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PERFORMANCE OF THE 60°C – ACCELERATED CONCRETE PRISM TEST FOR THE EVALUATION OF POTENTIAL ALKALI-REACTIVITY OF CONCRETE AGGREGATES

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ABSTRACT

Accelerated Concrete Prism Tests using a curing temperature of 60°C over a period of 3 months have been performed and correlated with the 38°C one-year Concrete Prism Test (CSA A23.2-14A, ASTM C1293) for the evaluation of the potential alkali-reactivity of concrete aggregates. Ninety-five (95) comparative tests are presented, grouped by different rock lithologies from distinct aggregate sources. The results indicate a very good correlation for carbonates and terrigenous aggregates. An expansion limit of 0.04% at 91 days is proposed. Some exceptions were found with igneous and metamorphic aggregates and a conservative expansion limit of 0.025% at 91 days is proposed for these.

Keywords: Aggregate-alkali-reactivity, concrete prism test, diagnostic, expansion limit, rock lithology, temperature.

INTRODUCTION

Several test methods are presently in use for the evaluation of potential alkali-aggregate reactivity of concrete aggregates. Among these, the one-year Concrete Prism Test (CSA A23.2-14A, ASTM C1293) is one of the most well recognized and is representative of field performance of the aggregates in Canada and USA. This test is performed with concrete prisms using a cement dosage of 420 kg/m^3 with the alkali content increased to 1.25% by adding NaOH solution for a total alkali load of 5.25 kg/m^3. This test takes 365 days before yielding a diagnostic on the aggregate. Besides this long-term testing method, other accelerated testing methods exist which involve testing coarse aggregates with mortar bars rather than concrete mixes and using different accelerating protocols, e.g. high temperature.

An Accelerated Concrete Prism Test is proposed using the same concrete prisms and mix design but adding an accelerating agent by increasing the curing temperature from 38°C to 60°C, thus reducing the curing period to be monitored to 3 months.

Ranc and Debray introduced the Accelerated Concrete Prism Test (60°C) in 1992. Twenty-one (21) natural and artificial aggregates ranging from deleteriously reactive to non-reactive were tested in concrete prisms stored at 38°C and 60°C. They found a good correlation between the two tests and proposed an expansion limit of 0.02% after 56 days of curing at 60°C. Murdock and Blanchette (1994) compared eleven (11) Canadian aggregate sources and also found a good correlation between the 38°C and the 60°C test using the expansion limit of 0.02% at 56 days of Ranc and Debray. They also proposed a maximum expansion limit of 0.03% at 91 days. The 60° Concrete Prism Test was also found sensitive enough to accurately reflect changes in expansions due to the addition of silica fume and/or entrained air (Murdock and Blanchette, 1994).

This study comprises a total of ninety-five (95) comparative expansion tests on prisms stored at 38°C and at 60°C. The tests were performed on different aggregate sources representing a wide range of aggregate petrography. The performance of the 60°C Concrete Prism Test is evaluated for each major rock classification and evaluation criteria such as maximum expansion limit and curing period are recommended.

CONCRETE PRISM TESTS PROCEDURES

The one-year Concrete Prism Tests were done according to the CSA Procedure A23.2-14A (Potential Expansivity of Aggregates - Procedure for Length Change Due to Alkali-Aggregate Reaction in Concrete Prism). This test is similar to ASTM C-1293 Test.

The first Accelerated Concrete Prism Tests by Ranc and Debray (1992) were done according to the AFNOR Procedure P 18-587 (Stabilité dimentionnelle en milieu alcalin – Essai sur béton) using a curing temperature of 60°C instead of the 38°C specified in Procedure P 18-587. Between the AFNOR and North American procedures for the 38°C Concrete Prism, there are only some slight differences in the concrete prism mix design, notably using a cement dosage of 410 kg/m^3 in the AFNOR compared to 420 kg/m^3 in the CSA Procedure. The main difference between the two procedures is related to the curing period which is set at 8 months in the AFNOR compared to 12 months in the CSA Procedure using the same maximum expansion limit of 0.04%. In this study, the Accelerated Concrete Prism Tests were done according to the CSA Procedure A23.2-14A, modifying the curing temperature from 38°C to 60°C. The prisms were stored in stainless steel containers in a metallic reactor at 60°C ± 2°C with the relative humidity at 100%. After initial measurement, expansion measurements are done at 7, 14, 28, 56 and 91 days.

INTERPRETATION OF RESULTS

The ninety-five (95) comparative tested aggregates used in this study, have been subdivided into 3 distinct lithological groups: Carbonates rocks, Terrigenous sedimentary rocks, and Igneous/Metamorphic rocks. The results are illustrated graphically and include correlation curves, correlation factors (R^2), and prediction intervals of 95%, using the equations described in Walpole and Myers (1993). For each lithological group, expansion values of the 60°C Concrete Prism Test corresponding to the maximum expansion limit of 0.04% with the one-year 38°C Concrete Prism Test, have been calculated from the regression curve equation used as a mean, and to give a more conservative point of view, from the lower prediction curve equation.

Correlation between the results of the 60°C and the 38°C Concrete Prism Tests have been compared at 56 and 91 days for each lithological group. The performance of the 60°C Concrete Prism Test is evaluated in terms of the accuracy of the diagnosis to detect the potential of alkali reactivity as determined by the long-term 38°C Concrete Prism Test. Three different evaluations will be discussed:

Good: Good correlation - 38°C and 60°C Concrete Prism Tests give the same diagnostic (reactive / non-reactive).

Over-Estimated: The potential of alkali-reactivity of the aggregate is over-estimated. Aggregate considered reactive with the 60°C Concrete Prism Test, but non-reactive according to the 1-Year Concrete Prism Test.

Under-Estimated: The potential of alkali-reactivity of the aggregate is under-estimated. Aggregate considered non-reactive by the 60°C Concrete Prism Test, but found reactive according to the 1-Year Concrete Prism Test.

Carbonate Rocks

This group comprises 47 comparative tests. The Carbonate rocks include relatively pure limestones, dolostones, dolomitic limestones, and calcareous dolostones. Shaley and sandy carbonate rocks contain a proportion of sand and/or silt and clay components of less than 50%. Mixed aggregates, such as found in gravel deposits, are also included in this group if the proportion of carbonate aggregates exceeds 50%. All tested carbonate samples are of Paleozoic Age and come from the St. Lawrence Lowlands, the Great Lakes Sedimentary Basins, and the Rocky Mountain Foothills.

Among those 47 tests, 3 were done with relatively high alkali-reactive aggregate samples (expansion from 0.11% to 0.19% at 365 days), which consist of limestones with high amount of chert either found finely disseminated in the limestone or present as centimetric chert nodules. The 60°C Concrete Prism Test was successful in identifying the high reactivity of these aggregates but we choose to not include these results in the correlation curve as well as any other results that would have expansion exceeding 0.1%, because we are more interested in those with expansion values close to the 0.04% limit on the 38° Concrete Prism Test.

For the remaining 44 comparative tests performed on carbonate aggregate samples, the correlation is slightly better at 91 days, compared to 56 days with respective correlation factors (R^2) of 0.89 and 0.85 (Fig. 1). The calculated expansions of the 60°C Concrete Prism Test corresponding to an expansion of 0.04% at one year with the 38°C Concrete Prism Test are summarized in Table 1.

TABLE 1: Carbonates Rocks - Calculated and Proposed Expansion Limits for the 60° C Concrete Prism Test Corresponding to an Expansion of 0.04% at One-Year with the 38°C Concrete Prism Test

	91 days				56 days			
	Expansion	Diagnostic*			Expansion	Diagnostic*		
		Good	Over	Under		Good	Over	Under
Regression Curve	0.039%	96%	2%	2%	0.029%	92%	2%	6%
Lower Prediction Curve (95%)	0.029%	70%	30%	0%	0.018%	66%	34%	0%
Proposed Maximum Expansion Limit	***0.04%***	***96%***	***2%***	***2%***	***0.02%***	***66%***	***34%***	***0%***

* The diagnostic is based on the 1-Year Concrete Prism Test result.
Good: 38°C and 60°C Concrete Prism Tests give the same diagnostic (reactive / non-reactive)
Over: Potentially reactive (60°C); but non-reactive according to the 1-year Concrete Prism Test.
Under: Non-reactive (60°C); but potentially reactive according to the 1-year Concrete Prism Test

Expansion limit for the 60°C Concrete Prism Test is recommended after a curing period of 91 days because the correlation factor is better and also because late expansion in some samples (especially carbonates mixed with granitic rocks) was not detected after 56 days of curing. In this case, the accelerated testing method is under-estimating the reactivity of these aggregates.

A maximum expansion limit of 0.04% after a curing period of 91 days is recommended for carbonates aggregates, for which 96% of the diagnostics are good. When being rounded to two decimals, the expansion values obtained with the 4% of under and over-estimated diagnostics fall to 0.04%. The maximum expansion of 0.02% at 56 days introduced by Ranc and Debray (1992) could be used since no tested sample in this study with an expansion below 0.02% at 56 days was found reactive with the one-year Concrete Prism Test. However, the reactivity of 34% of the samples is over-estimated and shows high expansions of over 0.02% at 56 days, but are found non-reactive with the one-year Concrete Prism Test.

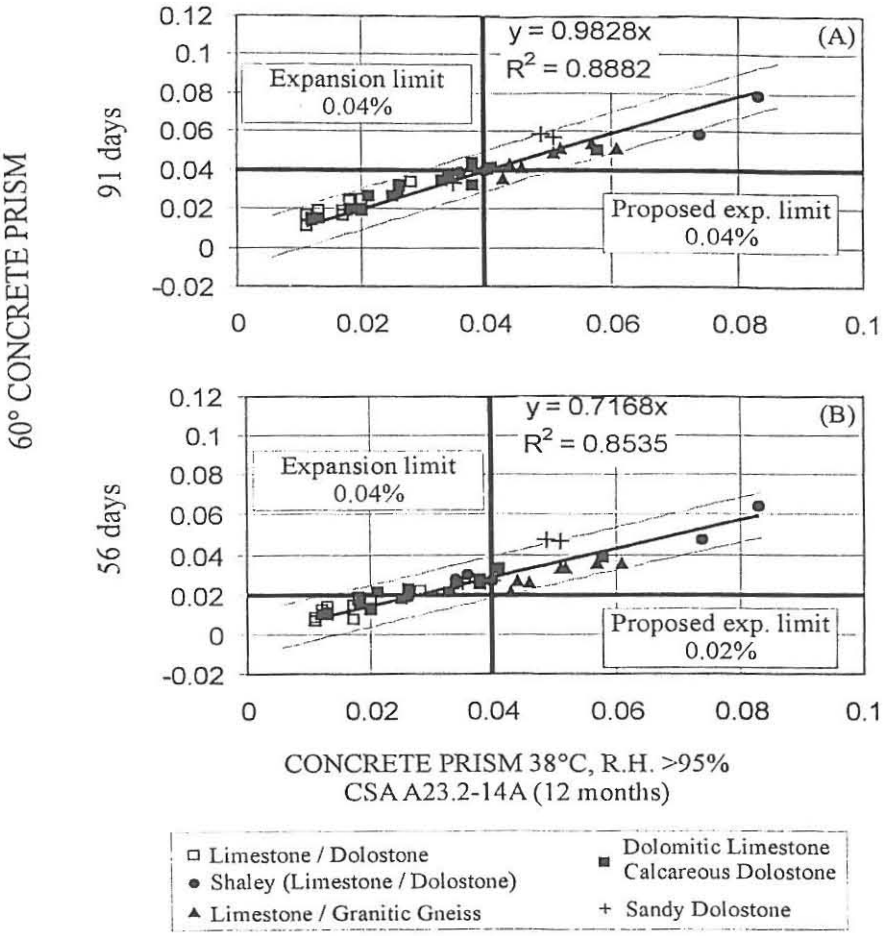

Fig. 1: Correlation between the 1-Year 38°C Concrete Prim Test and the 60°C Concrete Prism Test for Carbonate Rocks (n=44). (A) at 91 days, (B) at 56 days

The expansion limit of 0.029% at 91 days given by the lower prediction curve is too conservative and unfair since 30% of the tested aggregate samples would be considered reactive with the 60°C, but non-reactive with the 38°C Concrete Prism Test at one-year.

Terrigenous Sedimentary Rocks

Twenty-four (24) aggregate samples were tested in this group, which includes sandstones, siltstones and mudstones in proportions of higher than 50% of the aggregate. The sources of those aggregate samples are from the Rocky Mountains Foothills and the Appalachian Piedmont.

Tested samples included sandstones, quartz arenites, lithic and feldspatic arenites, quartz wackes, lithic and feldspatic wackes (classification of Gilbert in William et al., 1982). The majority of those aggregates come from sand and gravel pits and are thus mixed with other rock lithologies such as carbonates, crystalline intrusives and metamorphic gneiss. A large number of testing records come from France and several of those aggregates include a proportion of chert or flint particles reaching up to 90%. In France, the 38°C Concrete Prism Tests lasts 8 months compared to 1 year in Canada and thus, the expansions from the French records were estimated at 1 year using the expansion slope equation found from 6 to 8 months.

TABLE 2: Terrigenous Sedimentary Rocks – Calculated and Proposed Expansion Limits for the 60°C Concrete Prism Corresponding to an Expansion of 0.04% at One-Year with the 38°C Concrete Prism Test

	91 days				56 days			
	Expansion	Diagnostic*			Expansion	Diagnostic*		
		Good	Over	Under		Good	Over	Under
Regression Curve	0.037%	96%	4%	0%	0.026%	96%	4%	0%
Lower Prediction Curve (95%)	0.017%	83%	17%	0%	0.010%	67%	33%	0%
Proposed Maximum Expansion Limit	***0.04%***	***96%***	***4%***	***0%***	***0.02%***	***92%***	***8%***	***0%***

* The diagnostic is based on the 1-Year Concrete Prism Test result.
Good: 38°C and 60°C Concrete Prism Tests give the same diagnostic (reactive / non-reactive).
Over: Potentially reactive (60°C); but non-reactive according to the 1-year Concrete Prism Test.
Under: Non-reactive (60°C); but potentially reactive according to the 1-year Concrete Prism Test

Very good correlation factors (R^2) are found at 91 and 56 days, with respective values of 0.95 and 0.93 (Fig. 2). The correlation slopes are slightly lower for this group than the ones found for the Carbonate group, which means that terrigenous sedimentary rocks are found in general to be slightly less reactive in tests at 60°C compared to those at 38°C. Calculated expansion limits for the 60°C Concrete Prism are summarized in Table 2.

For the same reasons mentioned for the carbonates rocks, because of a better correlation factor and sufficient time for late expansion to develop, we recommend the use of the final expansion values after a curing period of 91 days. The expansion limit of 0.04% at 91 days recommended for the Carbonate rocks is also valid for the terrigenous sedimentary rocks, grouping all the rocks of sedimentary origin together. In 96% of the cases, the 60°C Accelerated Concrete Prism Test has a good diagnosis. The limit of 0.02% at 56 days is valid to give a good diagnostic in most of the cases, but some of the results are still over-estimating the reactivity of the aggregate by giving excessive expansion at 60°C.

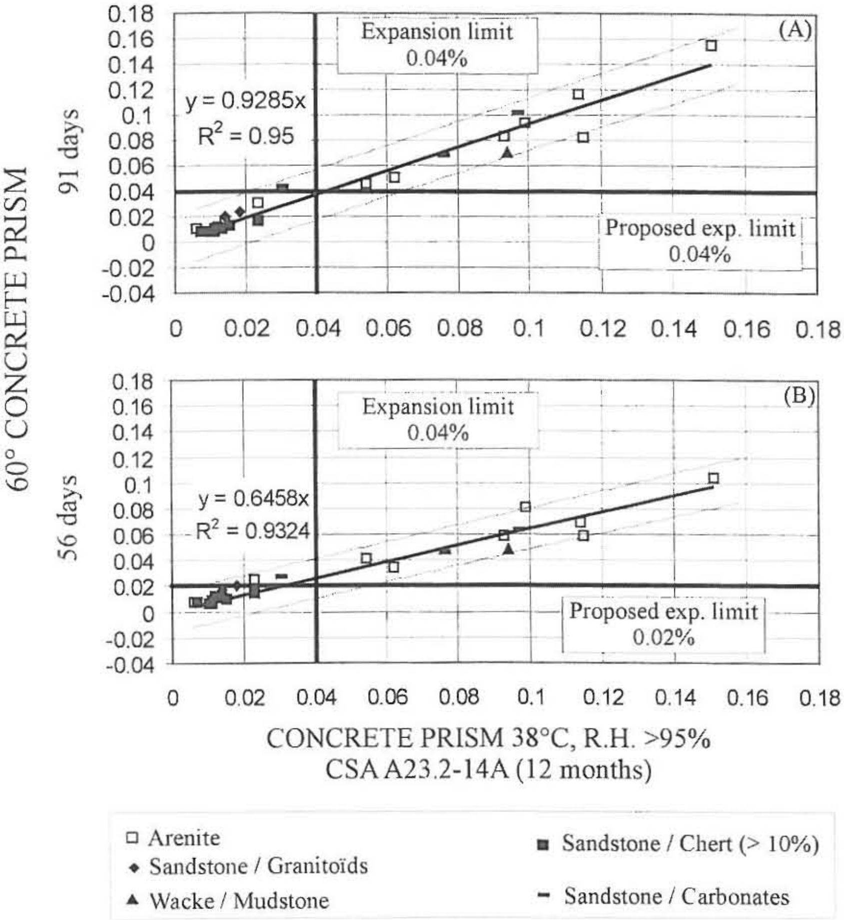

Fig. 2: Correlation between the 1-Year 38°C Concrete Prim Test and the 60°C Concrete Prism Test for Sedimentary Rocks (n=24). (A) at 91 days, (B) at 56 days

Igneous and Metamorphic Rocks

Twenty-two (22) aggregate samples belong to this group. This group can be subdivided into mafic and felsic aggregates. Mafic aggregates include serpentinite, mafic to intermediate volcanics, diorite, gabbro, and hornblende and biotite gneiss; while felsic aggregates are represented by granite, granodiorite, and granitic gneiss. The tested samples come from the Canadian Cordillera, the Appalachians and the Canadian Precambrian Shield. About half of them come from quarries and the other half from sand and gravel pits. A minimum of proportion of 50% of igneous and/or metamorphic aggregates is contained in each sample.

In this group, the correlation factors are not as good as with the sedimentary rocks showing values of 0.65 at 91 days and 0.73 at 56 days (Fig. 3). Only a fairly limited number of samples were tested to represent the large variability of rock lithologies found in this group.

After a curing period of 91 days, 6 outliers or exception results can be clearly identified and were numbered from 1 to 6 on Figure 3a. Numbers 1 to 3 consist of granite aggregates with an over-estimated expansions using the 60°C test (upper left quadrant). By comparing the mineralogy of those three granites with that of the granite that reacts as predicted by the regression curve, we found that the main difference is the alkali-feldspar content, which is higher in the three anomalous granites. Further studies and testing would be required for a better understanding of the granitic aggregate behaviors in the 60°C Concrete Prism Test.

TABLE 3: Igneous and Metamorphic Rocks – Calculated and Proposed Expansion Limits for the 60°C Concrete Prism Corresponding to an Expansion of 0.04% at OneYear with the 38°C Concrete Prism Test

	91 days				56 days			
	Expansion	Diagnostic*			Expansion	Diagnostic*		
		Good	Over	Under		Good	Over	Under
Regression Curve	0.042%	72%	14%	14%	0.026%	77%	9%	14%
Lower Prediction Curve (95%)	0.011%	50%	50%	0%	0.008%	45%	55%	0%
Proposed Maximum Expansion Limit	***0.025%***	***82%***	***18%***	***0%***				

* The diagnostic is based on the 1-Year Concrete Prism Test result.
Good: 38°C and 60°C Concrete Prism Tests give the same diagnostic (reactive / non-reactive).
Over: Potentially reactive (60°C); but non-reactive according to the 1-year Concrete Prism Test.
Under: Non-reactive (60°C) but potentially reactive according to the 1-year Concrete Prism Test

Comparative tests numbered 4 to 6 consist of a granitic gneiss (4), a basaltic meta-volcanic - greenschist facies (5) and a dioritic dyke (6). Tests No. 4 and 5 are characterized by showing late reactivity by doubling their expansion from 9 to 12 months in the 38°C Concrete Prism Test. Petrographic examination under the microscope reveals that hardly accessible fine-grained interstitial quartz (4) and poorly crystallized quartz amygdules (5) may be responsible for the late expansion of these specific petrographies. The dioritic dyke (6) shows alterations to epidote and potentially reactive fine-grained quartz. No explanation has yet been found to explain why this aggregate did not react as strongly in the 60°C test. These results suggest that the 60°C Concrete Prism Test may have some difficulty in detecting late expansion in some igneous and metamorphic aggregates. For this reason, a conservative expansion limit of 0.025% at 91 days is proposed for this group of aggregates (Table 3). The earlier limit of 0.02% at 56 days is not adequate to estimate the alkali-reactivity potential since in 9% (2/22) of the samples the test was not able to detect late expansion observed with the 38°C Concrete Prism Test (Fig

3b). An incorrect diagnosis was obtained by evaluating the aggregate as non-reactive with the accelerated testing method while it was subsequently revealed to be reactive with the one-year Concrete Prism Test.

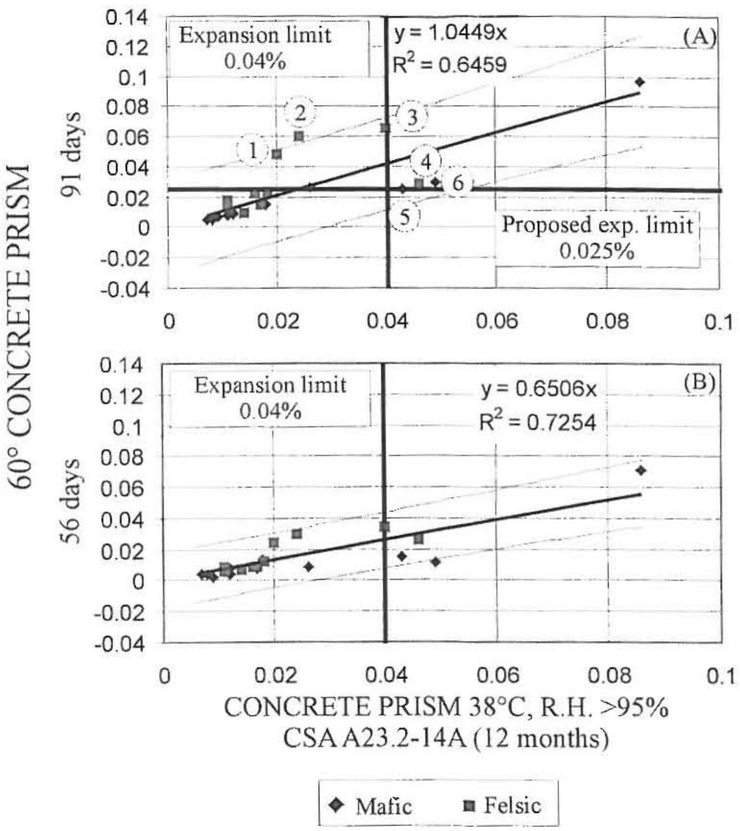

Fig. 3:Correlation between the 1-Year 38°C Concrete Prim Test and the 60°C Concrete Prism Test for Igneous/Metamorphic Rocks (n=22). (A) at 91 days, (B) at 56 days

CONCLUSIONS

(1) Accelerated Concrete Prism Test with curing at 60°C for 91 days is an adequate testing method for predicting the potential alkali-reactivity of aggregates as determined by the 38°C Concrete Prism Test.

(2) Correlation between the 38°C and the 60°C Concrete Prism Tests results is better at 91 than at 56 days. Late expansion is not always detected at 56 days.

(3) Very good correlation was found for Carbonate and Sedimentary Rocks. An expansion limit of 0.04% at 91 days is proposed for these types of aggregates.

(4) For Igneous and Metamorphic Aggregates (mafic and felsic), the correlation between the two Concrete Prism Tests is not as good as for Carbonate and Sedimentary Rocks. Some outliers or exceptions were found and further testing is required to better understand the behavior of those outliers. A conservative expansion limit of 0.025% at 91 days is proposed for Igneous and Metamorphic Aggregates. The expansion limit of 0.02% at 56 days is not adequate for those rock lithologies.

(5) The maximum expansion limit of 0.02% at 56 days was found adequate for Carbonate and Sedimentary Rocks and should be retained for those rock types. This limit is conservative since 8% to 34% of the tested aggregates were considered reactive with the 60°C but non-reactive with the 38°C Concrete Prism Test at 1-year.

(6) The expansion limits given by the lower prediction curve are too conservative since 17% to 55% of the tested aggregate samples would be considered reactive in the 60°C but non-reactive in the 38°C Concrete Prism Test at 1-year.

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