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A Critical Review of the Test Methods for Evaluating the ASR Potential of Aggregates

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Alkali-silica reaction (ASR) in concrete is now a global issue and has been studied extensively after it was first recognized by Stanton in the late 1930s as a source of deterioration. Numerous tests were developed in the last couple of decades to determine the alkali silica reaction (ASR) potential of aggregates. A few of the early test methods are still used widely (e.g. ASTM C1260 and ASTM C1293) and some of the methods are no longer in use (e.g. Conrow test). This article presents the critical review of the prominent test methods, the drawbacks of the different test standards that spurred the research in developing new methods and finally the comparison of a new rapid test method- Miniature Concrete Prism Test (MCPT) with the two most widely used standards - ASTM C1293 and ASTM C1260.

Field of Research: Concrete, cement, alkalinity, durability, ASR

1. Introduction

Alkali-silica reaction (ASR) is a chemical reaction between reactive silica (SiO_2) in certain aggregates (e.g.: chert, quartzite, opal, strained quartz crystals) and alkali hydroxides in the concrete pore solution. The pore solution alkalinity comes from the cement alkalinity (expressed as Na_2O_{eq}%). The alkali-silica reaction (ASR) in concrete was first recognized by Stanton in the late 1930s as a source of deterioration. Researchers have shown that alkali content in the cement greater than 0.60% causes the ASR (Stanton 1940, 1942). However, even with the low alkali cement, ASR can happen with highly reactive aggregates. The reaction (between reactive silica and alkali in the pore solution) produces a hydrous alkali-silica gel, often referred to as ASR gel. Formation of the ASR gel alone does not cause cracking, however when the gel absorbs water it shows significant potential to swell. The resulting expansion often results in pressures greater than what the concrete can withstand, which in turn causes cracks in the concrete. The reaction process can be viewed as a two- step process:

Step *1:* Silica + Alkali = Alkali-Silica-gel
$SiO_2+2NaOH+H_2O = Na_2SiO_3.2H_2O$ (2KOH can replace 2 NaOH)
Step 2: Gel Reaction Product + water = Expansion

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Over the last few decades considerable volume of research has been conducted to assess potential reactivity of aggregate to cause ASR distress in concrete. Numerous test methods to assess aggregate reactivity have been proposed and standardized in the USA, Canada, Europe, China, Japan, and South Africa. Of these, the Accelerated Mortar Bar Test (AMBT) (e.g., ASTM C1260, CSA A23. 2–25A, RILEM TC191-ARP-AAR2), originally proposed by Oberholster and Davis in 1986 has been widely adopted as an accelerated test method for evaluating alkali-silica reactivity of aggregate for use in concrete (ASTM C1260, RILEM AAR-2 2000, Oberholster 1986). However, the results from this test method can be unreliable (false positive and false negative results reported) due to the aggressive conditions used in the test. On the other hand, the Concrete Prism Test (CPT) (e.g., CSA A23.2–14A, ASTM C1293, RILEM TC191-ARPAAR3) is recognized as the most reliable test procedure which requires at least one or two years for results depending upon the purpose of the test. The long duration required in this test method renders this method impractical for use in routine testing and evaluation of aggregate materials. The limitations of the ASTM C1260 and ASTM C1293 test methods have spurred research in the development of new test procedure that are rapid and reliable in evaluating aggregate reactivity and efficacy of ASR mitigation measures.

This paper presents a critical review of major ASR test methods from the last couple of decades and a comparison of Miniature Concrete Prism Test (MCPT) method with the ASTM C1260 and ASTM C1293 test methods. The proposed Miniature Concrete Prism Test (MCPT) was developed incorporating selected features of the ASTM C1260 and ASTM C1293 test methods to ensure a reliable prediction of the performance of aggregate and ASR mitigation measures while obtaining the results within a reasonable time frame that is of value to the construction industry.

2. Literature review

The alkali-silica reaction (ASR) in concrete was first recognized by Stanton in the late 1930s as a source of deterioration [Stanton 1940, 1942]. Over the last few decades considerable volume of research has been conducted to assess potential reactivity of aggregate to cause ASR distress in concrete. Numerous test methods to assess aggregate reactivity have been proposed and standardized in the United States, Canada, Europe, China, Japan, South Africa and others. Of these, the Accelerated Mortar Bar Test (AMBT) (e.g., ASTM C1260, CSA A23.2–25A, RILEM TC191-ARP-AAR2), originally proposed by Oberholster and Davis in 1986 has been widely adopted as an accelerated test method for evaluating alkali-silica reactivity of aggregate for use in concrete [ASTM. 2007a, Canadian Standards Association. 1994a,, RILEM 2000b]. On the other hand, the Concrete Prism Test (CPT), e.g., ASTM C1293, CSA A23.2–14A, RILEM TC191-ARP-AAR3 is recognized as the most reliable test procedure which requires at least one or two years for results depending upon the purpose of the test (CSA A23.2, ASTM C1293, RILEM AAR-3)(ASTM. 2007b, Canadian Standards Association. 1994b RILEM 2000a).
The long duration required in this test method renders this method impractical for use in routine testing and evaluation of aggregate materials. The limitations of ASTM C1260 and ASTM C1293 test method have spurred research in

development of new test procedures that are rapid and reliable in evaluating aggregate reactivity and efficacy of ASR mitigation measures.

Miniature Concrete Prism Test (MCPT) was introduced to assess the ASR potential of aggregates with reliability greater than the AMBT method and that correlates well with the CPT method, and with results obtained within 2 months compared to 1 year in the CPT [Latifee 2013]. In this project, MCPT method was compared with ASTM C1260 and ASTM C1293.

Table 1: Comparison of Test Methods for Potential Aggregate Reactivity

Standard	Scope	Year of introduction	Sample size	Aggregate size	Test duration	Test condition	Test Temp.	Expansion criteria	Drawback
ASTM C227	Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)	1950	The test involves molding mortar bars (1 in. x 1 in. x 11.25 in)	4.75 mm (#4 sieve) to 150 µm (#100)	6 months	Specimens are placed over water in containers, and the containers are sealed to maintain 100 percent relative humidity.	38°C or 100°F	greater than 0.05% three months and greater than 0.10 percent at six months	1. reported alkali leaching Slow test (6-month) 2. failure to correctly identify the potential reactivity of a numerous rock types 3. Long duration-three months (>0.05%) and greater than 0.10 percent at six months 4. Insignificant expansion of mortar bars may result when potentially deleteriously reactive siliceous rocks are present in comparatively high proportion even when high-alkali cement is used.
ASTM C289	Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)	1952	150 to 300 µm (No. 100 to No. 50 sieve) particles	aggregate source to 150 to 300 µm (No. 100 to No. 50 sieve)	24 hours.	Crushing aggregate are immersing in a 1N NaOH solution at 80 degree C for 24 hours.	80°C	Not Applicable	1 Many aggregates are not adequately identified using this test. A significant number of ASR aggregates pass the test while many innocuous aggregates are identified as deleterious. 2. excessive crushing of aggregates

Standard	Scope	Year of introduction	Sample size	Aggregate size	Test duration	Ambient condition / Test condition	Temperature	Expansion criteria	Drawback
ASTM C295	Guide for Petrographic Examination of Aggregate for Concrete	1952	Core sample, thin sections, or pieces of aggregates	No restriction	Depends on the extent	Not Applicable	Not Applicable	NA (Appearance of dark rim at the surface of aggregate. Certain amount of reactive constituents.	1. Needs an experienced petrographer 2. can fail to identify slowly reactive aggregates 3. Precautions must be taken to ensure that the sample is representative of the source.
ASTM C1260:	Potential Reactivity of Aggregates (Mortar-Bar-Test	1986	mortar bars with standard dimensions 25x25x285 mm (1x1x11-1/4 in)	4.75 mm to 0.15 mm	14 days	Immersion of mortar bars in 1N NaOH solution.	80°C or 176°F	0.1% at 14 days (some follow 0.20%).	1. Excessive crushing, aggregates with good field performance may test reactive. 2. significant false positive and false negative results 3. Too high temperature
ASTM C1293	Determination of Length Change of Concrete Due to Alkali-Silica Reaction	1950	concrete prisms, 3 in. x 3 in. x 11.25 in. (75 mm x 75 mm x 285 mm)	19 mm - 4.75 mm	12 months minimum (24 for mitigation)	concrete prisms are stored over water in sealed containers at 100°F (38°C)	38°C or 100°F	0.04% at 12 months.	1.Too long duration (1 year for potential and 2 years for mitigation) and 2. it has been criticized for leaching out of alkali

Table 2: Parameters in accelerated tests for alkali-silica reactivity

Parameters	AMBT	Autoclave	CAMBT
Water-to-cement ratio	0.47	0.30	0.33
Cement alkalis (Na_2Oeq)	$1.0 \pm$ 0.1%[a]	1.5%[b]	1.5%[b]
Aggregate size (mm)	0.15 5.0[c]	0.15 0.80	0.15 0.80
Bar size (mm)	25x25x28.5	10x10x40	40x40x160
Cement-aggregate ratio	1:2.25	10:1, 5:1, 2:1	10:1,2:1,1:1
Curing temperature	80°C	150°C	80°C
Storage solution	1.0 M NaOH	10% KOH	1.0 M NaOH
Zero length	24h in water @ 80°C	24h moist @ 23°C	4h in 1 M NaOH @ 80°C
Criteria	0.10% @ 14 days	0.10% @ 6h	0.10% @ 7days

a. Use high-alkali cement.
b. Use low-alkali cement, add KOH to mix water.
c. Five required size fractions.

3. Methodology

3.1 Materials:

Aggregate: A well-known reactive coarse aggregate Spratt limestone was selected with a known non-reactive aggregate (properties are given in Table 3)

Reactive coarse aggregate: Siliceous Limestone from Spratt Quarry in Ontario, Canada

Non-reactive fine aggregate: Siliceous sand from Dixiana Plant in Pineridge, South Carolina (Fine Aggregate)

Table 3: Properties of the Aggregates

Property	Spratt (CA)	Foster Dixiana (FA)
SG_{OD}	2.69	2.63
SG_{SSD}	2.71	2.64
Absorption, %	0.46%	0.44%
DRUW (kg/m^3)	1568	X
DRUW (lb./ft^3)	97.91	X

Cement: The chemical composition of these cements is shown in **Table 4**.

Table 4: Chemical Composition of High-Alkali and Low-Alkali Cement

Material	Oxide composition by mass (%)							Specific gravity
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	[Na_2Oe]	
High-Alkali Cement	19.78	4.98	3.13	61.84	2.54	4.15	0.82	3.15
Low-Alkali Cement	20.6	5.1	3.4	64.50	1.0	3.1	0.49	3.15

Reagents: Reagent grade sodium hydroxide from Fisher Chemicals was used.

Water: De-ionized water was used in all cases.

3.2 Description of the MCPT method

Miniature Concrete Prism Test (MCPT) assesses the ASR potential of aggregates with reliability greater than the AMBT method and correlates well with the CPT method, and results are obtained within 2 months compared to 1 year in the CPT. In this method, concrete prisms of dimensions 50 mm x 50 mm x 285 mm (2 in. x 2 in. x 11.25 in.) (**Figure 1)** are used for evaluating the reactivity of both coarse and fine aggregates. Mixture proportions of ingredients used in preparing the MCPT specimens are standardized as follows:

Table 5: Mixture Proportions for the MCPT Specimens

Item	Mix Proportion
Cement Content of the Mix:	420 kg/m^3 (708 lb/yd^3)
Water-to-Cement ratio:	0.45
Coarse Aggregate Vol. Fraction (dry):	0.65
Maximum size of Coarse Aggregate:	12.5 mm (1/2 in.)
Fine aggregate:	Determined based on ACI 211 Absolute Volume Method, i.e. subtracting the proportions of all the other ingredients from 1 m^3 of concrete.
Coarse Aggregate Gradation: (% by weight of total coarse aggregate):	
12.5 mm – 9.5 mm:	57.5%
9.5 mm – 4.75 mm:	42.5%

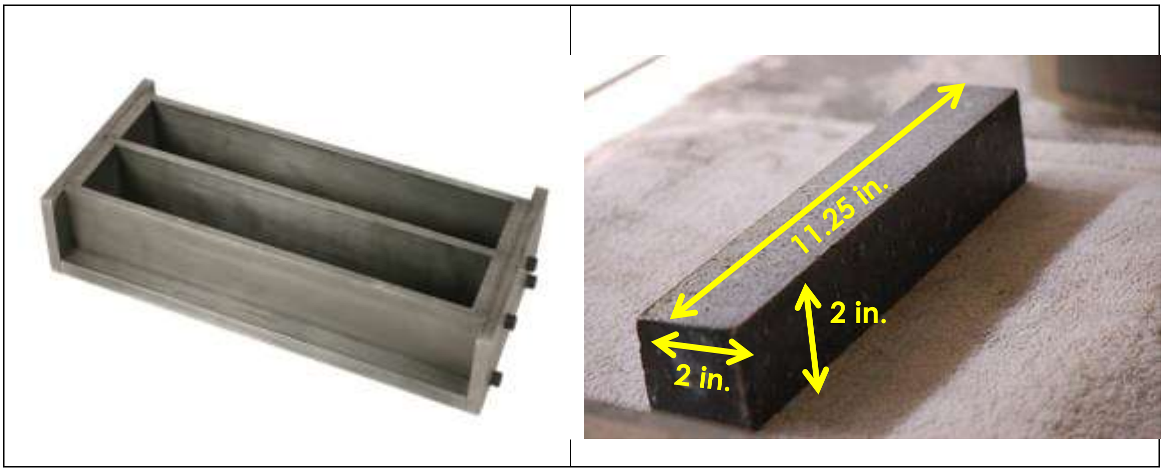

Figure-1 MCPT specimen and mold

4. Results and Discussions:

Correlation of MCPT with CPT and AMBT

MCPT, AMBT and CPT tests were conducted for 12 aggregates out of the 33 aggregates. **Table -6** shows the comparison of test results from MCPT, AMBT and CPT methods for these 12 aggregates, along with their field performance.

Correlation between MCPT and CPT

Figure 2 shows the correlation between the 56-day MCPT results and the 365-day CPT results for all the 12 aggregates including some highly reactive aggregates. The R^2 value of this correlation is very high at 0.99. In both of these methods an expansion limit of 0.040% was considered to distinguish reactive from non-reactive aggregates at the specified ages. **Figure 3** shows the same correlation as seen in **Figure 2**, however in a smaller domain of aggregate reactivity (with a maximum expansion of 0.120%). This comparison excludes some high and very highly reactive aggregates. The degree of correlation between the MCPT and CPT data is slightly less compared to that observed in **Figure 2**, with an $R^2 = 0.95$.

Based on the results in **Figures 2 and 3**, it is evident that 56-day MCPT data and 365-day CPT data shows a high degree of correlation, and for vast majority of aggregates that are low/slow reactive or moderately reactive aggregate, the 56-day MCPT expansion can be considered equal to 365-day CPT expansion.

Correlation between MCPT and AMBT

Figure 4 shows the correlation between the 56-day MCPT data and the 14-day AMBT data for the 12 aggregates. Expansion limits of 0.040% at 56 days in MCPT method and 0.10% at 14 days in AMBT method were used to distinguish reactive aggregates from non-reactive aggregates at the specified ages. It is evident from this data that a poor correlation exists between the two test methods.

In addition to the expansion data of different aggregates in the three test methods, **Table -6** also shows the field performance history of each of the 12 aggregates. The following correlations in particular highlight the positive correlation between MCPT and the field performance. For instance, in the case of Princeton Aggregate, the CPT and MCPT results indicate the aggregate to be reactive, whereas the AMBT result indicates it to be nonreactive (false-negative). On the other hand, the CPT and MCPT results of aggregates Geneva and St. Cloud indicate the aggregates to be non-reactive, whereas AMBT results indicate the aggregates to be reactive (false-positive). The field performance of these aggregates matches well with the predictions of aggregate reactivity from the CPT and the MCPT methods, and not with the predictions from the AMBT method.

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Table -6: Expansion Data of Selected Aggregates in the Different Test Methods

Aggregate Identity	*% Expansion*			Average % Rate of Expansion (8-12 wks)	*Field Experience*
	MCPT, 56 Days (CV %)	*ASTM C 1293, 365 days*	*ASTM C 1260, 14 days*		
Spratt	0.149 (4.08)	0.181	0.350	0.0152	Reactive
Dell Rapids	0.099 (4.97)	0.109	0.220	0.0043	Reactive
Las Placitas	0.185(3.43)	0.251	0.900	0.0231	Reactive
Gold Hill	0.149 (1.16)	0.192	0.530	0.0092	Reactive
Big Bend	0.017 (8.81)	0.032	0.042	0.0047	Innocuous
Galena	0.046 (4.34)	0.050	0.235	0.0122	Reactive
Princeton	0.070 (3.01)	0.070	0.080	0.0193	Reactive
Geneva	0.039 (8.31)	0.030	0.190	0.0102	Low reactive
St. Cloud	0.023 (2.47)	0.030	0.100	0.0070	Innocuous
Jobe (McComb)	0.440 (4.21)	0.590	0.640	0.0250	Reactive
Grand Island	0.091 (9.93)	0.090	0.260	0.0288	Reactive
Scottsbluff	0.115 (9.83)	0.150	0.460	0.0320	Reactive

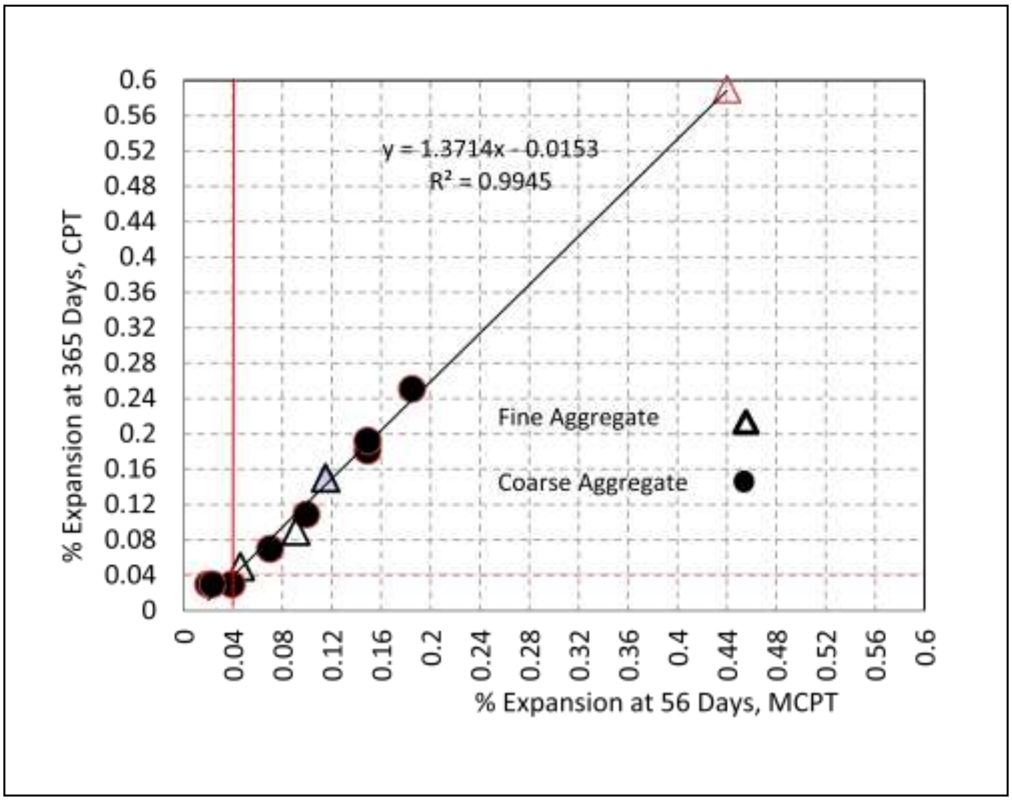

Figure -2: Correlation between the 56-Day MCPT data and the 365 Day CPT data.

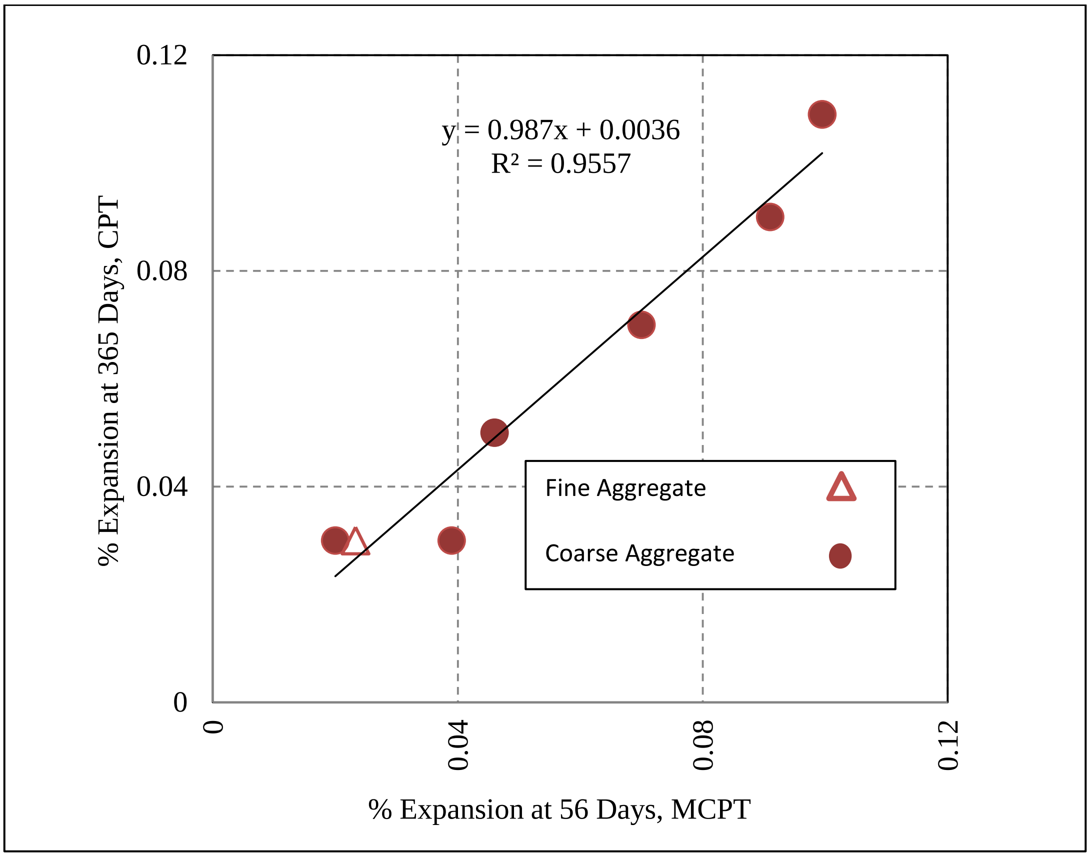

Figure -3: Correlation between the 56-Day MCPT data and the 365 Day CPT data excluding aggregates with very high expansion values (> 0.200% at 56 days).

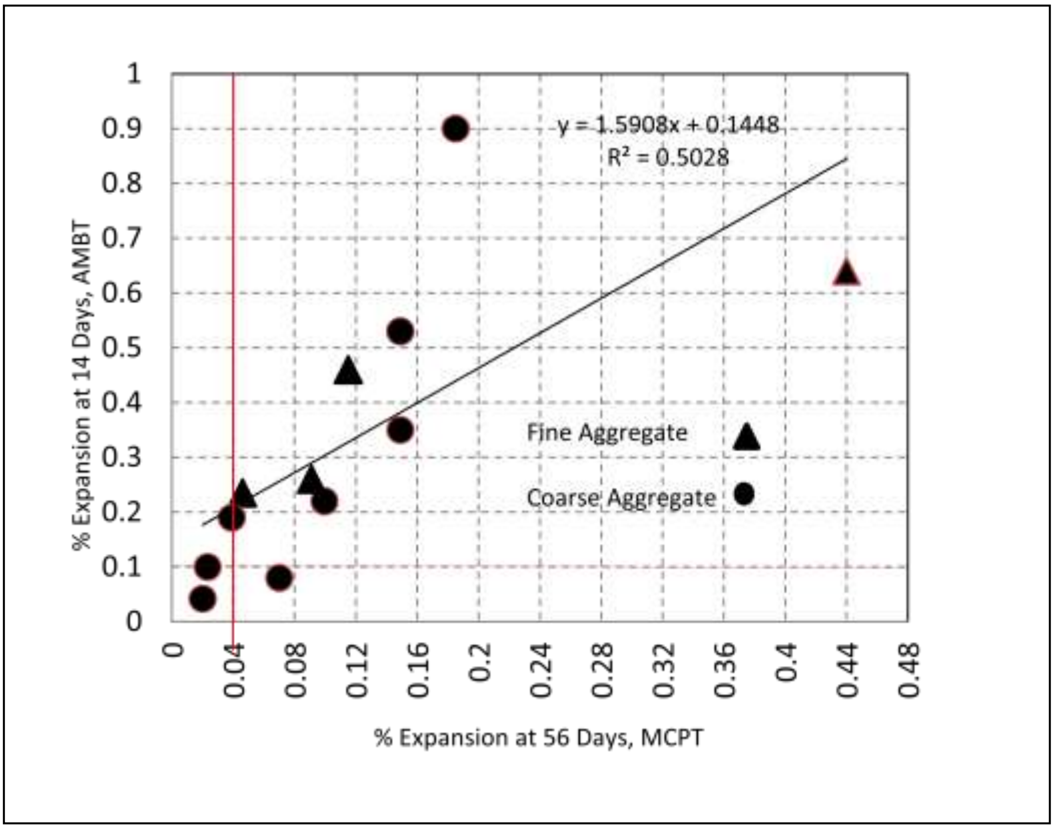

Figure -4: Correlation between the 56-day MCPT data and the 14-day AMBT data.

5. Conclusion

Based on the studies conducted, the following conclusions are drawn.

The previous test methods had some shortcomings which spurred the new research in the field of ASR potential. The aggressive nature of some tests resulted in false positive and false negative results. ASTM C 1260 tends to be overly severe, resulting in expansions exceeding the failure limit, even though these aggregates pass the concrete prism test and perform well in field applications (false positive). On the other hand, it also gives false negatives. The major drawback of ASTM C 1293 is its long duration (1 or 2 years) and it has been criticized for leaching out of alkali. From Industry perspective, 1 or 2 year test duration (CPT) is not practical, and false positives can lead to unnecessary exclusion and false negatives create potential ASR risk. MCPT has been developed to determine aggregate reactivity, with similar reliability as ASTM C 1293 test but shorter test duration (56 days vs. 1 year) and less aggressive exposure conditions than ASTM C 1260 test but better reliability

The test results based on evaluating 12 different aggregates have shown the viability of the MCPT as an alternative to the standard ASTM C 1293 and ASTM C 1260 test methods. An expansion limit of 0.040% in the MCPT method at 56 days appears to characterize the aggregate reactivity of majority of the aggregates, particularly those aggregates that show expansion well above (highly reactive) or well below (non-reactive) the 0.040% limit. An excellent correlation between the MCPT results and the field performance of the aggregates, based on testing different aggregates further reinforces the validity of the MCPT method as a rapid and a reliable predictor of aggregate reactivity, and as a suitable alternative to the standard ASTM C 1293 and ASTM C 1260 test methods.

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