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Alkali Silica Reaction Criteria for Accelerated Mortar Bar Tests Based on Field Performance Data

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SUMMARY

Supplementary cementitious materials (SCM) coupled with low alkali cement are used in concrete to mitigate alkali-silica reactivity (ASR) in Department of Defense (DOD) concrete airfield pavements. DOD specifications used to limit the expansion of accelerated mortar bar test (AMBT) results to 0.08% after 14 days of exposure, but in January 2008 this was changed to 0.08% after 28 days of exposure. While this more conservative approach further insures the prevention of ASR, it places significant constraints on aggregate supplies, and could result in unwarranted expenses if it unnecessarily required alternate aggregates to be transported from far away. Additional research has been performed based on existing extended studies of field concrete pavement slabs, along with AMBT tests (14-day as well as 28-day AMBT), and 2-year concrete prism tests (CPT) suggesting that this limit can be modified, at least for concrete not exposed to deicers, in an attempt to optimize the DOD specifications. The objective was to maintain the same level of safety in terms of ASR prevention, while either minimizing the costs, or maximizing the savings associated with these optimized specifications.

An analysis of these data has been performed and supports a reduced limit. A minimization process was employed to minimize false negative and false positive AMBT test results when compared to the field performance of the experimental concrete pavement slabs. This analysis clearly suggests that a reduced 14-day AMBT limit of 0.06% or a 28-day AMBT limit of 0.13% are equally as efficient for mitigating ASR (based on the available data), and would reduce costs by allowing the use of more local aggregates. The CPT is not recommended for evaluating ASR because of the number of false negatives and false positives associated with this test method when compared to the field performance of the concrete slabs, and because of the lengthy testing time and uncertainties associated with this test. Recommendations are made for further predictive model development of 14-day and 28-day AMBT test data using fly ash, and the use of class C fly ash.

BACKGROUND

Supplementary cementitious materials (SCM) coupled with low alkali cement are used in concrete to mitigate alkali-silica reactivity (ASR). Various SCMs are effective at preventing ASR [1]: 1) fly ash, Class F and some Class C, 2) ground granulated blast furnace slag (GGBFS), 3) class N pozzolans, e.g., calcined clays, 4) lithium salts, viz., lithium nitrate, and 5) silica fume. Fly ash is often of most interest because of its wide availability and relative low cost compared to slag, silica fume, lithium, and other pozzolanic materials. Fly ash is a by-product of the coal combustion process for energy generation and is largely a waste product, explaining its low cost. It is also cheaper than cement, so replacement of a portion of the cement with fly ash in a concrete mixture will tend to reduce the overall upfront cost of the concrete.

There are two classes of fly ash, class F ash, and class C ash. The differentiating point between the two classes of ash is in terms of their chemical constituency of the oxides of silica, alumina, and iron [2]. A class F ash has a sum of these oxides (SiO_2 + Al_2O_3 + Fe_2O_3), hereby denominated C618 sum, greater than 70% by mass of the ash, while a class C ash has between 50% and 70%. Class F ashes tend to have much less CaO by mass than class C ashes (ashes with high CaO tend to be less effective in the mitigation of ASR). It is well known that class F ash has, in general, superior mitigating effects on ASR compared to class C ash. For example, early DOD specifications [1] recommended class F fly ash in the range of 25% to 40% replacement for the cement in order to mitigate ASR (with a maximum CaO content of 8%), and recommended that class C ash not be used for ASR mitigation. More recent updates recognized that Class F ashes with higher C618 sum were more efficient at preventing ASR [3, 4], and that some Class C ashes could be used [4].

ASR is a reaction between the alkalis in the cement and reactive silicate aggregates such as opal, chert, chalcedony, tridymite, cristobalite, rhyolite, strained quartz, etc. The products of this reaction often result in significant concrete expansion and cracking, and ultimately failure of the concrete structure. Since the 1990s, there have been essentially two laboratory test methods for evaluating the degree of ASR of a given aggregate, viz., the concrete prism test (CPT, ASTM C1293 [5]) and the accelerated mortar bar test (AMBT, ASTM C1260 [6] or AASHTO T303 [7]). The CPT is typically a 1-year test when evaluating aggregate alone, or is extended to 2-years when evaluating SCMs. The AMBT, on the other hand, is performed over a nominal 14-day period (or in some cases is extended to 28-days, or even longer). Many researchers and agencies have used a modified form of ASTM C1260, over the years, for evaluating mortars with SCMs (e.g., McKeen, et al. [8, 9], as well as others). ASTM recently incorporated this modified approach for mortar bars with SCMs in ASTM C1567 [10].

Typically the differentiating point between reactive and non-reactive aggregates is 0.04% for the CPT (per ASTM C1293) and 0.10% for the AMBT (per ASTM C1260). On the other hand AASHTO T303 limits mortar bar expansion at 14 days to 0.08% for metamorphic aggregates, and 0.10% for all other aggregates. Other research also indicated that a 0.08% limit would be more appropriate (Stark et al. [11], ACI 221.1R [12]). De Grosbois, et al. [13] suggested lowering the AMBT specification from 0.10% to

0.08%, or even lower (e.g., they suggested that for carbonate aggregates, ASTM C1260 is not conservative enough, and a 0.06% threshold may be more appropriate). The DOD specification for the 14-day limit of AMBT expansion was initially established at 0.08% (based on [1]). More recently the DOD specification was changed to a 0.08% AMBT expansion at 28 days.

FIELD TEST DATA

Based on work by Fournier et al. [14, 15], Stokes et al. [16] showed that a more conservative DOD specification, than the original 14-day AMBT expansion of 0.08%, was needed to insure ASR prevention. Stokes et al. proposed 0.08% at 28 days, which was accepted by the DOD Tri-Services in January 2008, and included in the DOD specification for pavements. While this more conservative threshold would better prevent ASR, it may unnecessarily prevent some aggregates from being used that would have performed satisfactorily in the field. The paper of Stokes, et al., incorporates an analysis of Fournier's work with two additional aggregates (Stokes' aggregates C & D) and for a total of nine aggregates, and mixes with and without SCMs. Fournier's efforts encompassed a fairly exhaustive study of seven aggregates in various combinations of various fly ashes, silica fume, and cement replacement levels. Twenty-six combinations were reported with 14-day and 28-day AMBT results, 2-year CPT results, and an expansion study of 52 outdoor slabs.

Twenty-six of these slabs were boosted with sodium hydroxide (NaOH) to increase their total alkali content to 1.25% per cement mass in order to provide a more direct correlation with ASTM C1293 and simulate harsher environmental conditions, while the other 26 slabs were not boosted with NaOH. The age of these 52 slabs, at final expansion measurement, varied from 6 to 10 years. Figure 1 presents a fairly concise view of these data for 14-day AMBT vs. 2-year CPT for both failed and non-failed slabs. Note that the assumed level of failure for the slabs is the same as that for the CPT, viz., 0.04% (400 $\mu\varepsilon$). In Figure 1, slabs that failed with and without additional NaOH are shown in black, those that failed with additional NaOH but passed without it are shown in gray, and those that survived with or without NaOH are shown in white. Figure 2 shows a similar graph of 28-day AMBT vs. 2-year CPT data from these studies. Note that in their paper, Stokes et al. concentrated only on the boosted slabs.

INTERPRETATION OF ASTM C 1293 RESULTS

There are apparently two possible interpretations of ASTM C1293 CPT results. ASTM C1293 states, under Calculation:

> *11.1 Calculate the change in length between the initial comparator reading of the specimen and the comparator reading at each time interval to the nearest 0.001 % of the effective gage length…*

and in the Appendix:

> *X1.2 Work has been reported from which it may be inferred that an aggregate might reasonably be classified as potentially deleteriously reactive if the average expansion of three concrete specimens is equal to or greater than 0.04 % at one year.*

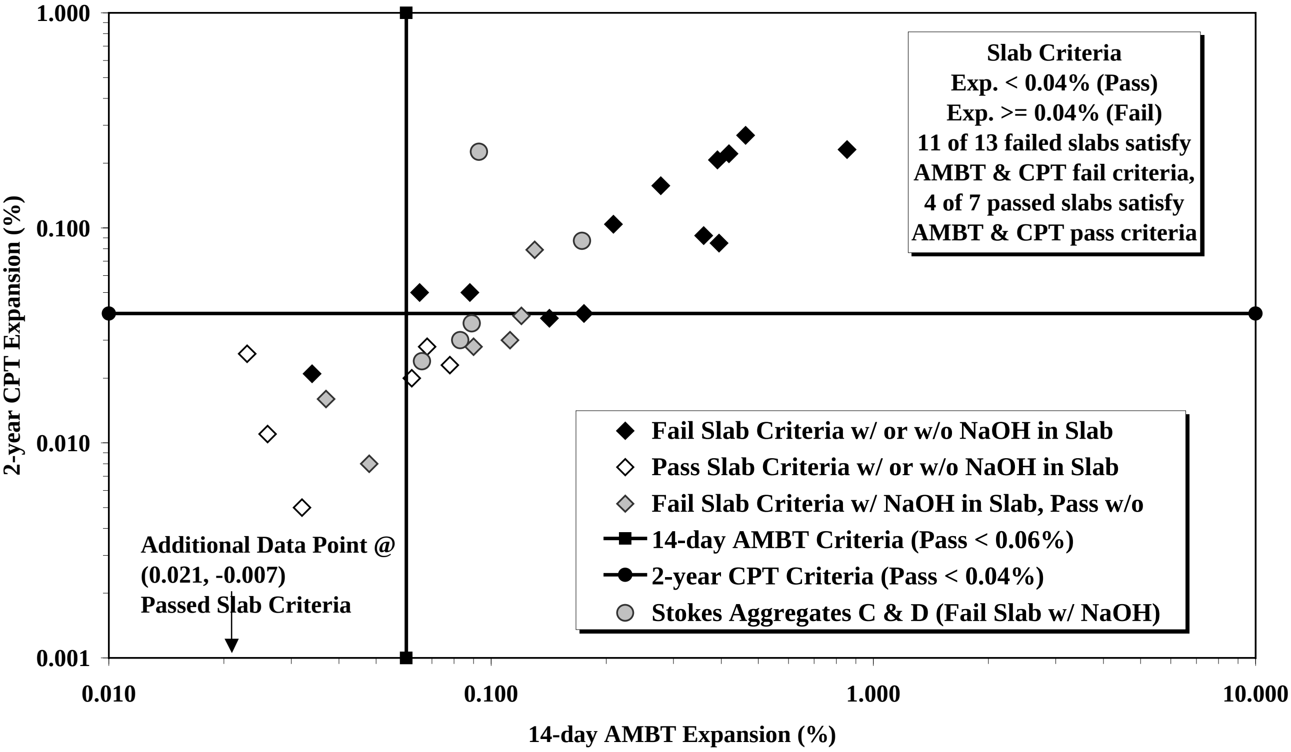

Figure 1. 14-day AMBT vs. 2-year CPT (Fournier, et al. [14,15], and Stokes, et al. [16]).

In the first interpretation, if an expansion is measured as 0.036% (with 3 decimals per Section 11.1), this value is less than 0.04%, and therefore the aggregate is innocuous (passes). This is the interpretation used here. The second interpretation, per Section X1.2, is to assume 0.04% and not 0.040% as a threshold, then the value of 0.036% should be rounded up to 0.04%, and therefore the aggregate is potentially deleterious (fails). This second interpretation seems less likely since Section 11.1 does not state that the calculated value should be rounded up (Section 9.1 of ASTM C1260 does require a round up, but it is a different standard). This second interpretation was used in Stokes et al.'s paper, and explains discrepancies with the reported data herein. For comparison purposes, in this paper even the C1260 data is not rounded (similar to Section 11.1 of ASTM C1293).

FALSE POSITIVES AND FALSE NEGATIVES

To minimize confusion, these terms are defined here:

- False Negative (False -): if the ASTM threshold used predicts no failure (negative) but the field specimens show failure, this is a false negative. False negatives will result in premature structural loss and significant costs, as the whole structure may need replacement. Hence the first objective is to minimize false negatives.
- False Positive (False +): if the ASTM threshold used predicts failure (positive) but the field specimens show no failure, this is a false positive. False positives will result

in increased construction expense, as more remote aggregate sources may be needed, although this increased expense should typically be less than structural replacement. Hence the second objective is to reduce false positives.

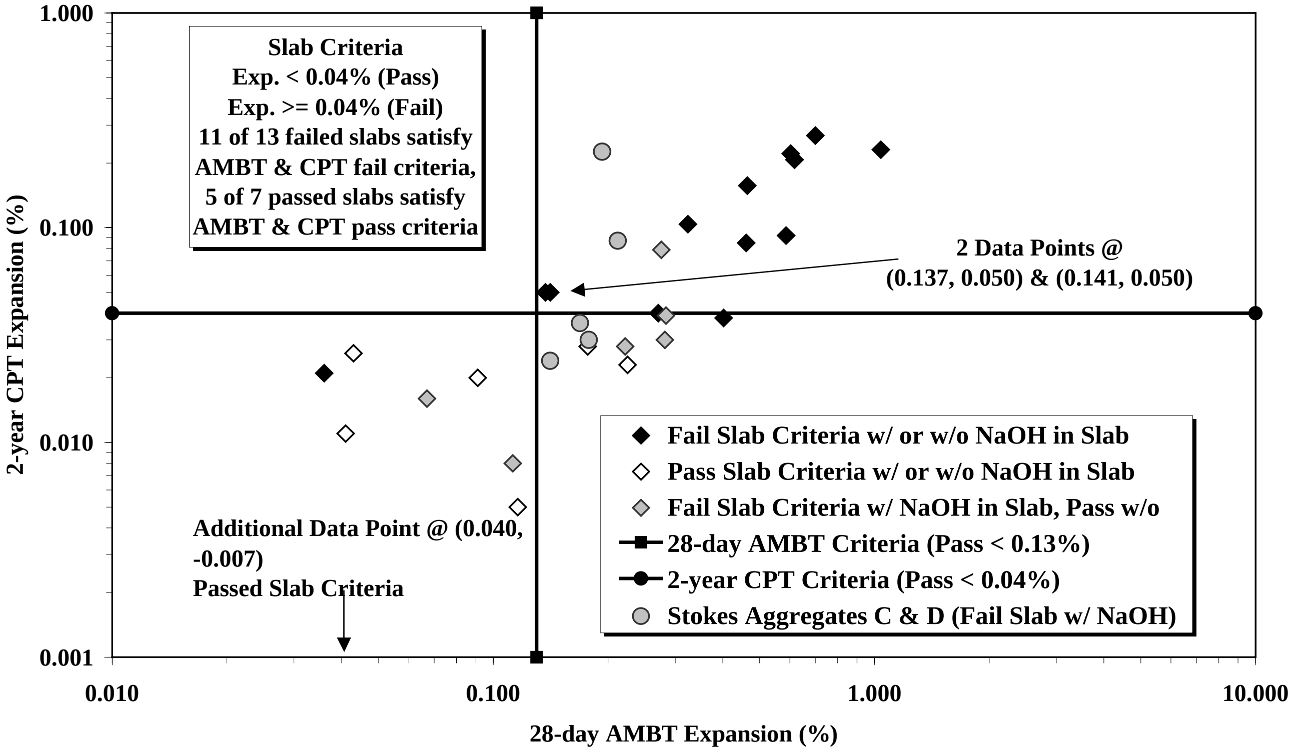

Figure 2. 28-day AMBT vs. 2-year CPT (Fournier, et al. [14,15], and Stokes, et al. [16]).

Table 1 shows (at the bottom) the percentages of false positives and false negatives for various ASTM thresholds and slabs with added NaOH. The last line shows percentages reported by Stokes et al., and the line before that the percentages based on the current interpretation of the thresholds (no rounding) and adjustment of a couple of data values. The following observations can be made:

- ASTM C1293 has up to 36% of false negatives and is one of the worst predictors of field behavior.
- ASTM C1260 with 0.1% at 14 days also has up to 36% of false negatives and is the other worst predictor of field behavior.
- Since both previous indicators have so many false negatives (i.e. allow so many aggregates to mistakenly pass the test), they show no false positives (they could hardly reject any aggregate).
- ASTM C1260 with 0.08% at 14 days is a significant improvement over the standard threshold of 0.10% at 14 days and over ASTM C1293.

- ASTM C1260 with 0.08% at 28 days is best at preventing ASR (least false negatives), but would reject many acceptable aggregates (highest false positives).

Fournier et al. [14, 15] also used slabs without added NaOH. When the ASTM thresholds are used to predict the field behavior of these slabs, it is to be expected that the number of false negatives will be lower, and the false positives will be higher when compared to the slabs with added NaOH. This is shown in Table 2. It should be noted that these slabs are probably more representative of actual structures, e.g. general airfield pavements. The previous slabs with added NaOH are perhaps more representative of airfield pavements exposed to deicers, although the latter represent a worst case scenario since they are subjected to an on-going external alkali source.

From these two comparisons it can be stated that:

- ASTM C1293 is not recommended
- ASTM C1260 with a threshold of 0.10% at 14 days is not recommended
- It may be possible to find two equivalent thresholds with ASTM C1260, one at 14 days and one at 28 days, which have the same minimum false negatives reported so far, and also have lower false positives.

PROPOSED NEW THRESHOLDS FOR ASTM C 1260

Table 3 shows proposed thresholds for ASTM C1260 at 14 days (0.06%) and at 28 days (0.13%) that minimize first the false negatives (to 4% for no added alkali, which is the minimum in Table 2, line before last), and then the false positives. These two thresholds are also shown in Figure 1 and Figure 2. These figures indicate that both thresholds are mostly equivalent to each other, and both are better than ASTM C1293.

The equivalency between 0.06% at 14 days and 0.13% at 28 days is perhaps best shown in Figure 3, where both thresholds agree on the false negatives and are similar on the false positives. Note, of course, that all these conclusions are based on the limited data presented herein, and could perhaps be further adjusted later on, as more data become available.

Figure 4 graphically presents data showing the relation between 14 and 28-day AMBT for aggregates with no SCMs (test per ASTM C1260). The data shown is from ten studies (McKeen, et al. [8, 9], Stark, et al. [11], Fournier, et al. [14, 15], Touma, et al. [17, 18], Shon, et al. [19, 20, 21], Rangaraju and Desai [22], da Cunha Munhoz, et al. [23], and Xie, et al. [24]. These aggregates range from very slightly reactive to extremely reactive. Clearly, all of the aggregates exceed the proposed 14-day and 28-day AMBT criteria of 0.06% and 0.13%, respectively. There is quite good agreement between both the 14-day AMBT 0.06% criteria and the 28-day AMBT 0.13% criteria based on the data shown.

Table 1. Percentage of false positives and false negatives for various ASTM thresholds and slabs with added NaOH.

Mixture	14-day AMBT			28-day AMBT		2-year CPT		Outdoor Slab		14-day	14-day	28-day	2-year	14-day	14-day	28-day	2-year
	0.10%	0.08%	expansion	0.08%	expansion	0.04%	expansion	0.04%	expansion	0.10%	0.08%	0.08%	0.04%	0.10%	0.08%	0.08%	0.04%
Aggregate	(P/F)	(P/F)	%	(P/F)	%	(P/F)	%	(P/F)	%	False +	False +	False +	False +	False -	False -	False -	False -
Aggregate A	F	F	0.391	F	0.617	F	**0.207**	F	0.255	0	0	0	0	0	0	0	0
A w/ 10% silica fume	F	F	0.142	F	0.402	**P**	0.038	F	0.086	0	0	0	0	0	0	0	1
B	F	F	0.278	F	0.464	F	**0.157**	F	0.11	0	0	0	0	0	0	0	0
B w/ 20% class F fly ash	P	P	0.048	F	0.125	P	0.008	F	0.044	0	0	0	0	1	1	0	1
B w/ 30% class F fly ash	P	P	0.021	P	0.04	P	-0.007	P	0.03	0	0	0	0	0	0	0	0
B w/ 7.5% silica fume	F	F	0.112	F	0.282	P	0.03	F	0.042	0	0	0	0	0	0	0	1
B w/ 10% silica fume	P	P	0.078	F	0.225	P	0.023	P	0.018	0	0	1	0	0	0	0	0
C	P	F	0.093	F	0.193	F	0.226	F	0.176	0	0	0	0	1	0	0	0
D	F	F	0.173	F	0.212	F	0.087	F	0.171	0	0	0	0	0	0	0	0
D w/ 7.5% silica fume	P	F	0.089	F	0.169	**P**	0.036	F	0.103	0	0	0	0	1	0	0	1
D w/ 10% silica fume	P	F	0.083	F	0.178	P	0.03	F	0.075	0	0	0	0	1	0	0	1
D w/ 12.5% silica fume	P	P	0.066	F	0.141	P	0.024	F	0.085	0	0	0	0	1	1	0	1
E	F	F	0.463	F	0.7	F	**0.269**	F	0.395	0	0	0	0	0	0	0	0
E w/ 20% class F fly ash	P	P	0.065	F	0.137	F	0.05	F	0.145	0	0	0	0	1	1	0	0
E w/ 30% class F fly ash	P	P	0.034	P	0.036	P	0.021	F	0.087	0	0	0	0	1	1	1	1
E w/ 7.5% silica fume	F	F	0.13	F	0.276	F	0.079	F	0.152	0	0	0	0	0	0	0	0
E w/ 10% silica fume	F	F	0.12	F	0.284	**P**	0.039	F	0.081	0	0	0	0	0	0	0	1
F	F	F	0.36	F	0.587	F	0.092	F	**0.141**	0	0	0	0	0	0	0	0
F w/ 20% class F fly ash	P	P	0.037	P	0.067	P	0.016	F	0.048	0	0	0	0	1	1	1	1
F w/ 30% class F fly ash	P	P	0.026	P	0.041	P	0.011	P	0.019	0	0	0	0	0	0	0	0
F w/ 7.5% silica fume	P	F	0.09	F	0.222	P	0.028	F	0.062	0	0	0	0	1	0	0	1
F w/ 10% silica fume	P	P	0.068	F	0.177	P	0.028	**P**	**0.029**	0	0	1	0	0	0	0	0
G	F	F	0.419	F	0.603	F	0.221	F	0.254	0	0	0	0	0	0	0	0
G w/ 20% class F fly ash	F	F	0.175	F	0.271	F	0.04	F	0.101	0	0	0	0	0	0	0	0
G w/ 20% class F fly ash	P	P	0.062	F	0.091	P	0.02	**P**	0.038	0	0	1	0	0	0	0	0
H	F	F	0.854	F	1.04	F	0.231	F	0.4	0	0	0	0	0	0	0	0
H w/ 20% class F fly ash	F	F	0.395	F	0.461	F	0.085	F	0.247	0	0	0	0	0	0	0	0
H w/ 30% class F fly ash	P	F	0.088	F	0.141	F	0.05	F	0.128	0	0	0	0	1	0	0	0
										0	0	11	0	**36**	**18**	7	**36**
									Stoke's et al. paper	0	0	4	0	43	29	7	32

Table 2. Percentage of false positives and false negatives for various ASTM thresholds and slabs with no added NaOH.

Mixture	14-day AMBT			28-day AMBT		2-year CPT		Outdoor Slab		14-day	14-day	28-day	2-year	14-day	14-day	28-day	2-year
	0.10%	0.08%	expansion	0.08%	expansion	0.04%	expansion	0.04%	expansion	0.10%	0.08%	0.08%	0.04%	0.10%	0.08%	0.08%	0.04%
Aggregate	(P/F)	(P/F)	%	(P/F)	%	(P/F)	%	(P/F)	%	False +	False +	False +	False +	False -	False -	False -	False -
Aggregate A	F	F	0.391	F	0.617	F	**0.207**	F	**0.164**	0	0	0	0	0	0	0	0
A w/ 10% silica fume	F	F	0.142	F	0.402	**P**	0.038	F	**0.044**	0	0	0	0	0	0	0	1
B	F	F	0.278	F	0.464	F	**0.157**	F	**0.102**	0	0	0	0	0	0	0	0
B w/ 20% class F fly ash	P	P	0.048	F	**0.1125**	P	0.008	**P**	**0.039**	0	0	1	0	0	0	0	0
B w/ 30% class F fly ash	P	P	0.021	P	0.04	P	-0.007	P	**0.008**	0	0	0	0	0	0	0	0
B w/ 7.5% silica fume	F	F	0.112	F	0.282	P	0.03	**P**	**0.022**	1	1	1	0	0	0	0	0
B w/ 10% silica fume	P	P	0.078	F	0.225	P	0.023	P	**0.026**	0	0	1	0	0	0	0	0
C	P	F	0.093	F	0.193	F	0.226	F	**0.176**	0	0	0	0	1	0	0	0
D	F	F	0.173	F	0.212	F	0.087	F	**0.171**	0	0	0	0	0	0	0	0
D w/ 7.5% silica fume	P	F	0.089	F	0.169	**P**	0.036	F	**0.103**	0	0	0	0	1	0	0	1
D w/ 10% silica fume	P	F	0.083	F	0.178	P	0.03	F	**0.075**	0	0	0	0	1	0	0	1
D w/ 12.5% silica fume	P	P	0.066	F	0.141	P	0.024	F	**0.085**	0	0	0	0	1	1	0	1
E	F	F	0.463	F	0.7	F	**0.269**	F	**0.345**	0	0	0	0	0	0	0	0
E w/ 20% class F fly ash	P	P	0.065	F	0.137	F	0.05	F	**0.107**	0	0	0	0	1	1	0	0
E w/ 30% class F fly ash	P	P	0.034	P	0.036	P	0.021	F	**0.046**	0	0	0	0	1	1	1	1
E w/ 7.5% silica fume	F	F	0.13	F	0.276	F	0.079	**P**	**0.018**	1	1	1	1	0	0	0	0
E w/ 10% silica fume	F	F	0.12	F	0.284	**P**	0.039	**P**	**0.001**	1	1	1	0	0	0	0	0
F	F	F	0.36	F	0.587	F	0.092	F	**0.119**	0	0	0	0	0	0	0	0
F w/ 20% class F fly ash	P	P	0.037	P	0.067	P	0.016	**P**	**0.032**	0	0	0	0	0	0	0	0
F w/ 30% class F fly ash	P	P	0.026	P	0.041	P	0.011	P	**0.014**	0	0	0	0	0	0	0	0
F w/ 7.5% silica fume	P	F	0.09	F	0.222	P	0.028	**P**	**0.027**	0	1	1	0	0	0	0	0
F w/ 10% silica fume	P	P	0.068	F	0.177	P	0.028	**P**	**0.029**	0	0	1	0	0	0	0	0
G	F	F	0.419	F	0.603	F	0.221	F	**0.189**	0	0	0	0	0	0	0	0
G w/ 20% class F fly ash	F	F	0.175	F	0.271	**F**	0.04	F	**0.073**	0	0	0	0	0	0	0	0
G w/ 30% class F fly ash	P	P	0.062	**F**	0.091	P	0.02	**P**	**0.032**	0	0	1	0	0	0	0	0
H	F	F	0.854	F	1.04	F	0.231	F	**0.4**	0	0	0	0	0	0	0	0
H w/ 20% class F fly ash	F	F	0.395	F	0.461	F	0.085	F	**0.247**	0	0	0	0	0	0	0	0
H w/ 30% class F fly ash	P	F	0.088	F	0.141	F	0.05	F	**0.128**	0	0	0	0	1	0	0	0
									Without added alkali	11	14	**29**	4	25	11	4	18
									With added alkali	0	0	11	0	36	18	7	36

Table 3. Minimum percentage of false positives and false negatives for ASTM C1260.

Risk	Additional Alkali in Slab	0.06% at 14 days	0.13% at 28 days
False Negative	**No**	**4**	**4**
	Yes	**11**	**11**
False Positive	**No**	**25**	**21**
	Yes	**11**	**7**

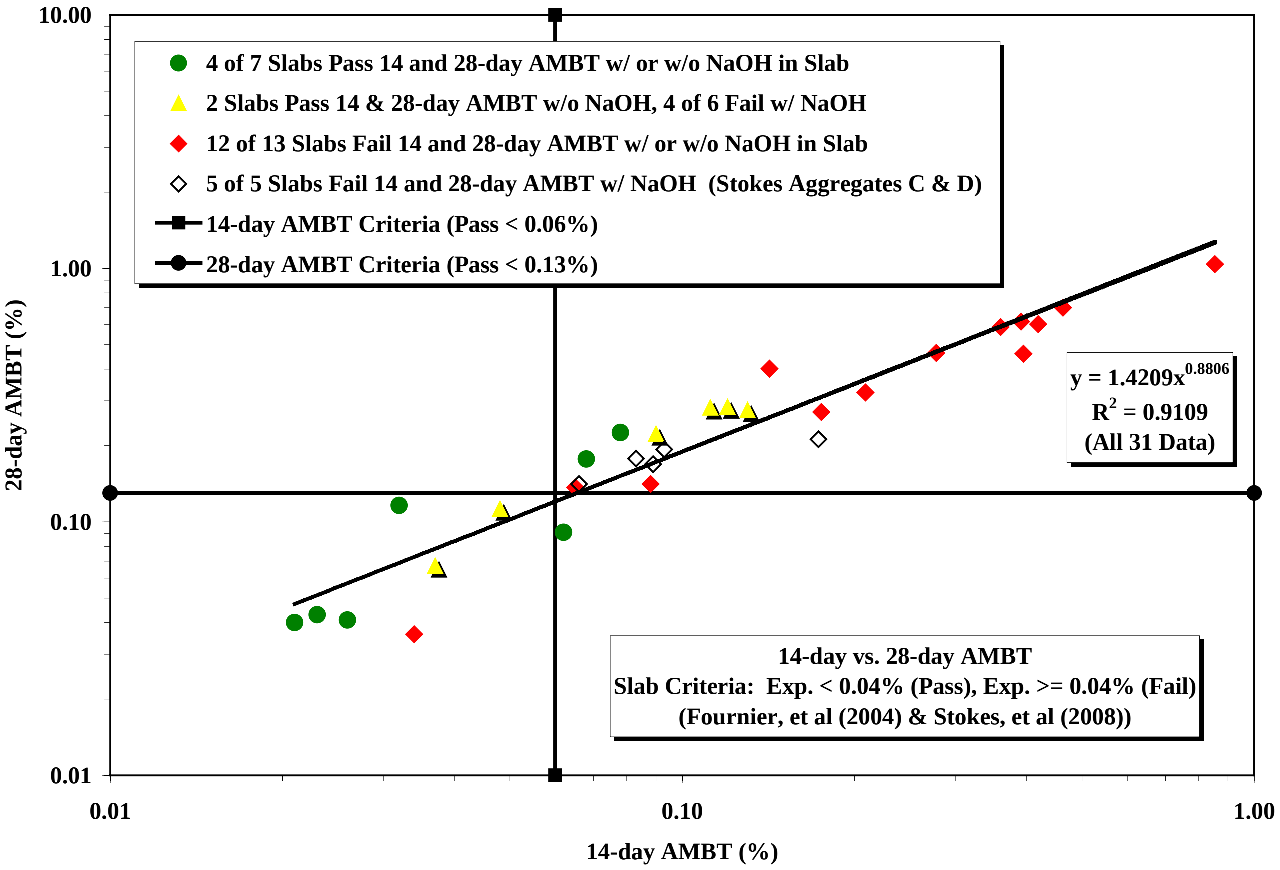

Figure 3. 14-day vs. 28-day AMBT (Fournier, et al. [14,15], and Stokes, et al. [16]).

Figure 5 presents a similar graph based on these ten aforementioned studies. This Figure shows 259 data points of not only the control tests per ASTM C1260 (aggregates alone, as depicted in Figures 3 and 4), but also data from ASTM C1567 (or equivalent) using class C and class F fly ash of varied chemistry and replacement rates between 10% and 70% with the same aggregates of Figure 4. Of the 259 data points shown, 68 pass both the 14-day 0.06% and the 28-day 0.13% criteria (26% of the observations). These that passed the criteria clearly have made use of quality SCMs and/or replacement levels for mitigating the ASR per ASTM C1567. Those that have not passed either the 14-day or 28-day criteria are test results where insufficient ash replacement has been used or poor quality fly ash has been used. Again note that the cited correlation passes through the intersection of the 0.06% and 0.13% criteria, indicating their equivalency.

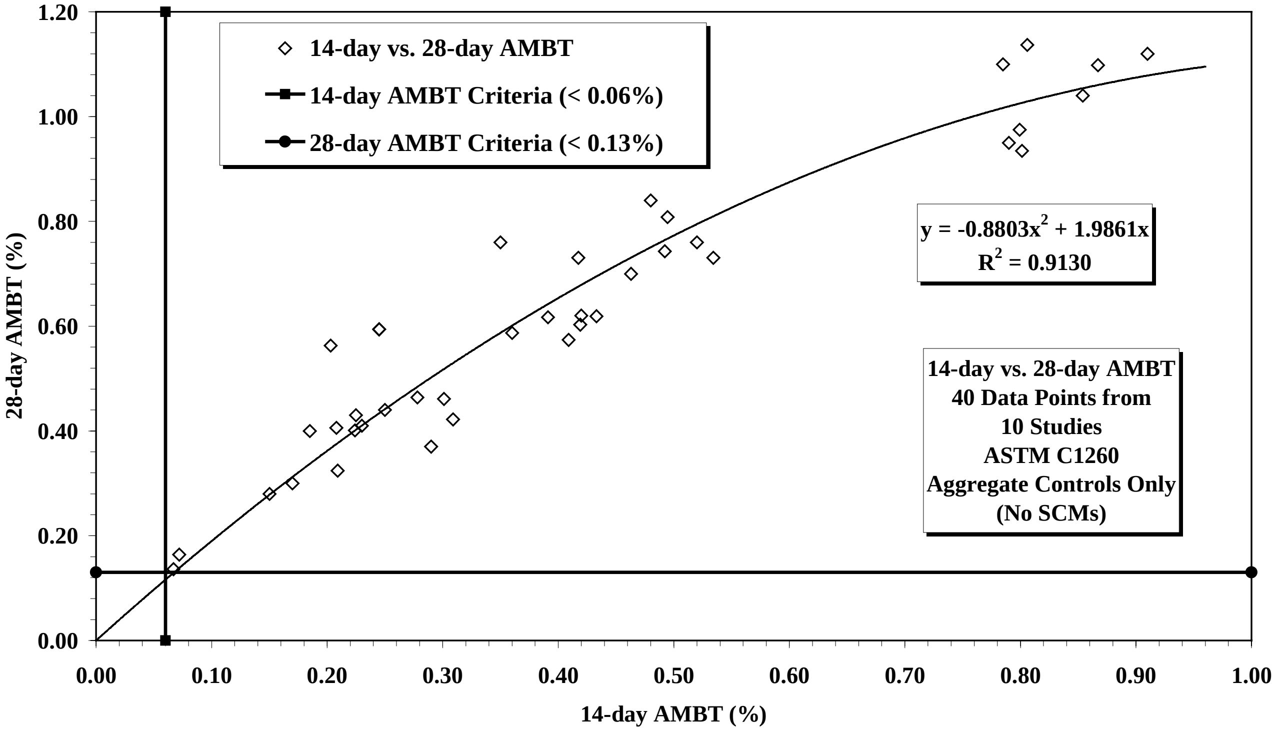

Figure 4. 14-day vs. 28-day AMBT from 10 Studies (controls, with no fly ash).

PREDICTIVE MODELS FOR ESTIMATING FLY ASH REPLACEMENT

While the 70% criteria for the ASTM C618 sum distinguishes between class C and class F ashes, it does not distinguish well between two Class F ashes, or between two class C ashes, in terms of their ability to mitigate ASR. Furthermore for a class C ash near the 70% level and a class F ash near the 70% level, the question can be posed, are they significantly different in terms of their ability to mitigate ASR?

A predictive model was developed for ascertaining the superiority of one ash versus another in terms of the 14-day AMBT on aggregate alone and the chemistry of the fly ash and cement [3, 4]. This model incorporated all of the usual chemistry constituents normally characterized for both fly ash and cement. Specifically included are the constituents that tend to mitigate ASR (SiO_2, Al_2O_3, Fe_2O_3) and those that exacerbate ASR (CaO, MgO, SO_3, and the alkalis NaO_2 and K_2O). The model was based on existing studies of AMBT results with and without ash at varied replacement levels. The five studies used in the model included: 1) McKeen, et al. [8, 9], 2) Touma, et al. [17, 18], 3) Shon, et al. [19], 4) Detwiler [25], and 4) Thomas and Innis [26] and Shehata and

Thomas [27]. In the model the efficiency of the fly ash to mitigate ASR is characterized by all its components in the form of a fly ash chemical index C_{fa} :

$$C_{fa} = \frac{CaO + \alpha(0.905Na_2O + 0.595K_2O + 1.391MgO + 0.700SO_3)}{SiO_2 + \beta(0.589Al_2O_3 + 0.376Fe_2O_3)}$$

where α and β were approximately taken as 6 and 1, respectively. As the fly ash components that reduce ASR expansion increase, and the components that produce expansion decrease, this index decreases (it theoretically would reach zero if the ash had no deleterious components). This index was shown to (inversely) correlate very well with the ASTM C618 sum. As this sum increases towards 100% the index tends towards zero, and the ash is most suited to prevent ASR (Figure 6).

The predictive model can be summarized in Figure 7. For a given cement, a given aggregate (characterized by its ASTM C1260 expansion), and a given fly ash (characterized by its chemical index or its ASTM C618 sum), Figure 7 shows the amount of cement replacement with fly ash that has to take place to insure (with 50% reliability in this case) that the 14-day expansion will not exceed 0.08%.

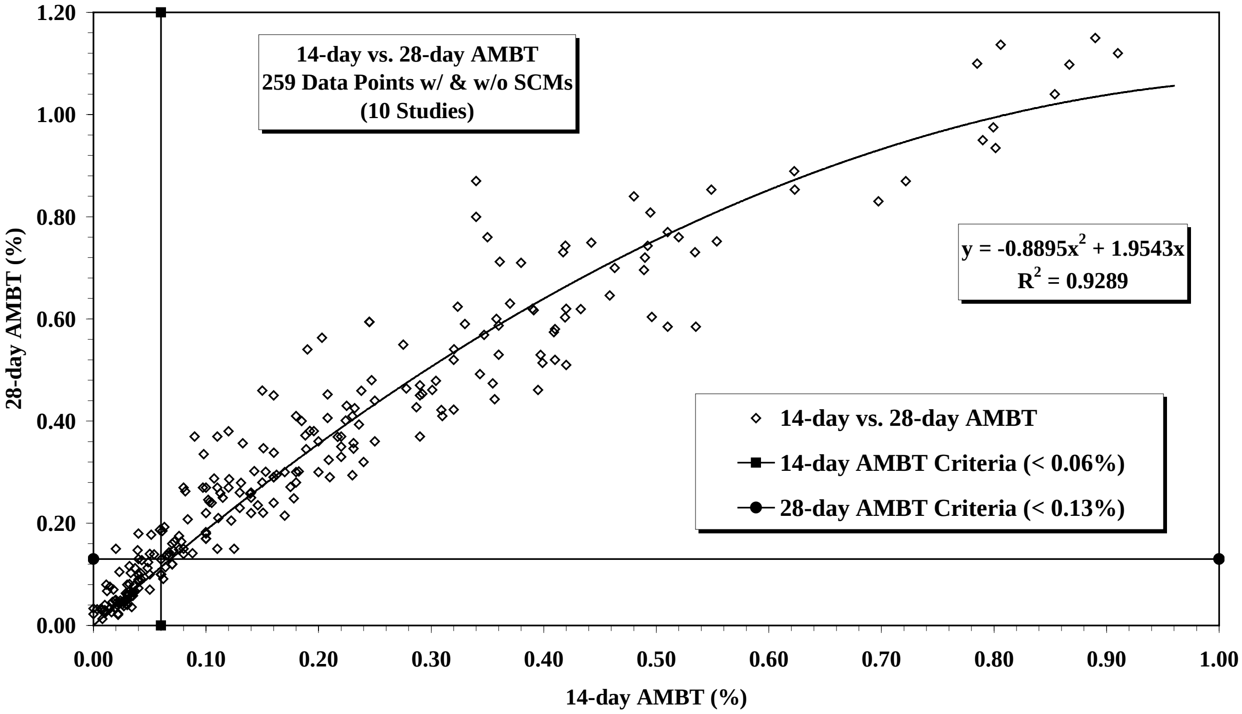

Figure 5. 14-day vs. 28-day AMBT from 10 Studies (with and without fly ash).

While a suitable model has been developed for estimating the cement replacement level for a given ash and aggregate reactivity for 14-day AMBT, a similar model has yet to be developed for 28-day AMBT data. 28-day AMBT data do exist, however, many from the same references used in the 14-day model. 28-day data is available in at least the following sources, 1) McKeen, et al. [8, 9], 2) Stark, et al. [11] Fournier, et al. [14, 15] Touma, et al. [17, 18], 5) Shon, et al. [19, 20, 21], 6) Rangaraju and Desai [22], 7) da Cunha Munhoz, et al. [23], and 8) Xie, et al. [24].

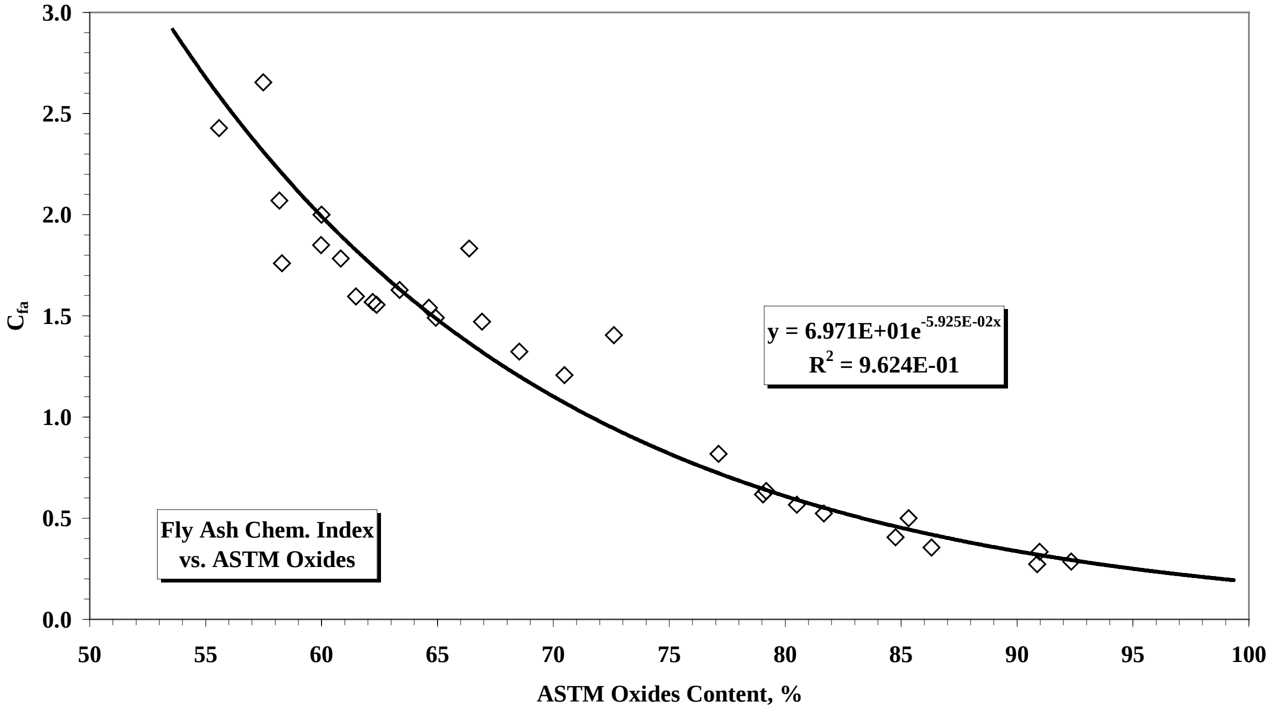

Figure 6. Fly ash ASTM C618 sum vs. Chemical Index, C_{fa} .

ADDITIONAL DIFFICULTIES WITH ASTM C 1293

One additional significant problem with ASTM C1293 is the 1-year test duration (or 2-year duration if SCMs are used). It is impossible to insure that the reactivity of the aggregate being mined today is the same as the reactivity of the aggregate used in the test 1 year ago (or 2 years ago). In fact the variation in reactivity from one year to the next can be very significant, for example Shrimer [28] reports: “in one pit, evaluation… showed reaction levels ranging from low (safe use) for one year’s production to high (very reactive) in tests conducted for another year’s production.”

CONCLUSIONS

Based on the literature reviewed and the analysis conducted in this report it has been shown that that the 2-year concrete prism test (CPT) produces more false negatives than past and current DOD criteria, as well as either the 14-day 0.06% expansion criteria or 28-day 0.13% expansion criteria using the accelerated mortar bar test (AMBT). Hence, the CPT (ASTM C1293), even though it has previously been a recommended test method for determining the potential ASR reactivity of an aggregate, is currently not recommended for routine evaluation of aggregate reactivity. This is even more the case considering the extended test period required for the CPT, since the aggregate being mined now may have very different reactivity than when the test was started. The 14-day or 28-day AMBT provide meaningful test results of an aggregate's reactivity in a more timely fashion.

Once false negatives are minimized, and false positives minimized to the extent possible, recommended thresholds for the 14-day and 28-day AMBT, using ASTM C1260 and ASTM C1567 are 0.06% and 0.13%, respectively. These criteria should be considered for future Navy and DOD concrete pavement ASR evaluations.

While a 14-day model has been developed for estimating the fly ash replacement for cement in concrete, a 28-day model has yet to be developed for estimating fly ash replacement. However, sufficient data does exist for developing such a model.

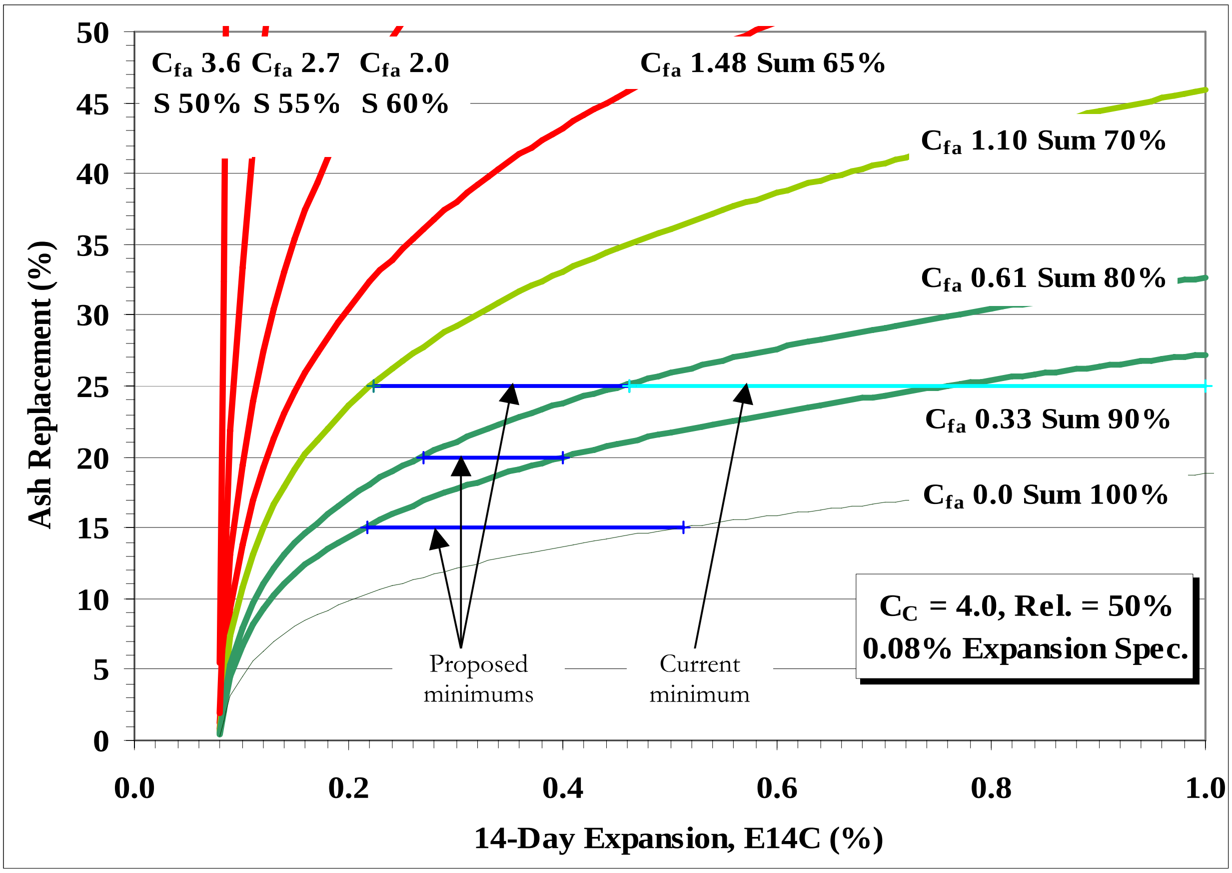

Figure 7. Minimum fly ash replacement to mitigate ASR with 50% reliability [3].

RECOMMENDATIONS

While a 14-day model has been developed for estimating the fly ash replacement for cement in concrete, additional efforts should be directed at expanding this database in order to incorporate studies with additional aggregates, fly ash, and cement. Particular emphasis should be aimed toward the inclusion of more Class C ash with high CaO levels and high replacement levels of ash. Additional studies, beyond those cited in Malvar and Lenke [3], are known and have been cited in this paper. Such an expanded database will allow for verification and recalibration of the model [3]. Once this revised model is devised, design charts and design tables can be developed for cements with different chemistries, and the lower 14-day AMBT threshold of 0.06%. Undoubtedly, additional studies exist with 14-day AMBT data that will allow for inclusion of a broader range of aggregates, cement, and fly ash (both C and F) from a wide range of geographical areas nationwide and worldwide.

28-day data are now also available, allowing for the development of a similar model as described by Malvar and Lenke [3]. Ten studies do exist with a plethora of 28-day data, and have been noted and cited in the references. It is likely that additional studies do exist with 28-day AMBT data that will allow for inclusion of a broader range of aggregates, cement, and fly ash (both C and F). As suggested above, design charts and design tables can then be developed for cements with different chemistries, and the recommended 28-day AMBT threshold of 0.13%.

Lastly, efforts should be extended to find additional field performance data of concrete pavement slabs coupled with AMBT and CPT results that will further reinforce and validate the proposed lower thresholds of 0.06% and 0.13% for the 14-day and 28-day AMBT, respectively.

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