	+50	-5	-10	-15

Table (12): Test results of volume change of SCC internally cured with thermostone aggregate and externally cured with air until 28 days

Mixes	Shrinkage × 10^{-6}					
	Air curing					
	1 day	4 days	7 days	14 days	21 days	28 days
Mix-R	0	-105	-190	-220	-240	-255
Mix-T5%	0	-25	-50	-65	-75	-85
Mix-T10%	0	-15	-30	-45	-50	-65
Mix-T15%	0	-10	-20	-35	-40	-50

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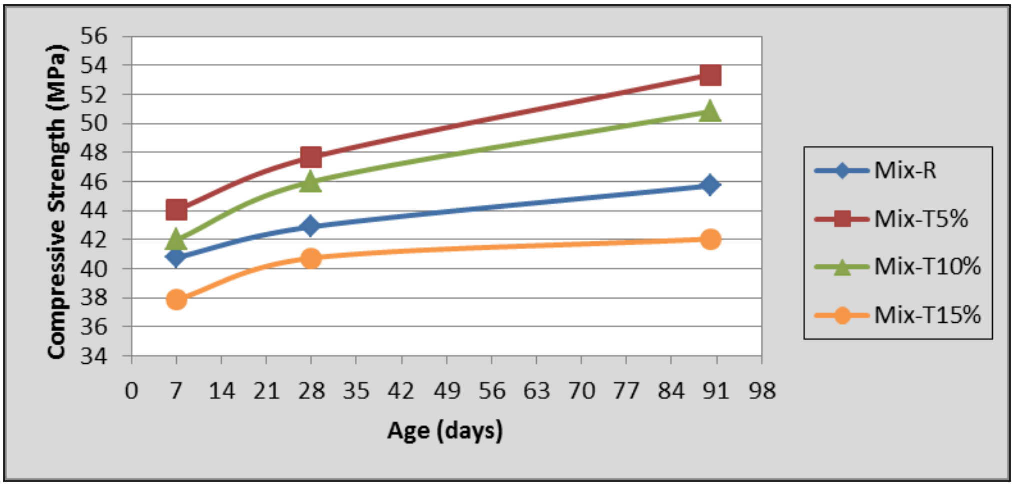

Figure (1): Compressive strength development of SCC internally cured with thermostone aggregate and externally cured with water

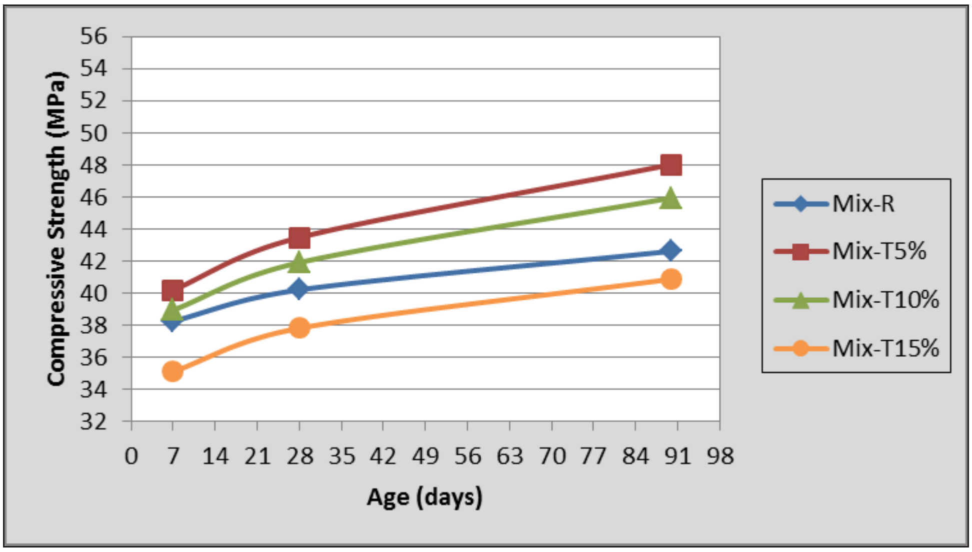

Figure (2): Compressive strength development of SCC internally cured with thermostone aggregate and externally cured with air

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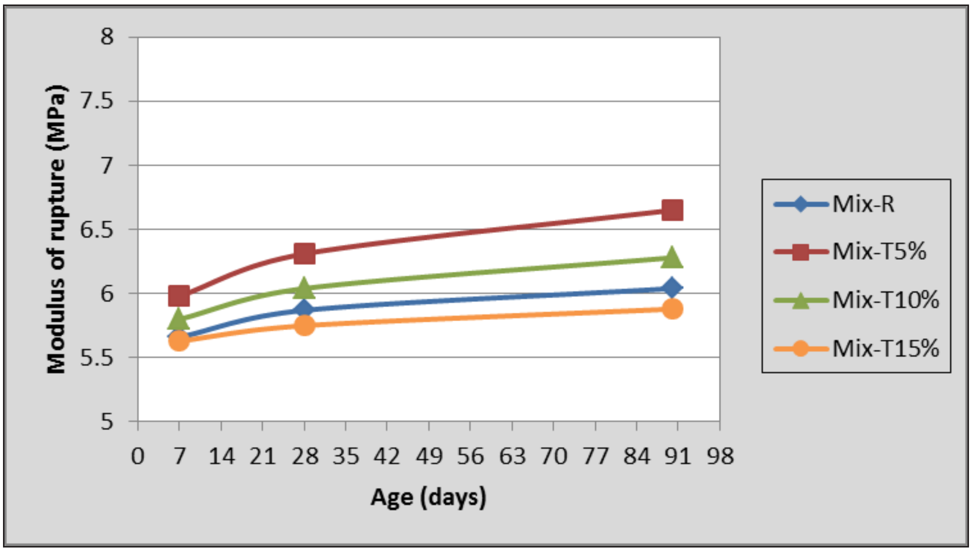

Figure (3): Modulus of rupture development of SCC internally cured with thermostone aggregate and externally cured with water

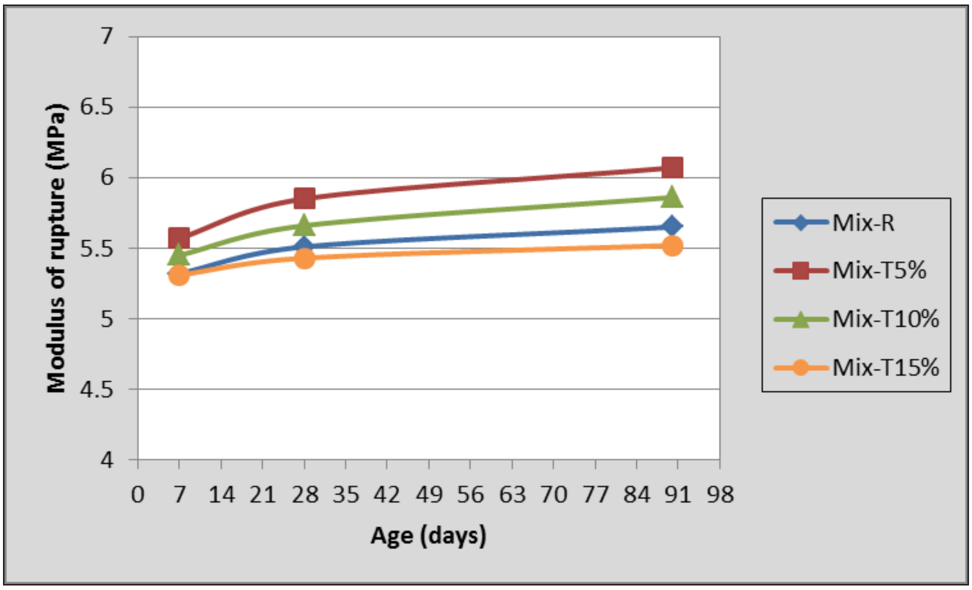

Figure (4): Modulus of rupture development of SCC internally cured with thermostone aggregate and externally cured with air

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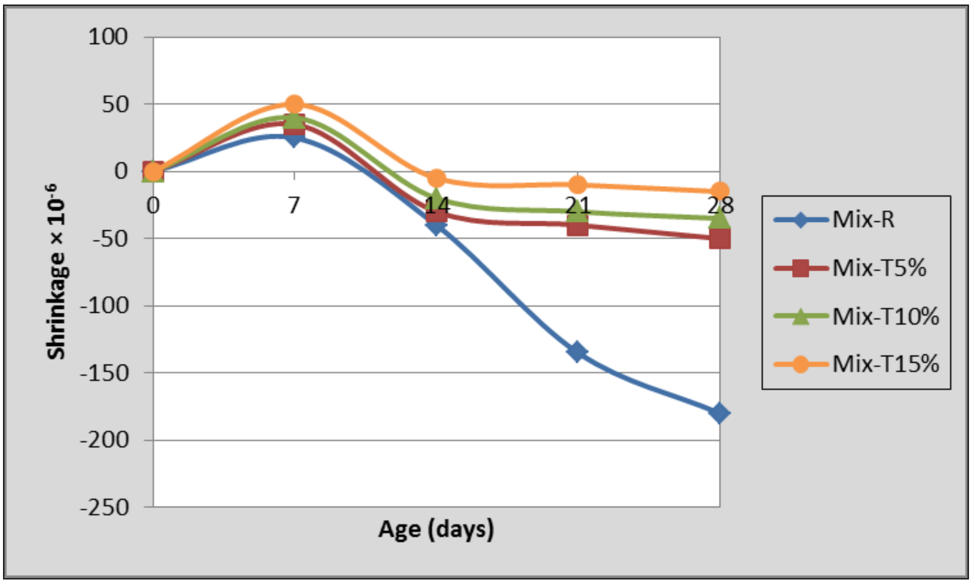

Figure (5): Volume change development of SCC internally cured with thermostone aggregate and externally cured with water for 7 days and with air until 21 days

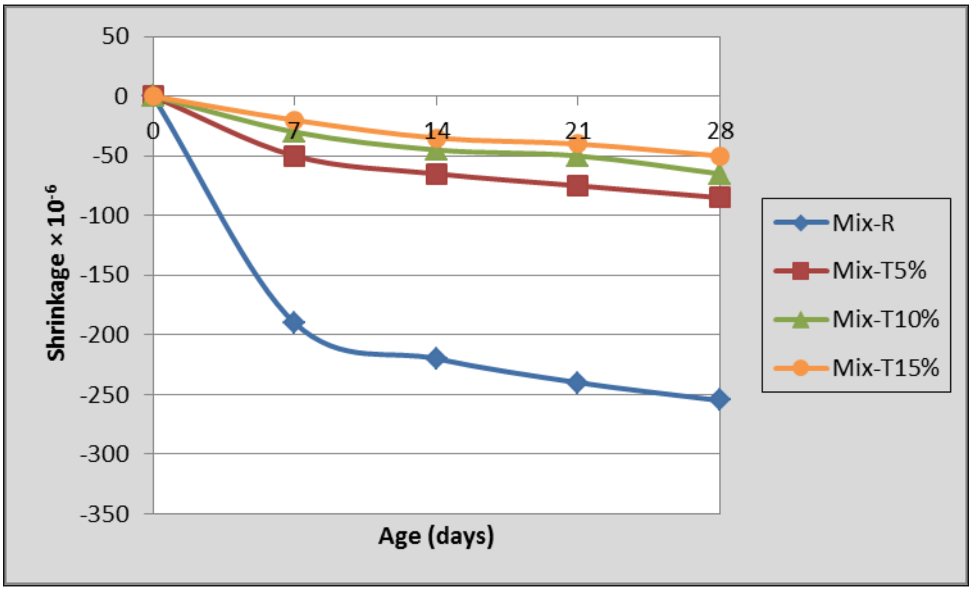

Figure (6): Volume change development of SCC internally cured with thermostone aggregate and externally cured with air until 28 days