

EFFECT OF LITHIUM ADMIXTURES IN VCAS BLENDED CEMENTS TO MITIGATE ALKALI SILICA REACTION

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Abstract

In this study, the effectiveness of vitreous calcium aluminosilicate (VCAS) pozzolan and lithium nitrate to mitigate alkali silica reaction (ASR) were investigated using the ASTM C 1260 and ASTM C 1567 test methods. The VCAS was used as a cement replacement material at 10% and 20% dosage levels while the lithium nitrate was used at a dosage of 0%-150%. The ASR expansion behavior of seventeen mortars containing highly-reactive aggregate was studied.

Results from this investigation suggested that the VCAS, both in the ground and unground form (VCAS1 and VCAS2) showed 88%-92% reduction in ASR expansion but did not completely mitigate ASR. In addition, a minimum lithium dosage of about 125%, 50% and 25% were required to completely mitigate ASR in the control, VCAS1-20% and VCAS2-20% mortars, respectively, indicating that either very high lithium dosages or very high VCAS replacement levels with low lithium dosages were needed to completely mitigate ASR.

KEYWORDS: Lithium admixtures, vitreous calcium aluminosilicate, alkali-silica reaction, pozzolan, reactive aggregates

1.0 INTRODUCTION

Alkali silica reaction (ASR) is a well known durability distress in concrete over the past 70 years, however, its deleterious effects in concrete has been observed recently in several structures including airport runways, pavements and bridge decks. ASR is a chemical reaction which occurs between the reactive silica present in aggregates and the alkaline hydroxide in cement to form a gel, known as an ASR gel, which in contact with moisture, swells and expands, creating tensile stresses and eventually leading to premature failure of concrete. The different strategies to mitigate the ASR in concrete has been well documented [2, 3], the most effective being the use of supplementary cementing material (SCM). The mechanisms by which the commonly used SCMs such as fly ash, slag and silica fume mitigate ASR is well known but the maximum replacement level of these SCMs used to mitigate ASR depend primarily on their chemical composition and physical characteristics [1-4]. In recent years, studies on highly reactive SCMs such as metakaolin and ultra-fine fly ash to mitigate ASR have been reported [4, 5] and a new entrant to this class of SCM is a vitreous calcium aluminosilicate (VCAS) pozzolan. VCAS is an aluminosilicate material, and as compared to metakaolin, it has similar silica content but lower alumina content. This pozzolan is a patented product and obtained by the incineration of ground silica, lime and alumina compounds to a molten state followed by quenching and final grinding [6]. Limited research has been conducted to determine the effectiveness of VCAS to serve as an SCM in concrete and to understand the influence of VCAS on the hydration behavior in cementitious system [7].

The other strategy to mitigate ASR, which is gaining popularity during the last decade, is the use of lithium admixtures in concrete. Though different types of lithium compounds are available to reduce ASR expansion, the most effective among them is lithium nitrate [8]. A previous study conducted to determine the effectiveness of this chemical admixture on the cement hydration process indicated that the use of very-high

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lithium dosage at early ages generated high amounts of heat by accelerating the C_3S and C_3A components of cement and produced high chemical shrinkage [9]. Hence, the lithium dosages in concrete are optimized to less than or equal to 100%. More recently, a few studies were conducted to understand the mechanism by which lithium nitrate mitigates ASR [10, 11].

The choice of the above mentioned strategies to mitigate ASR primarily depends on the aggregate reactivity, the availability of SCMs and chemical admixtures, and the alkali content of cement. In regions where only highly-reactive aggregates and high-alkali cements are available (worst situation), the use of single strategy to mitigate ASR may not be always effective. In such situations, different strategies have to be employed in order to obtain a feasible solution. Hence, this study is designed to apply both of these strategies in order to yield a feasible and an optimal solution.

2.0 OBJECTIVES

The principle objectives of this study are:

- 1) To determine the effectiveness of VCAS blended cements in mitigating alkali silica reaction.
- 2) To determine the effect of fineness of VCAS in mitigating alkali silica reaction.
- 3) To determine the effect of lithium admixtures in mitigating ASR
- 4) To determine the effect of lithium admixtures in VCAS blended cements to mitigate ASR

3.0 MATERIALS, MIXTURE PROPORTIONS AND METHODS

3.1 Materials and their properties

The ordinary portland cement used in this study belonged to the ASTM Type I Cement and had a sodium oxide equivalent of 0.82% by the mass of total oxides. A vitreous calcium aluminosilicate (VCAS) pozzolan, satisfying the requirements of the ASTM C 618 and having a specific gravity of 3.10 was used as a cement replacement material. The X-ray diffractogram of this pozzolan shown in **Figure 1** indicated that VCAS contains glassy and amorphous silica in the 2θ range of 16° to 38° with no well defined peaks.

This material was available from the manufacturer in two different finenesses denoted as VCAS1 and VCAS2, with the VCAS2 finer than the VCAS1. The median particle size of the VCAS1 and VCAS2 was 8 and 3 microns, respectively; both of them were used in this study to determine the effect of fineness on ASR mitigation. The chemical composition of cement and the VCAS are shown in **Table 1**.

Lithium nitrate was used in this study as a chemical admixture for reducing the expansions due to ASR. A commercial grade of 30% weight solution was used. It is odorless and white to yellow in color having a pH of 8.20 at $25^\circ C$. The specific gravity of the solution was 1.20 g/cc at $25^\circ C$. In this study, the effectiveness of lithium nitrate in mitigating ASR was investigated using two lithium dosages of 50% and 100%, where a 100% dosage represents a Li/Na ratio of 0.74 in the binder.

Two types of aggregate were used in this study: (a) Liberty Aggregate (non-reactive) and (b) New Mexico (highly-reactive aggregate). The non-reactive aggregate was used to determine the strength activity index (SAI) while the highly reactive aggregate was used in the ASR test. The aggregate gradation used for preparing the mixtures in the ASR test was specified in the ASTM C 1260 or C 1567 test procedure. The basic properties of these aggregates are shown in **Table 2**.

3.2 Mixture proportions and methods

The mix proportions used in the different tests conducted are shown in **Table 3**. In both the SAI and ASR tests, the replacement levels of the VCAS used for cement were 0% (Control), 10% and 20%. The procedures used to determine the SAI and the ASR expansions are discussed below.

The SAI was determined using the ASTM C 311 test procedure. Accordingly, standard mortar cubes without (Control) and with VCAS (blend) were cast in standard cubes of size 50 x 50 x 50 mm. After demolding, these cubes were moist-cured for 1 day and tested at 7 and 28 days of curing period. The SAI for all the mixtures were calculated by considering the strength registered by the control mixture at the specified curing period as 100.

To determine the ASR expansions, three test methods were employed depending on the type of materials used in the mixture. For mixtures containing no VCAS and no lithium admixture, the standard ASTM C 1260 test method was adopted. In this method, the standard mortar bars of size 25 x 25 x 285 mm with studs at both ends were cast and moist cured for one day before demolding. Then, the bars were soaked in a water bath maintained at a temperature of 80^o C for 1 day, before soaking them in the standard 1N sodium hydroxide solution at a temperature of 80^o C. The expansion readings taken before soaking the bars in this solution at 80^o C was considered as the reference reading and subsequent readings were noted after regular intervals of time until 28 days.

For mixtures containing VCAS blends with no lithium admixture, the standard ASTM C 1567 test method was adopted. This test method is almost the same as that of the ASTM C 1260 test method except that the cement was replaced by VCAS at 10% and 20% dosage levels.

The first modification was the addition of lithium nitrate solution to achieve a desired Li/Na molar ratio in the mortar mixture. The second modification was to add adequate amount of lithium nitrate solution to the soak solution to achieve a Li/Na molar ratio that is half of that in the mortar bars, while maintaining a 1N NaOH concentration. The calculations for the quantity of lithium to be added in the soak solution and in the mortar bars are shown in Appendix 1. The lithium dosages used in the soak solution for mixtures containing no VCAS were 0%, 100% and 150% while that for mixtures containing VCAS were 0%, 50% and 75%. The ASR expansion of 0.10% at 14 day immersion period was considered as the maximum limit for evaluating the effectiveness of the VCAS blends and lithium nitrate to mitigate ASR. The mixture IDs and experimental program for this study are presented in **Table 4**.

4.0 RESULTS AND DISCUSSIONS

4.1 Strength activity index of VCAS blended mortars

Figure 2 (a) and (b) shows the strength activity index of VCAS1 and VCAS2 blended mortars, respectively. As the Figure 2 (a) shows, the SAI of all the VCAS blended mortars were found to be well above the minimum SAI of 75 as specified by the ASTM C 618 specifications. Their SAI values were also found to be above 100 (the SAI of control mortars), indicating that VCAS is effective in increasing the strength when used as a cement replacement material. Similar SAI values were also obtained in a previous study conducted on VCAS cementitious paste [7]. The SAI of all the blended mortars appears to slightly decrease with increase in the period of curing. Figure 2 (b) shows that, in the case of VCAS1 blended mortars, their SAI decreases with an increase in the VCAS1 replacement level, whereas the same is not true in the case of VCAS2 blended mortars; their SAI either remain the same or increase with an increase in the VCAS2 replacement level. The differential behavior in strength enhancements may be due to the variations in the fineness of VCAS1 and VCAS2.

4.2 Effectiveness of VCAS in ASR mitigation

ASR expansion behavior of VCAS blended mortars

Figure 3 (i) shows the ASR expansion behavior of VCAS blended cement mortars. As this figure shows, the ASR expansion decreases with an increase in the VCAS replacement level up to 20%. This expansion behavior was observed in both the VCAS1 and VCAS2 blended mortars. In addition, the 14-day and 28-day ASR expansions of the VCAS1 and VCAS2 blended mortars as shown in **Table 5** indicated that the latter showed higher reduction in ASR expansion than the former.

Effect of fineness of VCAS on ASR expansion

Figure 3 (ii) shows the effect of fineness of the VCAS on the 14-day ASR expansion. As the **Figure 3 (ii)-(a)** shows, the 14-day ASR expansion of the VCAS1 and VCAS2 blended mortars reduce linearly up to a 20% replacement level. The reduction in the 14-day ASR expansion of the VCAS blended mortars may be due to two effects: (a) the dilution effect, in which the quantity of calcium hydroxide that is formed in the VCAS blended mortar from cement hydration is less than that in the control mortar, as the cement quantity in the former is less than the latter. (b) the pozzolanic effect, in which the hydration of cement in the presence of the VCAS may result in the formation of calcium-silicate-hydrate (C-S-H) and/or calcium-alumino-silicate hydrate (C-A-S-H) gels in the cementitious matrix and at the interfacial transition zone (ITZ). These gels are characterized by very low porosity and permeability, protecting the highly-reactive aggregates from the reach of alkalis [12]. In addition, these gels also have good alkali binding ability, because of which the Na (or) K ions are exchanged by the Ca ions present in these gels. Also, the process of formation of these gels is the result of calcium hydroxide depletion from the cement hydration and; hence, with high VCAS replacement levels, more calcium hydroxide may have depleted. A recent research conducted on VCAS cementitious pastes indicated that calcium hydroxide was depleted when VCAS was used at a 15% cement replacement material by mass [6].

Even though there is a substantial reduction in the 14-day ASR expansion for the VCAS blended mortars at 20% replacement level, complete ASR mitigation below 0.10% was not achieved in both the VCAS1 and VCAS2 blended mortars. As indicated in the **Figure 3 (ii)-(b)**, the percentage reduction in the 14-day ASR expansion of the VCAS1 mortars was found to be 43% and 88% while that of the VCAS2 mortars was found to be 53% and 92% at 10% and 20% replacement levels, respectively. The higher percentage reduction in expansion of the VCAS2 mortars compared to the VCAS1 mortars is obviously due to the higher fineness of the VCAS2 compared to the VCAS1. The finer the pozzolanic material, the higher is the calcium hydroxide depletion and; hence, more C-S-H and/or C-A-S-H gel is formed, thereby making the cementitious matrix less permeable for the alkalis to reach the reactive aggregates in mortars.

In addition, the percentage decrease due to the fineness of the VCAS was found to be 23.25% and 4.54% at 10% and 20% replacement levels, respectively. This decrease was found to be higher at a low VCAS replacement level compared to a high VCAS replacement levels.

4.3 Effectiveness of lithium nitrate on ASR mitigation

ASR expansion behavior of control mortars containing lithium nitrate

Figure 4 (a) shows the ASR expansion behavior of the control mortars containing lithium nitrate. As this figure shows, the ASR expansion decreases with an increase in the lithium dosage up to 150%. The mechanism involved in the reduction of ASR expansion with lithium can be due to various reasons such as reduction in the dissolution of silica by hydroxyl attack, the binding of alkali (Na^+ , K^+ and Li^+) and calcium cations at negatively charged sites on the silicate surface, the formation of Li-Si crystals by silicate species in solution with lithium ions in solution and the formation of Li-bearing ASR gels [10, 11].

Figure 4 (b) shows the effect of lithium dosage on the 14-day ASR expansion and a horizontal limit line in this figure shows the standard ASTM C 1260 expansion limit of 0.10% at 14-day immersion period. This figure shows that the 14-day ASR expansion of mortars containing highly-reactive aggregates can be brought within the standard expansion limit of 0.10% only by using a lithium dosage of more than 125%. A previous research conducted on using lithium nitrate to mitigate ASR has indicated that a typical lithium nitrate dosage from 50%-100% was required to completely mitigate ASR [8]. However in that study, a standard borosilicate glass has been used. The higher quantity of lithium required to mitigate ASR in this study may be due to the use of highly-reactive aggregates. Such high quantities of lithium admixtures are prohibitively expensive, and; in addition, may have certain unintended consequences such as accelerated setting behavior [9]. Hence, the use of lithium nitrate at a typical dosage of 50%-100% along with other pozzolan (VCAS) is explored in the next section to obtain the synergetic effects of both.

ASR expansion behavior of VCAS blended mortars containing lithium nitrate

Figure 5 (a) through **(f)** show the effectiveness of lithium admixture in VCAS blended mortars to mitigate ASR. The **Figures 5 (a)** and **(b)** shows the ASR expansion behavior of mortars containing the VCAS1 while the **Figures 5 (c)** and **(d)** shows that containing VCAS2.

As the **Figure 5 (a)** shows, the ASR expansion of the mortars containing VCAS1 decreases with an increase in the lithium dosage from 0% to 75%. The ASR expansions of all the mixtures were well above the 0.10% limited expansion even before 7 days of immersion period, indicating that even a 10% replacement level of VCAS1 and a 75% dosage of lithium nitrate were not effective to reduce the ASR expansion within limits. Similar trends were also observed in the ASR expansion of mortars containing VCAS2 and lithium as shown in **Figure 5 (c)**. However, at a VCAS replacement level of 20% as shown in **Figure 5 (b) and (d)**, a substantial reduction in the ASR expansion even below 0.10% was observed. With addition of lithium nitrate from 0% to 75%, the expansion was reduced still further.

In order to clearly understand the effect of lithium dosage on ASR mitigation of mortars containing the VCAS1 and VCAS2, the 14-day ASR expansion was plotted against the lithium dosage as shown in **Figure 5 (e) and (f)**. These figures show that the 14-day ASR expansion decreases with increase in the lithium dosage as expected. A complete ASR mitigation within 0.10% is not achievable in a 20% replaced VCAS1/VCAS2 blended mortars containing no lithium dosage. However, a complete ASR mitigation was achievable with the same 20% replaced VCAS1/VCAS2 blended mortars containing a minimum lithium dosage of 50%. In addition, the VCAS1 blended mortars required higher dosages of lithium nitrate to completely mitigate ASR compared to the VCAS2 blended mortars, indicating that finer pozzolans are more effective in ASR mitigation.

5.0 CONCLUSIONS

From the investigations conducted to determine the effectiveness of VCAS and lithium admixtures to mitigate ASR in mortars containing highly-reactive aggregates, the following conclusions can be drawn:

- (1) The VCAS blended mortars had higher SAI than the control mortars at both 10% and 20% replacement levels studied and; hence, the VCAS1 and VCAS2 can serve as an effective SCM.
- (2) Even at a 20% replacement level, neither the VCAS1 nor the VCAS2 completely mitigated ASR. However, between the two blended mortars, the VCAS2 mortars performed better than the VCAS1 mortars.
- (3) The lithium nitrate admixture was very effective in completely mitigating ASR only at a high dosage of 125%.
- (4) Though the high replacement level of VCAS and the dosage of lithium nitrate are required to completely mitigate ASR, such high quantities are primarily due to the use of highly-reactive aggregates.
- (5) The VCAS blended mortars containing 10% VCAS and 75% lithium dosage was ineffective in mitigating ASR, whereas that containing 20% VCAS and 50%-75% lithium dosages was effective.
- (6) The VCAS2 blended mortars containing 20% VCAS2 required only a minimal lithium dosage of 25% while the VCAS2 blended mortars containing 20% VCAS1 required a slightly higher lithium dosage of 50% for complete ASR mitigation, indicating that the VCAS2 is more effective.

6.0 RECOMMENDATIONS

Though this study gives comprehensive information on the performance of VCAS-lithium combinations in the ASTM C 1260 or C 1567 test, long-term ASR tests such as the ASTM C 1293 have to be conducted to confirm these results. Also, additional ASR tests may be conducted to evaluate the performance of these VCAS-lithium combinations on broader set of aggregates with varied levels of reactivity. Since the current study dealt with only using a highly reactive aggregate, one can usually expect lesser VCAS replacement levels and/or lithium dosages to completely mitigate ASR in mortars containing moderately and/or less reactive aggregates.

REFERENCES

- [1] Shehata, MH and Thomas, MDA (2000): The effect of fly ash composition on the expansion of concrete due to alkali silica reaction. *Cement and Concrete Research*, Elsevier Journal, 30, 1063-1072.
- [2] Shehata, MH, and Thomas, MDA (2002): Use of ternary blends containing silica fume and fly ash to suppress expansion due to alkali-silica reaction in concrete. *Cement and Concrete Research*, Elsevier Journal, 32, 341-349.
- [3] Thomas, MDA and Innis, FA (1998): Effect of slag on expansion due to alkali aggregate reaction in concrete. *ACI Materials Journal*, 95, 6, 716-724.
- [4] Ramlochana, T, Thomas, MDA, and Gruberb KA (2000): The effect of metakaolin on alkali silica reaction in concrete. *Cement and Concrete Research*, Elsevier Journal, 30, 339-344.
- [5] Obla, KH, Russell, LH, Thomas, MDA, Sashiprakash, SG, and Perebatova, O (2003): Properties of concrete containing ultra-fine fly ash. *ACI Materials Journal*, 100, 5, 426-433.
- [6] Neithalath, N, Persun, J, and Hossain, A (2009): Hydration in high-performance cementitious systems containing vitreous calcium aluminosilicate or silica fume. *Cement and Concrete Research*, Elsevier Journal, 39, 473-481.
- [7] Hossain, AB, Shirazi, SA, Persun, J, and Neithalath, N (2008): Properties of concrete containing vitreous calcium aluminosilicate pozzolan. *Transportation Research Record*, Journal of Transportation Research Board, 20, 32-38.
- [8] Collins, CL, Ideker, JH, Willis, GS, and Kurtis, KE (2004): Examination of the effects of LiOH, LiCl and LiNO₃ on alkali silica reaction. *Cement and Concrete Research*, 34, 1403-1415.
- [9] Millard, MJ, and Kurtis, KE (2008): Effects of lithium nitrate admixture on early-age cement hydration. *Cement and Concrete Research*, Elsevier Journal, 38, 500-510.
- [10] Feng, X, Thomas, MDA, Bremner, TW, Folliard, KJ and Fournier, B (2010): New observations on the mechanism of lithium nitrate against alkali silica reaction (ASR). *Cement and Concrete Research*, 40, 94-101.
- [11] Tremblay, C, Berude, MA, Fourier, B, Thomas, MD, and Folliard, KJ (2010): Experimental investigation of the mechanisms by which LiNO₃ is effective against ASR. *Cement and Concrete Research*, 40, 583-597.
- [12] Moser, RD, Jayapalan, AR, Garas, VY, and Kurtis, KE (2010): Assessment of binary and ternary blends of metakaolin and Class C fly ash for alkali-silica reaction mitigation in concrete. *Cement and Concrete Research*, Elsevier Journal, 40, 1664-1672.

Table 1 Chemical composition of cement and VCAS

Materials	Oxide contents by mass (%)							
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O _{equi}
OPC cement	19.78	4.98	3.13	61.84	2.54	4.15	-	0.82
VCAS*	52.5	17.5	<1	22.5	<1	<0.1	<0.2	<1

*Average composition as reported by the manufacturer

Table 2 Properties of aggregate

Aggregate Property	Aggregate type	
	Non-reactive	Highly reactive
Water absorption (%)	0.2	0.344
Bulk specific gravity	2.65	2.75
Bulk specific gravity (SSD)	2.66	2.76

Table 3 Mixture proportions of the cementitious mixtures

Property	Mortar Mixture	Quantity of materials (g)					w/cm
		Cement	Pozzolan	Fine Agg.	Water	SP	
SAI	Control	500	0	1375	242	RQ	0.48
	VCAS	500 (1-x*/100)	500 (x*/100)	1375	242	RQ	0.48
ASR Expansion	Control	440	0	990	206.7	RQ	0.47
	VCAS	440 (1-x*/100)	440 (x*/100)	990	206.7	RQ	0.47

Note: SP – Superplasticizer; RQ – Required quantity; x – Replacement levels for cement in %

Table 4 Experimental program for this study

Mixtures	Lithium dosage (%)				
	0	50	75	100	150
Control	X	-	-	X	X
VCAS1-10%	X	X	X	-	-
VCAS1-20%	X	X	X	-	-
VCAS2-10%	X	X	X	-	-
VCAS2-20%	X	X	X	-	-

Note: VCAS1-Vitreous Calcium Alumino-silicate (coarse); VCAS2 – Vitreous Calcium Alumino-silicate (fine)

Table 5 Fourteen and twenty eight day ASR expansion of mortar bars containing different cements

Mixtures	Expansion of VCAS blended mortars with varying percentage lithium dosages after 14 days immersion period (%)				
	0%	50%	75%	100%	150%
Control	1.244	-	-	-	-
VCAS1-10%	0.708	0.453	0.340	-	-
VCAS1-20%	0.145	0.145	0.058	-	-
VCAS2-10%	0.583	0.353	0.302	-	-
VCAS2-20%	0.102	0.051	0.045	-	-

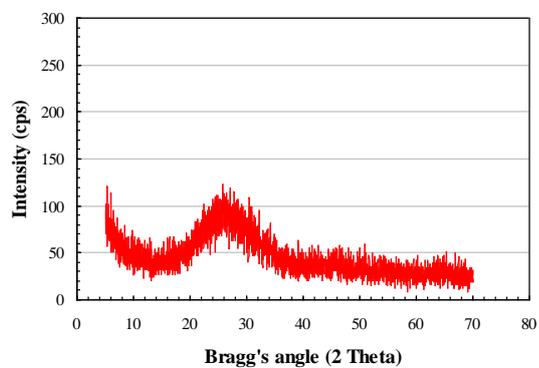
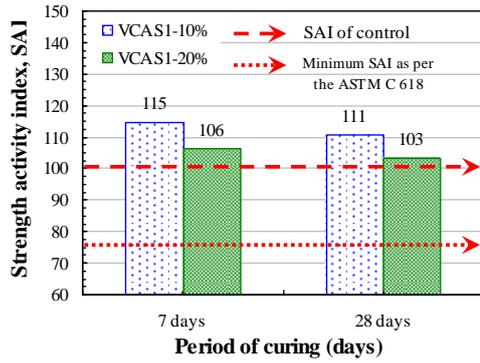
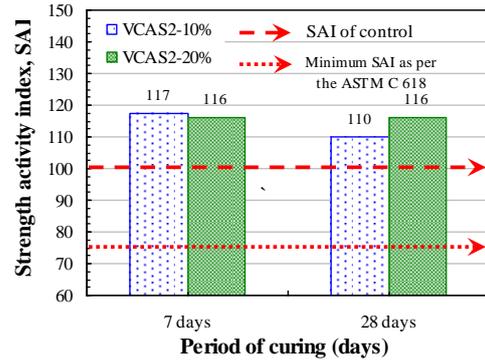


Figure 1 X-ray diffractogram of VCAS powder

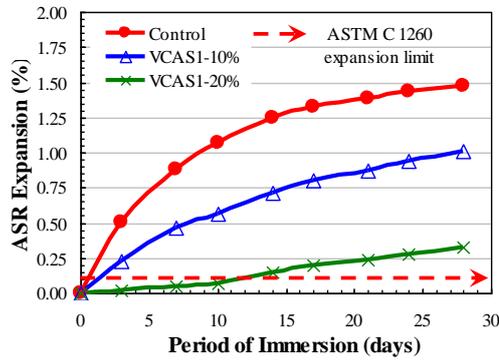


(a) VCAS1 blended mortars

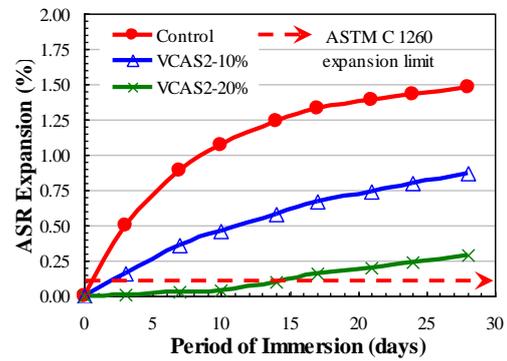


(b) VCAS2 blended mortars

Figure 2 Strength activity index of VCAS blended mortars

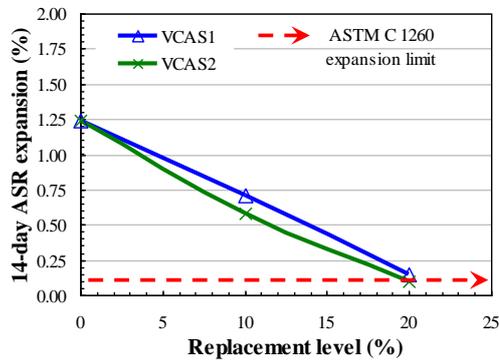


(a) VCAS1 blended mortars

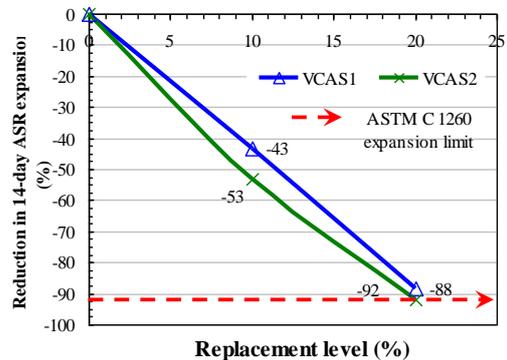


(b) VCAS2 blended mortars

(i) ASR expansion behavior of VCAS blended mortars



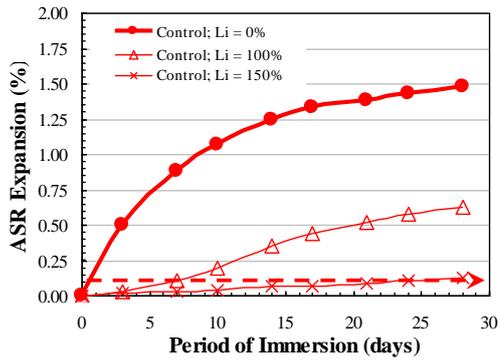
(a) VCAS1 vs VCAS2: Comparison of 14-day ASR expansions



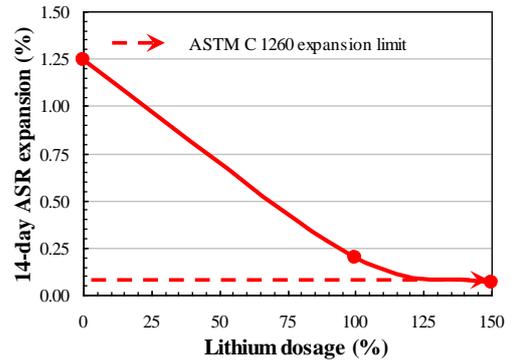
(b) VCAS1 vs VCAS2: Percentage reduction in 14-day ASR expansions

(ii) Effect of fineness of VCAS on 14-day ASR expansion

Figure 3 Effectiveness of VCAS blended cement mortars to mitigate ASR

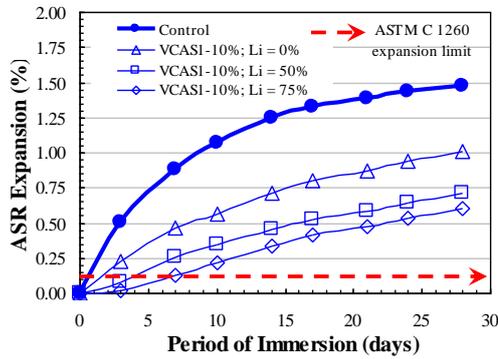


(a) ASR expansion behavior

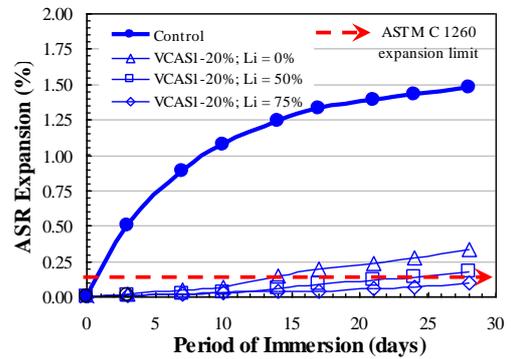


(b) 14-day ASR expansion vs lithium dosage

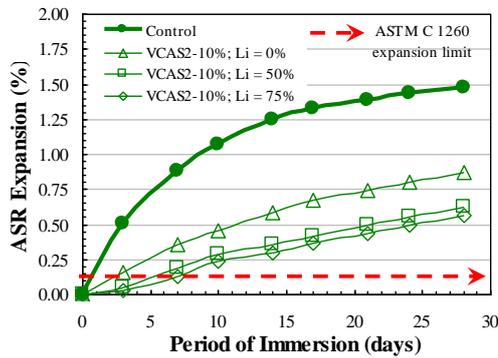
Figure 4 ASR expansion behavior of control mortars containing lithium nitrate



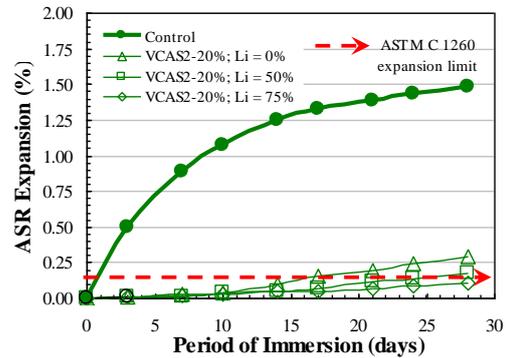
(a) VCAS1: At 10% replacement level



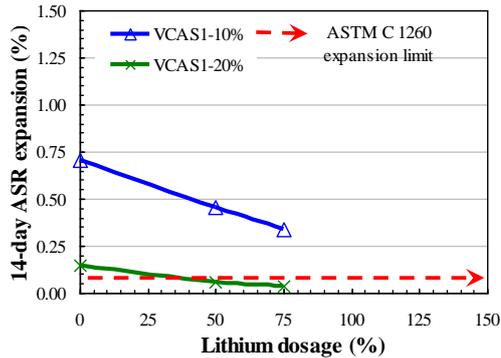
(b) VCAS1: At 20% replacement level



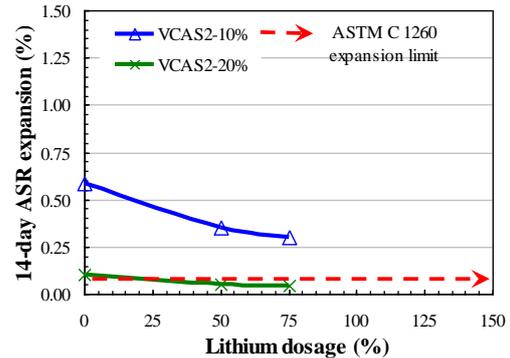
(c) VCAS2: At 10% replacement level



(d) VCAS2: At 20% replacement level



(e) VCAS1: Effect of lithium dosage on 14-day ASR expansion



(f) VCAS2: Effect of lithium dosage on 14-day ASR expansion

Figure 5 ASR expansion behavior of VCAS blended mortars containing lithium nitrate

APPENDIX: 1 SAMPLE CALCULATIONS FOR LITHIUM DOSAGE

(a) **Sample calculation to determine the dosage of 30% lithium nitrate solution in mortar bar to arrive at a desired Li/Na molar ratio**

Desired Li/ Na ion molar ratio	= 0.74	
Cement content per batch of four mortar bars	= 500 grams	
Cement alkali content (%)	= 0.82% Na ₂ O _{eq.}	
Alkali Content per batch (grams)	= 0.0082 × 500 grams	= 4.1 grams
Molecular Weight of Na ₂ O	= (2 × 23 + 16)	= 62 grams/ mole
Moles of Na ₂ O	= Alkali Content/ 62	
	= 4.1/62	= 0.0661 moles
Moles of Na	= 2 × 0.0661	= 0.1322 moles
Moles of lithium / moles of Na	= 0.74	
Moles of lithium	= 0.74 × 0.1322	
Moles of lithium	= 0.0978 moles	
1 Mole of LiNO ₃ contains 1 mole of lithium ion	Molecular weight of LiNO ₃	= 69 grams/ mole
Grams of LiNO ₃ that contain 0.0978 moles of Li ion	= 69 × 0.0978	= 6.753 grams
30% solution of LiNO ₃ that contains 6.753 grams of lithium	= 6.753/0.30	= 22.510 grams

(Add to mix water).

(b) **Sample calculation to determine the dosage of 30% lithium nitrate solution required to arrive at a desired Li/Na molar ratio in soak solution**

Desired Li/ Na ion molar ratio in soak solution	= 0.74 × 0.5	= 0.37
Molecular weight of LiNO ₃	= 69 grams	
Amount of LiNO ₃ salt required	= Li/Na ratio × molecular weight of LiNO ₃	
= 0.74 × 69	= 51.06 grams	
Amount of 30% LiNO ₃ solution required for 1 liter of soak solution	= 51.06/0.3	= 170.2 grams
Volume of 30% LiNO ₃ solution needed for 1 liter of soak solution	= 170.2 / 1.20	= 141.8 ml

(c) **To prepare one liter of soak solution with a Li/Na molar ratio of 0.74, the following procedure is followed:**

- Step 1 – A stock solution of 2N NaOH by adding 80 grams of NaOH pellets to 900 ml of de-ionized water and further diluting to prepare one liter of 2N NaOH solution was prepared.
- Step 2 – A 500 ml of 2N NaOH solution to a one-liter flask was then added
- Step 3 – A 141.8 ml of 30% solution of LiNO₃ to flask in Step 2 was then added
- Step 4 – The contents of flask to one-liter solution was diluted by adding de-ionized water