Enhancing Performance of Self–Compacting Concrete with Internal Curing Using Thermostone Chips

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ABSTRACT

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

Key words: self-compacting concrete, internal curing, thermostone chips, silica fume.

تحسين اداء الخرسانه ذاتية الرص بواسطة الانضاج الداخلي باستعمال فتات الكتل الخرسانية الخلوية

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الخلاصة

ان الغرض من هذا البحث هو التحري عن تأثير تقنية المعالجه الداخليه على خصائص الخرسانه ذاتية الرص. في هذه الدراسه تم انتاج الخرسانة ذاتية الرص باستعمال غبار السليكا كإستبدال جزئي من وزن السمنت بنسبة 5 % ، وتم استبدال الرمل جزئيا بركام ناعم خفيف الوزن ومشبع وجاف السطح هو فتات الكتل الخرسانية الخلوية كمادة معالجة داخلية وبثلاث نسب حجمية هي (5%،10%،15%) كاستبدال حجمي، ظرفين للمعالجة الخارجية هما الماء والهواء. قسم العمل المختبري في هذه الدراسه الى ثلاثة اجزاء اساسية : في الجزء الاول تم اجراء الفحوص المختبرية للخرسانه ذاتية الرص الطريه لايجاد قابلية التشغيل. أما القسم الثاني فيتضمن اجراء فحوص مقاومة الانضغاط و مقاومة الانثناء للخرسانه ذاتية الرص المتصلبه بأعمار (7، 28 ، 90) يوم. والجزء الثالث يتضمن اجراء فحص الانكماش باعمار (7، 14، 21، 28) يوم . لوحظ من استعراض نتائج فحوص الخصائص الطريه والمتصلبه للخرسانة ذاتية الرص المعالجه داخليا بفتات الكتل الخرسانيه الخلوية حصول تحسن واضح في قابلية التشغيل وكذلك حصول تحسن ملحوظ في الخصائص المتصلبه والتي تشمل (مقاومة الانضغاط و مقاومة الانثناء) في كلا ظرفي المعالجه الخارجيه مقارنة بالخرسانه المرجعية. كما ان الخصائص المتصلبه للخرسانه ذاتية الرص باستعمال فتات الكتل الخرسانيه الخلوية بنسبة استبدال (10%) هي الافضل قياسا بنسب الاستبدال الاخرى. وبشكل عام بينت النتائج حصول نقصان واضح في انكماش الخرسانه ذاتية الرص المعالجه داخليا.

كلمات رئيسيه: الخرسانه ذاتية الرص، المعالجه الداخليه، فتات الكتل الخرسانيه الخلوية، غبار السليكا.

1. INTRODUCTION

Self compacting concrete is characterized by high resistance to segregation that can be cast without compaction or vibration. It flows like honey, deaerates, self-compacts and has nearly a horizontal concrete level after placing, **Holm**, and **Bremner**, **2000**.

The 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, **ACI 213-03R**, **2003**.

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, **Bouzoubaa**, and **Lachemi**, **2001**. **Horta**, **2005**.

- No need for vibration.
- Reducing the construction time and labor cost.
- Reducing the noise pollution.
- Improving the filling capacity of highly congested structural member.
- Facilitating and ensuring good structural performance.

The use of SCC is spreading world wide because of its very attractive properties in the fresh state as well as after hardening. The use of SCC leads to reduce the technical costs of in situ concrete constructions and eliminate some of the potential human error. It replaces the manual compaction of fresh concrete with a modern semi-automatic placing technology that way improve health and safety on and around the construction site, **Selvamony**, **et al.**, **2010**.

It is possible to get benefit from the internal curing instead of traditional external curing. Internal curing has a significant contribution in shrinkage reduction and enhancing concrete performance as well as environmental friendly, **Munaz**, **et al.**, **2011**.

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, **Cusson**, and **Hoogeveen**, **2005**. **Bentz**, **2007**.

The main properties of lightweight aggregate (LWA) are its high porosity, high absorption, low specific gravity and cellular structure [Muhsen 1996] and [Dhaher 2001]. These properties make LWA a suitable material for internal curing technique, **Lura**, **et al.**, **2004**.

2. EXPERIMENTAL WORK

2.1 Materials

Tasluga Ordinary Portland Cement complied with the Iraqi specification, **IQS No.5**, **1984** was used. The coarse aggregate was brought from Al-Nibaii quarry with a nominal size of (14) mm. Al-Ekhaider natural sand is used as fine aggregate in concrete mixes. **Tables 1** and **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 Iraqi specification, **IQS No.45**, **1984**.

Thermostone chips is used as a lightweight aggregate in this study to be the internal curing material. Thermostone was from Karbala thermoston Factory as waste and broken into smaller size particles. Then, the crushed thermostone is washed 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 Iraqi specification, **IQS No.45**, **1984**. 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 crushed thermostone aggregate.

Glenium 51 (G51) is used in this research as chemical admixture and complies with **ASTM C 494-05**, **2005** type F.

Silica fume is used as a highly pozzolanic mineral admixture. The fineness (Blaine specific surface) of SF is (23000 m^2/kg). The chemical analysis of SF which is used in this research conforms to the chemical requirements of **ASTM C 618-03**, **2003** as shown in **Table 4**.

2.2 Mix Design and Proportions

The mix design method of the used SCC in this study is according to **ERMCO**, **2005**. 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**.

2.3 Tests of Fresh Concrete

Slump flow test, T50cm test, V- funnel test and L-box test were used for workability properties of SCC according to the European Federation Guidelines **ERMCO**, **2005**.

2.4 Tests of Hardened Concrete

Tests of hardened concrete in this research are shown below:

- Compressive strength test was conducted according to the British Standard, **BS1881 part 116**, **1985**. Three cubes (100*100*100) mm were tested for each mix at each age of (7, 28 and 90) days for determination of compressive strength using two sets of mixes for SCC, one of these sets is cured in water and the other is cured in air.
- Modulus of rupture test was performed on two (100x100x400) mm prisms according to **ASTM C 293-02**, **2002**, with span of (300) mm at age of (7, 28 and 90) days. The average of two prism specimens of each mix was adopted.
- Shrinkage test was conducted according to **ASTM C 490-00**, **2000**. A micrometer 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 was cured for 7 days in water, after that it was taken out from water tank and left in air (laboratory conditions) for 21 days, the second set was cured in air along test period for 28 days. The changes in length were calculated at age of (7, 14, 21 and 28) days.

3. RESULTS AND DISCUSSION

3.1 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 was improved with increasing thermostone chips as partial sand replacement percentage when it is compared with reference concrete mix. This is due to 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, **Friggle**, and **Reeves**, **2008**. **Villareal**, **2008**. These results are within the acceptable criteria **EFNARC**, **2002** for SCC and indicate also satisfactory deformability and filling ability without any segregation, bleeding and blocking.

3.2 Test Results of Hardened Concrete

The results of the properties of hardened concrete which include (compressive strength, modulus of rupture and shrinkage) of SCC are shown in **Tables 7** to **12**, and represented in **Fig. 1** to **Fig. 6**. From these results, it can be seen that internally cured SCC by using pre-wetted thermostone chips as fine aggregate has better properties then that of externally cured SCC for both water and air curing as compared with reference concrete mix, as a result of internal curing technique. The highest increasing of compressive strength reaches 27.63% and 21.89% for SCC internally cured with thermostone chips as partial sand replacement with percentage of (10%) and cured in water and air respectively.

In general, the results of shrinkage test shows a reduction in shrinkage of internally cured SCC with thermostone chips as compared with reference concrete mix.

The mechanism of reduction of shrinkage by internal curing technique can be explained as follows, internal curing is a curing system that supplies water from pre-saturated porous LWA which has absorbed a huge amount of water when soaked in it. The pores of the cement paste absorb the water from the LWA by capillary suction as a result of the difference in water pressure in pores between LWA and cement hydrates, then an internal curing water leads to increase the final degree of hydration and decrease the unhydrated cement content and the capillary porosity by increase in the gel hydration products which cause increase in the crystallization pressure and reduce the shrinkage of concrete. The increased strength may be attributed to the 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 induce micro cracking and decrease the porosity of SCC. This complies with studies carried out by, **Lura**, **2003**. **Cusson**, **et al.**, **2010**. **Al-Awadi**, **2013**.

4. CONCLUSION

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

- The internal curing technique may be achieved by using thermostone chips as partial sand replacement by volume as internal curing material.
- Improving the workability and the properties of the hardened concrete such as (compressive strength and modulus of rupture) may be achieved by internally curing SCC by using thermostone chips as partial sand replacement as compared with reference concrete.
- The SCC mixes are internally cured with thermostone chips as fine aggregate and externally cured in both water and air exhibit very low shrinkage as compared with reference concrete.
- It is useful to employ internal curing instead of traditional external curing due to its ease to use and its a significant contribution to shrinkage reduction, enhancing durability, sustainability and hence improving overall SCC performance.

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List of Abbreviations and Symbols

IQS= Iraqi specification.
LWA= lightweight aggregate.
SCC= self-compacting concrete.
SF= silica fume.
T_{50cm}= slump flow time at diameter 50cm .
TV= flow time of v-funnel test.
TV_{5min}= flow time of v-funnel test after 5min. of filling.

Table 1. Sieve analysis of sand and thermostone chips.

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/m^3)	1710	------
Sulphate content (SO_3)	0.19%	0.50% (max)

Table 3. Physical properties of thermostone chips.

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

Table 4. Chemical composition of SF (with fineness is 23000 m^2/kg) and the chemical requirements of ASTM C 618-03.

Oxide composition	Oxide content %	Chemical requirements of ASTM C 618-03 class (N)
SiO_2	91.39	(SiO_2) plus (Al_2O_3) plus (Fe_2O_3), min, = 70.0%
Al_2O_3	2.90	
Fe_2O_3	0.30	
SO_3	Nil	(SO_3), max, = 4.0%
L.O.I	3.35	L.O.I, max, = 10.0%
CaO	Nil	-------
MgO	2.02	-------

Table 5. Mix proportions of SCC mixes*.

Index of Mixes	Sand kg/m^3	Thermostone Chips kg/m^3		
		5%	10%	15%
Mix-R	825	---	---	---
Mix-T5%	783.75	16.3	---	---
Mix-T10%	742.5	---	32.6	---
Mix-T15%	701.25	---	---	48.9

*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.

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	698	4.5	12	13.5	0.82	5
Mix-T5%	706	4.4	11.7	13	0.83	4.8
Mix-T10%	715	4.2	10.5	12	0.84	4.5
Mix-T15%	723	4	9.5	11.2	0.85	4.2

.

Table 7. Test results of compressive strength of SCC internally cured with thermostone chips and externally cured with water

Mixes	Compressive strength (MPa)		
	7 days	28 days	90 days
Mix-R	43.65	45.87	52.76
Mix-T5%	48.42	52.58	63.65
Mix-T10%	50.14	56.64	67.34
Mix-T15%	46.31	50.84	58.63

Table 8. Test results of compressive strength of SCC internally cured with thermostone chips and externally cured with air.

Mixes	Compressive strength (MPa)		
	7 days	28 days	90 days
Mix-R	40.84	42.96	48.43
Mix-T5%	43.69	48.04	55.90
Mix-T10%	45.73	51.14	59.03
Mix-T15%	42.68	45.59	52.92

Table 9. Test results of modulus of rupture of SCC internally cured with thermostone chips and externally cured with water.

Mixes	Modulus of rupture (MPa)		
	7 days	28 days	90 days
Mix-R	6.06	6.32	6.95
Mix-T5%	6.35	6.86	7.68
Mix-T10%	6.78	7.19	7.98
Mix-T15%	6.24	6.58	7.34

Table 10. Test results of modulus of rupture of SCC internally cured with thermostone chips and externally cured with air.

Mixes	Modulus of rupture (MPa)		
	7 days	28 days	90 days
Mix-R	5.74	5.98	6.65
Mix-T5%	6.06	6.40	7.18
Mix-T10%	6.29	6.65	7.44
Mix-T15%	5.90	6.24	6.91

Table 11. Test results of volume change of SCC internally cured with thermostone chips and externally cured with water for 7 days and with air until 21 days.

Mixes	Shrinkage × 10^{-6}				
	Water curing		Air curing		
	4 days	7 days	14 days	21 days	28 days
Mix-R	+30	+35	-60	-165	-215
Mix-T5%	+35	+45	-40	-55	-80
Mix-T10%	+40	+50	-30	-40	-50
Mix-T15%	+45	+60	-20	-30	-35

Table 12. Test results of volume change of SCC internally cured with thermostone chips and externally cured with air until 28 days.

Mixes	Shrinkage × 10^{-6}				
	Air curing				
	4 days	7 days	14 days	21 days	28 days
Mix-R	-130	-215	-245	-265	-285
Mix-T5%	-40	-70	-85	-100	-110
Mix-T10%	-30	-50	-70	-75	-85
Mix-T15%	-25	-40	-55	-65	-70

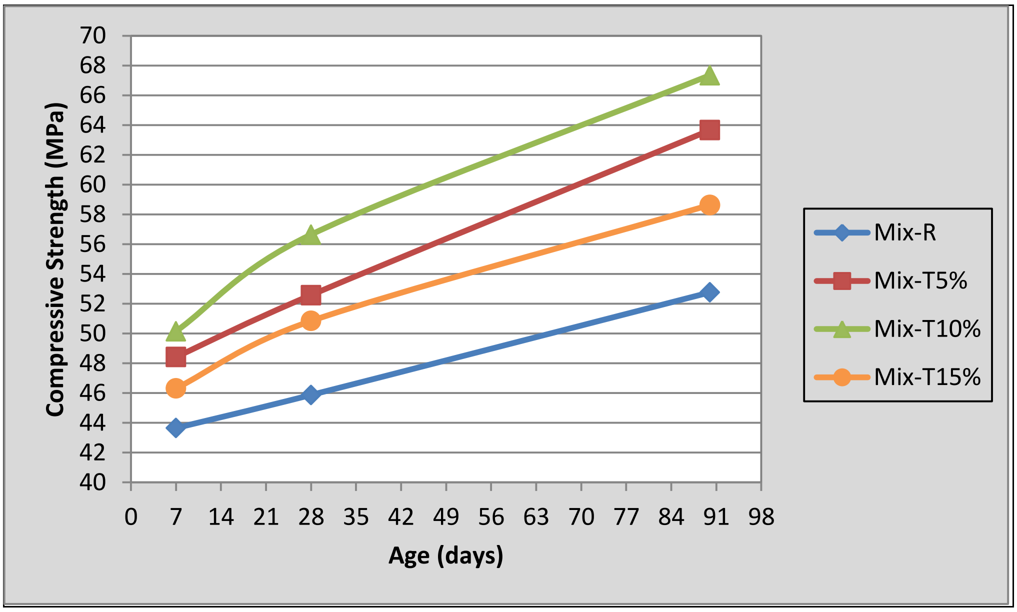

Figure 1. Compressive strength development of SCC internally cured with thermostone chips and externally cured with water.

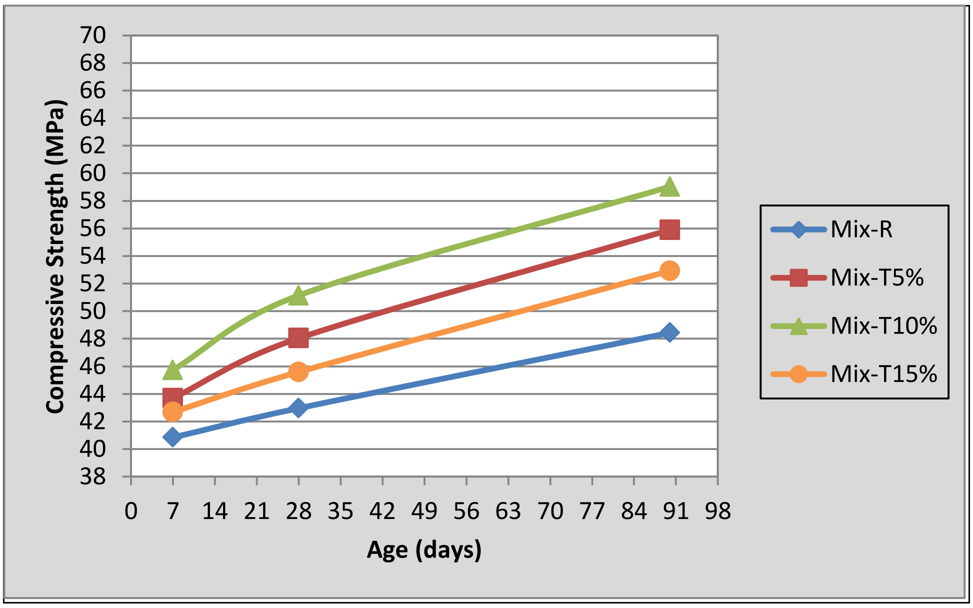

Figure 2. Compressive strength development of SCC internally cured with thermostone chips and externally cured with air.

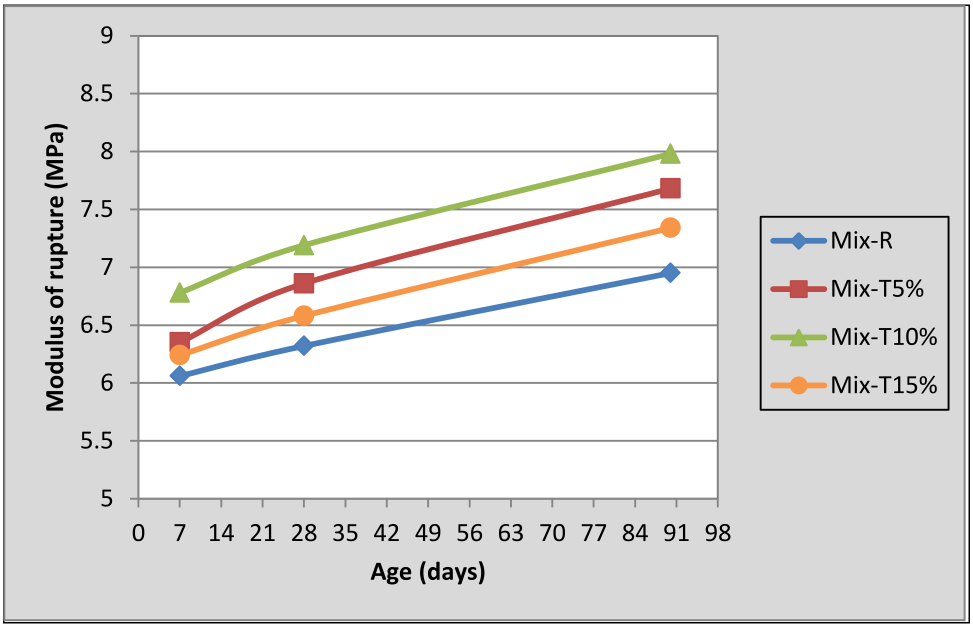

Figure 3. Modulus of rupture development of SCC internally cured with thermostone chips and externally cured with water.

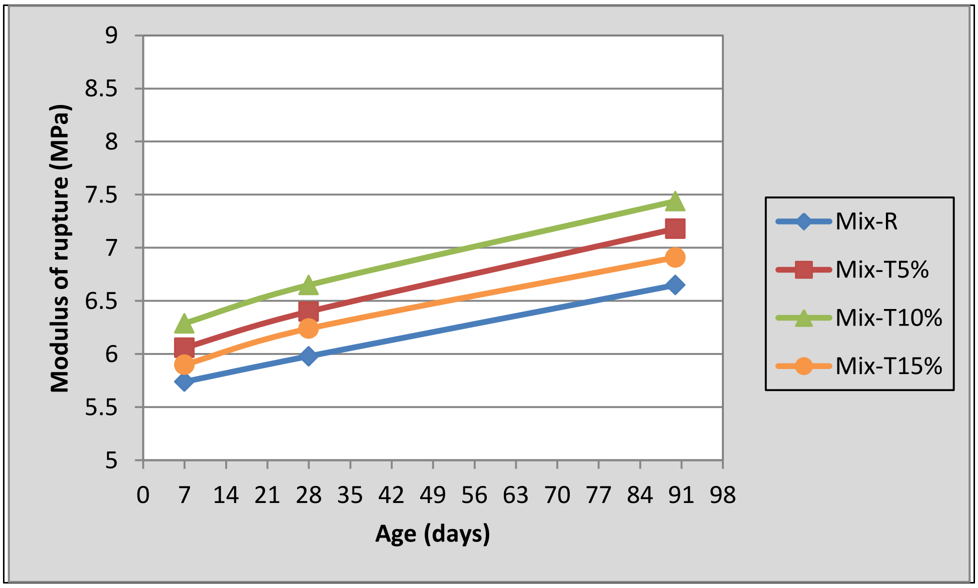

Figure 4. Modulus of rupture development of SCC internally cured with thermostone chips and externally cured with air.

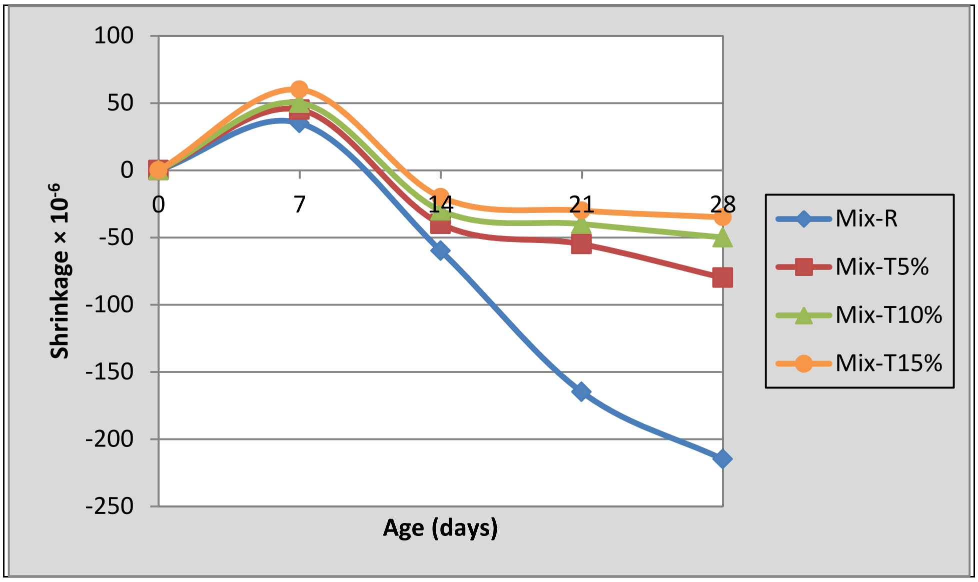

Figure 5. Volume change development of SCC internally cured with thermostone chips and externally cured with water for 7 days and with air until 21 days.

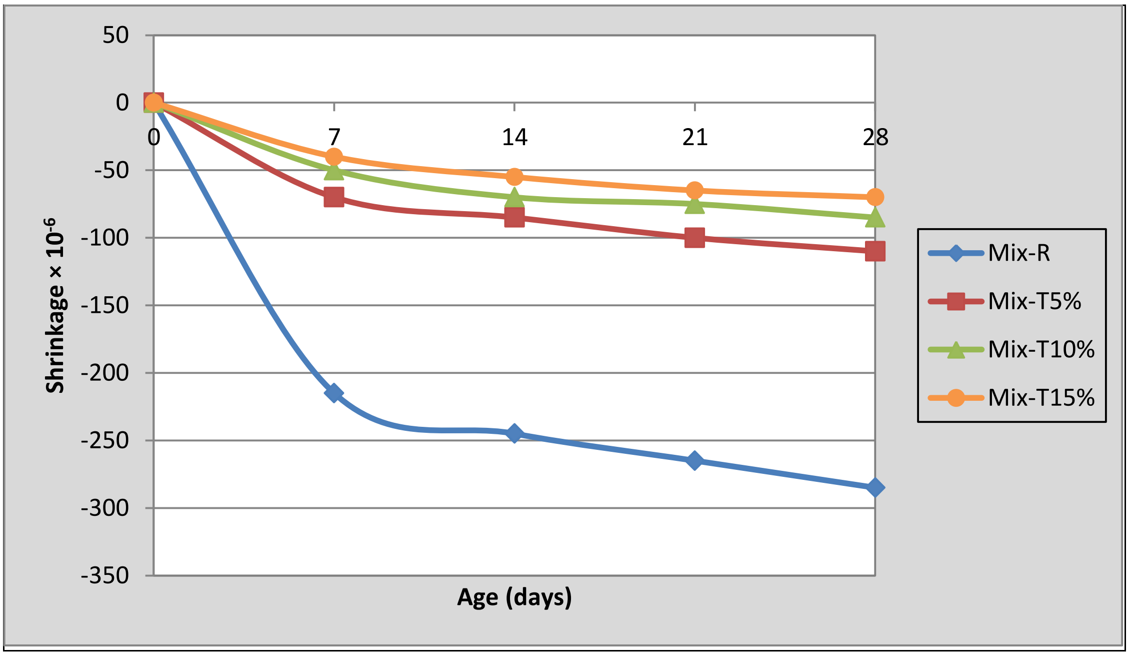

Figure 6. Volume change development of SCC internally cured with thermostone chips and externally cured with air until 28 days.