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Decay Model for Alkali-Silica Reaction

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ABSTRACT

This study predicts the ultimate expansion of mortar bars (UME) due to alkali-silica reactivity (ASR). The experimental expansión data utilized in this study were obtained from two previous studies. The experimental expansion data over the test duration of 28 days was fitted with the existing proposed decay model to predict the UME and time required to reach at 50%, 75% and 90% of UME. Finally, aggregates susceptible to alkali-silica reactivity were determined based on the existing proposed limit of UME, and were compared with the results obtained by the aggregate geology and expansion limits at the test durations of 14 and 28 days. The study showed that the ultimate mortar expansion and time required reaching various percentages of UME varied on aggregate mineralogy.

INTRODUCTION

Alkali-silica reaction (ASR) is one of the most deleterious chemical phenomena in concrete structures, and is a major concern in many countries of the world (Touma 2000; Islam 2010; Islam et al. 2015). ASR can cause significant expansion and cracking in concrete (Touma 2000; Islam and Ghafoori 2015). Among all the standard test methods to determine the ASR reactivity of an aggregate, ASTM C 1260 (2007) is the most widely used testing method due to its short test duration (Johnston 2000; Golmakani 2013).

Since ASR is a kinetic type reaction, Mukhopadhyay et al. (2005) and Ghanem et al. (2010) demonstrated that a kinetic model can be implemented to predict the characteristic of ASR-induced expansion. Most recently, concrete at the nuclear power plants has been shown to be decayed resulting a great concern for nuclear safety authorities (MacLeod 2012). Ghanem et al. (2010) also proposed the ASR decay model (ADM), shown in Eq. (1), to determine the ultimate mortar expansion (UME) and time to reach at the UME. The utilization of ASR decay model to predict the ultimate mortar expansion was very limited in the post studies. It is a vital topic that needs to be addressed.

$$\varepsilon_t = \varepsilon_0[1 - e^{(-\lambda\, t)}] \tag{1}$$

Where, ε_0 is the ultimate mortar expansion; t is the test duration in days; ε_r is the residual expansion at t days; λ is the first order rate constant, which has a unit of 1/t.

RESEARCH SIGNIFICANCE

The utilization of ASR kinetic model (ADM) in predicting the ultimate expansion of mortar bar is a unique technique, which can widely be used by the field engineers and researchers to reduce the test duration. Finally, the ASR evaluation of the aggregates was determined using the existing limit of the ultimate mortar expansion, and was compared with the results generated from the aggregate geology and the expansion limits at the test durations of 14 and 28 days.

EXISTING EXPERIMENTAL DATA

The experimental data utilized in this study was compiled from the two existing research investigations, conducted by Touma (2000) and Islam (2010). The raw materials utilized in this study consisted of ten aggregates (five from Touma (2000) and the remaining five from Islam (2010)). The identification and rock type of the investigated aggregate groups were shown in Table 1. The aggregate susceptibility due to the alkali-silica reaction was then determined according to the geological nomenclature, as described in the studies conducted by Ghafoori and Islam (2009), Islam (2010), Ghafoori and Islam (2013) and Islam and Ghafoori (2013a,b). The results are also shown in Table 1. The expansion reading of mortar bar was taken at the test durations of 0, 4, 6, 10, 14, 21 and 28 days.

Table 1. Identification, rock type and ASR potential of the investigated aggregate groups

Previous Studies	Aggregate Id	Rock Type	Potential ASR Reactivity
Touma (2000)	A1-WY	Rhyolite	Innocuous
	A9-NE	Granite	Innocuous
	B4-VA	Quartz	Reactive
	C2-SD	Quartz	Reactive
	D2-IL	Dolomite	Innocuous
Islam (2010)	SN-A	Dolomite	Innocuous
	SN-C	Dolomite-Limestone	Reactive
	SN-D	Dacite	Reactive
	NN-B	Andesite	Reactive
	NN-C	Basaltic-andesite	Reactive

RESULTS AND DISCUSSIONS

Mortar expansion over the test duration

The development of mortar expansion of the investigated five aggregate groups, obtained from the research study conducted by Islam (2010), is shown in Fig.1. As can be seen, the mortar expansion increased with an increase in test duration, and the expansion rate was extensive and faster for the reactive aggregates as compared to that of innocuous aggregate groups.

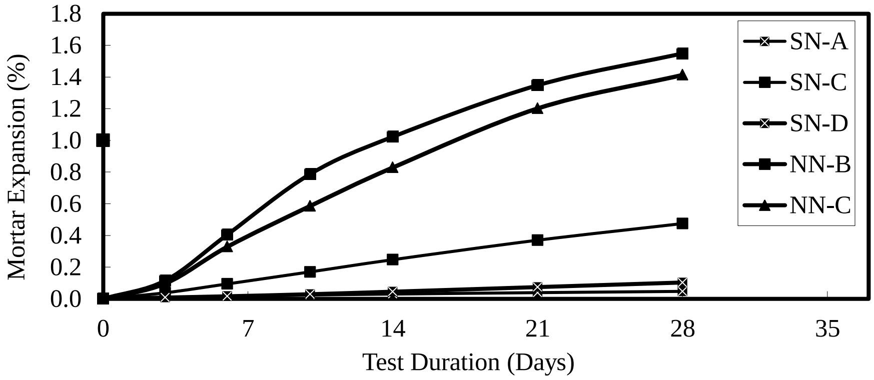

Figure 1. Progression of mortar expansions obtained the study conducted by Islam (2010)

Step by step procedures to apply ASR decay on mortar expansión data

The step by step procedures to apply ASR decay modelo n mortar expansión data are shown below:

a) The mortar expansion of the aggregates over the 28-day test duration was fitted with Eq. (1).
b) The values of coefficient ε0 and λ, their Prob(t), Prob(F) and R^2 were determined. The ε0 indicates the ultimate mortar expansion and λ indicates first order rate constant.
c) Finally, time needed in reaching at 50%, 75% and 90% of ultimate mortar expansions was evaluated using the values of ε0 and λ from step (b).

Utilizing the above three steps for the expansión data of this study, the statistical analysis of ADM model (Eq. (1)), ultimate mortar expansion (ε_0) and time required to reach 50%, 75% and 90% of ε_0 of each aggregate group were evaluated. The results are documented in Table 2. As can be shown, a strong correlation existed with R^2 values of 0.848~0.993 with an average of 0.944. Additionally, another reliable parameter for multiple regression models (R^2_{adj}) was shown very close to the R^2 values for the respective aggregate group. The Prob(t) for all regression coefficients, and Prob(F) were shown to be close proximity to 0.0000. Moreover, the standard errors of the estimate for each aggregate were shown to be very small.

Table 2. Statistical analysis of ADM model (Eq. (1)), ultimate mortar expansion (ε_0) and time required to reach 50%, 75% and 90% of ε_0

Agg. ID	Regression Coefficients (RC)		t-ratio of RC		Prob(F)	R^2	R^2_{adj}	$t_{1/2}$[a] (Days)	$t_{3/4}$[b] (Days)	$t_{9/10}$[c] (Days)
	λ	ε_0	λ	ε_0						
A1-WY	0.0921	0.3703	-22.58	-24.41	0.0000	0.993	0.992	7.53	15.05	25.00
A9-NE	0.0781	0.4245	-8.92	-9.48	0.0007	0.957	0.947	8.88	17.75	29.48
B4-VA	0.062	0.3053	-11.14	-6.78	0.0025	0.920	0.900	11.18	22.36	37.14
C2-SD	0.0679	0.2952	-12.63	-8.20	0.0012	0.944	0.930	10.21	20.42	33.91
D2-IL	0.1475	0.0418	-8.70	-4.72	0.0092	0.848	0.810	4.70	9.40	15.61
SN-A	0.083	0.0498	-61.41	-19.41	0.0000	0.990	0.987	8.35	16.70	27.74
SN-C	0.0712	0.5475	-6.44	-8.68	0.0010	0.950	0.937	9.74	19.47	32.34
SN-D	0.0589	0.1168	-23.22	-7.27	0.0019	0.930	0.912	11.77	23.54	39.09
NN-B	0.0988	1.8678	6.20	-11.19	0.0004	0.969	0.961	7.02	14.03	23.31
NN-C	0.0897	1.7226	4.26	-8.02	0.0013	0.941	0.927	7.73	15.45	25.67

[a]Time (days) required to reach 50% of ultimate mortar expansion; [b]Time (days) required to reach 75% of ultimate mortar expansion; [c]Time (days) required to reach 90% of ultimate mortar expansion

Time required to reach various percentages of UME of the investigated aggregate groups is shown in Fig. 2. It can be shown, the 50%, 75% and 90% of the UME of the investigated ten aggregates occurred from 4.70 to 11.77 days with an average of 8.71 days, from 9.40 to 23.54 days with an average of 17.42 days, and from 15.61 to 39.09 days with an average of 28.93 days, respectively.

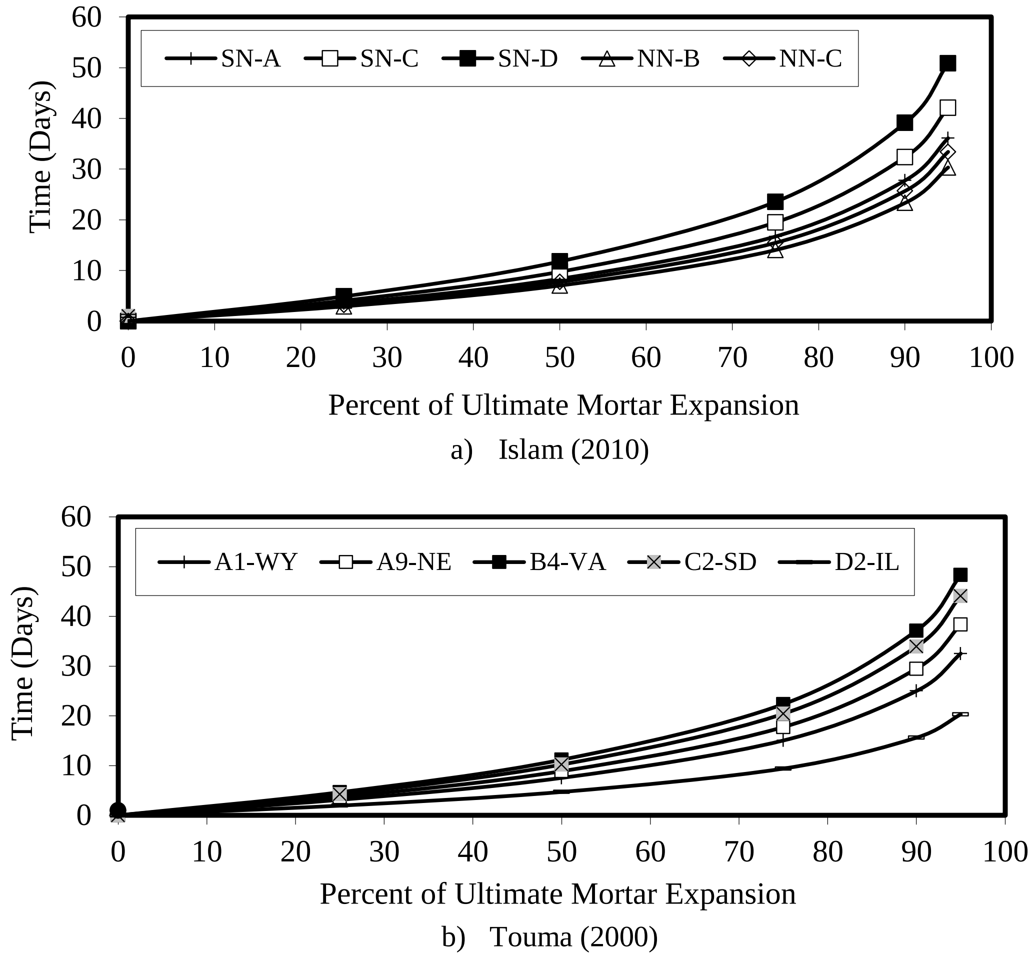

Figure 2. Time required to reach percent of ultimate mortar expansion

ASR Classifications of the Selected Aggregates

Table 3 shows the ASR classifications of the aggregates based on the aggregate geology and expansion limits at the ages of 14 and 28 days. Additionally, the results obtained by the failure limit of ultimate mortar bar were also evaluated, and were presented in Table 3.

The 14-day failure criteria of the ASTM C 1260 resulted in some innocuous aggregates as reactive. As compared to the results obtained at 14 days, the limit at the extended age of 28 days showed more liable. Finally, the ultimate expansion limit underestimated some reactive aggregates as innocuous. The reason can be stated that the mortar expansion data up to the 28 testing period was not sufficient for the ADM model to predict the ultimate mortar expansion. The expansion data at the extended testing period of at least 56 days would better predict the UME of aggregates, and hence, the ASR classifications of the aggregates can be improved.

Table 3. ASR classifications based on the expansion limits of mortar bars

Agg. ID	Aggregate Mineralogy	14-Day	28-Day	UME
		(0.10%)[a]	0.28%[b]	0.64%[c]
A1-WY	Innocuous	0.034 (I)	0.050 (I)	0.3703 (I)
A9-NE	Innocuous	0.118 (R)	0.233 (I)	0.4245 (I)
B4-VA	Reactive	0.272 (R)	0.502 (R)	0.3053 (I)
C2-SD	Reactive	0.055 (I)	0.117 (I)	0.2952 (I)
D2-IL	Innocuous	0.044 (I)	0.067 (I)	0.0418 (I)
SN-A	Innocuous	0.465 (R)	0.620 (R)	0.0498 (I)
SN-C	Reactive	0.161 (R)	0.277 (I)	0.5475 (R)
SN-D	Innocuous	1.098 (R)	1.610 (R)	0.1168 (I)
NN-B	Reactive	0.940 (R)	1.472 (R)	1.8678 (R)
NN-C	Reactive	0.186 (R)	0.322 (R)	1.7226 (R)

I: Innocuous; R: Reactive; [a]Expansion limit suggested by ASTM C 1260 (2007)
[b]Failure limit recommended by Islam (2010); [c]Failure limit suggested by Ghanem et al. (2010)

CONCLUSION

This study showed that the ASR decay model was well suited with the mortar expansion over the testing duration of 28 days. The ultimate mortar expansion (UME) and time needed in reaching at 50%, 75%, and 90% of the UME varied mainly on the geology of the investigated aggregate group. When compared to the 14-day expansion limit, the proposed failure criteria of ultimate mortar expansion showed better correlations with the findings obtained from the previously suggested 28-day the expansion limit in evaluating alkali–silica reactivity of the investigated aggregates.

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