RE-EVALUATION OF TESTING PARAMETERS IN THE ACCELERATED MORTAR BAR TEST

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Abstract

The accelerated mortar bar test (AMBT) is used as a rapid screening method to determine the potential of an aggregate to be alkali-silica reactive. However, aggregate grading, temperature, and the concentration of the NaOH soak solution will affect the observed reactivity of aggregates. This research presents a study of aggregate reactivity using the AMBT in which an examination of the impact of temperature, normality, and aggregate grading on expansion was determined. A siliceous, fine aggregate was tested to assess the impact of each of these parameters in the AMBT (according to ASTM C1260), and ultimately compared to concrete prism tests (CPT-ASTM C1293). Under standard testing procedures this aggregate was determined to be very highly reactive, according to ASTM C1778, with an expansion of 0.49% at 14 days, yet was deemed non-reactive in the CPT with an expansion of 0.02% at 1 year. To assess the effect of temperature and aggregate preparation, a standard 1 N NaOH solution was used. The temperature study was done at 23 °C, 38 °C, 60 °C, and 80 °C. As received and the prescribed grading were used to assess the effect of aggregate preparation. A study of the impact of normality examined NaOH solutions of 0.5 N, 0.75 N, 1 N, 1.25 N, 1.5 N, and 1.75 N at 80 °C. It was found that expansion peaked in a 0.75 N NaOH solution at 14 days. Expansion was shown to increase as temperature increased, particularly above 38°C. It was shown that modifications to the AMBT test typically did not correspond to the results in the CPT.

Keywords: temperature, normality, AMBT, ASR, alkali content

1 INTRODUCTION

The accelerated mortar bar test (AMBT) is one of the most widely used methods for rapid assessment of an aggregate's potential for alkali-silica reaction (ASR). However, this test method may indicate an aggregate is reactive, where it determined to be innocuous in other methods, such as the concrete prism test (CPT) [1] or field performance. Similarly, aggregates may be considered innocuous in the AMBT, but have poor field performance. Historically, the development of an accelerated ASR test methods included higher temperatures and increased alkali contents during the testing [2]. Increased alkalis are added either at mixing, or in a soak solution. The alkalis were provided through solutions such as NaOH [3], NaCl [4, 5], KOH [6], and salt water [7]. The development of the current ASTM C1260 [8] was founded on the research by Oberholster and Davies [3] with testing conditions at 1 N NaOH storage solution at 80 °C [8].

During the development of the AMBT, six different aggregates were assessed at different temperatures and normalities of NaOH storage solution on expansion of mortar bars. The aggregates were quartz or silicate bearing. Maximum expansion was observed in three of the six aggregates at 80 °C, while maximum expansion was observed at 90 °C in the others. Furthermore, maximum expansion was observed at 1.0 N NaOH in five of the six aggregates, whereas maximum expansion in the other aggregate was 1.5 N [3]. Similarly in another study, it was found that in a hornfels aggregate, maximum expansion was also observed in a 1 N NaOH solution stored at 80 °C [6], further establishing support for these testing conditions as a worst case scenario for accelerated testing.

However, correlation discrepancies between the AMBT and field performance or other methods to assess ASR potential have arisen [9-11]. The aggressive testing conditions of the AMBT does not represent real world conditions, and thus can result in aggregates that fail in the AMBT and show good field performance [12]. Furthermore, the testing environment was optimized for a quartz, silica, or hornfels aggregates, which could ultimately lead to incorrect expansion values for other types of aggregates. Modifications to the AMBT procedures have been previously reported in literature. It was found that a 1 N NaOH testing environment resulted in higher expansion when compared to a

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0.5 N or 0.25 N solution; cements with a higher Na_2O_{eq} had a higher expansion; and prolonging the curing duration had little effect on expansion [13].

Preliminary testing showed a locally sourced siliceous fine aggregate was highly reactive (0.49% at 14 days) when tested under standard testing conditions in the AMBT. Anecdotal reports of field performance of this aggregate were good (i.e. no ASR observed). However, when the same aggregate was tested in the CPT (ASTM C1293) the aggregate was considered innocuous at 1 year (0.02% expansion). The main motivation of this research was to assess the key variables in the AMBT, and their effect on 14-day expansion for this particular aggregate. The variables studied in this research include the effect of storage temperature, normality of the NaOH soak solution, aggregate grading, and initial alkali content of the cement.

2 MATERIALS AND METHODS

2.1 Materials

Aggregates

A siliceous, locally sourced, natural river fine aggregate was tested to determine its potential reactivity in the AMBT and CPT. This aggregate was composed of various igneous rocks and minerals, many of which are known to participate in ASR. These potentially reactive components include fine-grained volcanic rock types (e.g. basalt, andesite, dacite, crystalline rhyolite), glassy volcanic rocks (e.g. rhyolite and tuff), and microcrystalline quartz (e.g. quartzite, microcrystalline silica, optically-strained quartz). A full summary of the aggregate constituents are seen in Table 1. In order to test the reactivity of the fine aggregate in the CPT, a calcareous coarse aggregate was used as the non-reactive aggregate. This coarse aggregate passed the AMBT and CPT test methods, and was therefore deemed non-reactive.

Cement

A type I/II portland cement meeting the requirements outlined in ASTM C150 [14] was used for all testing. The Na_2O_{eq} for this cement was 0.83. For all testing the cement was sieved over an 850 μm screen before using. Table 2 shows the oxide analysis of the cement used in this research.

2.2 Methods

2.2.1 Accelerated Mortar Bar Test

The AMBT is a widely used test method to rapidly assess the potential for alkali-silica reactivity in aggregates. Typically, an aggregate with an expansion value greater than 0.20% at 14 days of testing is considered potentially deleterious expansive. If the expansion value is between 0.10% and 0.20% at 14 days, the aggregate could be either innocuous or deleterious, and further testing should be done in order to determine the reactivity of aggregates that fall in this expansion range. Recommendations include continuing the AMBT to 28 days [15, 16], or supplement with ASTM C1293 [17] (CPT) and/or ASTM C289 (chemical method) [18]. If an aggregate has an expansion value less than 0.10% at 14 days, it is considered innocuous. However, due to the aggressive nature of standard AMBT conditions, this test may not accurately predict the potential for reactivity when compared to field testing or the concrete CPT [9-12].

Sampling and preparation of test specimen procedures outlined in ASTM C1260 [8] were used as guidance for all mixtures. For the temperature, normality, and alkali content studies, the aggregates were sieved to the proper gradating and washed per the requirements in the standard. In the aggregate grading study, the as received aggregates were washed before mixing. After preparation of the aggregates, mixing of mortars occurred per ASTM C305 [19]. After mixing, the samples were cast in 25 mm x 25 mm x 285 mm molds and allowed to cure for 24 hours. The specimens were removed from their respective molds at 24 ± 2 hours and placed into preconditioned water for 24 hours. The water temperature and resultant storage temperature is discussed below. Initial measurements were taken 48 hours after the initial contact and the specimens were transferred into a preconditioned NaOH solution. The normality of the NaOH solution is discussed below. Length change measurements were taken every 2 to 3 days up to 28 days of immersion in the NaOH solution, or until 0.10% expansion was measured. Results from each study were compared to the length change of mortar bars tested under standard conditions (80 °C and 1 N NaOH) at 14 and 28 days of exposure. A summary of the mixtures and all testing parameters is seen in Table 3.

Normality of NaOH solution

Six different normalities of the NaOH were tested. The normalities tested were 0.5 N, 0.75 N, 1.0 N, 1.25 N, 1.5 N, and 1.75 N. The specimens were stored at 80 °C for all mixtures where normality was studied. Sieved and washed aggregates were used for this study. Four bars for each normality solution were cast.

Storage temperature

Four different storage temperatures were studied to determine the effect on expansion. The temperatures were 23 °C, 38 °C, 60 °C, and 80 °C. Sieved and washed aggregates were used for this study. After the specimens cured for 24 hours, they were transferred to preconditioned water at the respective temperature for 24 hours. For example, if the testing temperature was 38 °C, the specimens were transferred to pre-heated water at 38 °C after demolding. Next, the initial measurement was recorded and the specimens were transferred into a 1 N NaOH solution preconditioned to the correct temperature. The specimens were stored in the NaOH solution until 28 days or an average expansion of 0.10% was observed.

Aggregate preparation

A comparison was done between the grading of the aggregates per ASTM C1260 and the as received state of the fine aggregate. Sieve analysis of the as received aggregate compared to the ASTM C1260 graded aggregate is seen in Table 4. Sampling of the as received aggregates was done according to ASTM D75 [20]. Due to the inherent variability in grading of as received aggregates, three sets of four mortar bars using the as received aggregate were cast and compared to a control set.

2.2.2 Concrete Prism Test

While the AMBT is a rapid test method that can quickly determine the reactivity of an aggregate, it is reported that the concrete prism test is best recommended for determining the potential reactivity [12, 21-23], although there are reported shortcomings of this test method [21]. Procedures outlined in ASTM C1293 [22] were followed for the CPT testing. Expansion results from the 1-year CPT were compared to 14- and 28-day expansion values from all variations of the AMBT.

3 RESULTS

AMBT results

The control set of mortar bars tested at standard testing conditions (80 °C and 1 N NaOH) and aggregate grading specified in ASTM C1260 had an expansion of 0.49% at 14 days and 0.73% at 28 days. Based on these results, this aggregate is considered to be potentially deleterious. The measured expansion was the average of 4 mortar bars. This measurement was the baseline for comparison of all the parameters studied.

Figure 1 displays the incremental growth of mortar bars stored in various NaOH normalities at 80 °C. It can be seen that storing the mortar bars in a 0.75 N NaOH solution resulted in the highest 14 day expansion (0.66%) and highest rate of expansion up to 14 days of exposure. At 28 days of exposure, the 0.75 N NaOH solution had the second highest expansion (0.96%). When storing the mortar bars in a 0.5 N NaOH solution, the 14 day expansion was the lowest (0.45%) amongst all soak solution normalities. However, the 28 day expansion was the highest (1.04%). As the normality of the NaOH solutions increased, there were similar values in the 14 and 28 day expansion were observed for the 1 N, 1.25 N, 1.5 N, and 1.75 N NaOH solutions. Graphical representation of the 14 and 28 day expansion values for all the NaOH solutions is seen in Figure 2.

The results of the effect of different storage temperatures on length change of mortar bars stored in 1 N NaOH solution are seen in Figure 3. The amount and rate of expansion increased with an increase in temperature. Minimal expansion was observed at 28 days in mortar bars stored at 23 °C and 38 °C. Measurements of the mortar bars at this temperature were monitored until an average expansion of 0.10% was achieved. An exposure time of 140 days was required for the mortar bars stored at 23 °C to reach an expansion of 0.10%. Exposure of 42 days in the NaOH solution was required for the mortar bars stored at 38 °C to reach an expansion of 0.10%.

Results for the effect of aggregate grading on length change are seen in Figure 4. The use of as received aggregates resulted in a range of expansion values at both 14 and 28 days. Expansion at 14 days for the as received samples was 0.56%. . The expansion for the as received samples at 28 days was 0.82%.

Comparison of AMBT and CPT results

Figure 5 shows expansion the 14- and 28-day AMBT expansion values compared to the 1-year CPT expansion. The 1-year CPT expansion was 0.02% whereas the 14-day AMBT expansion was 0.49%. The expansion value from the CPT suggests that the aggregate was innocuous, yet the expansion value from the AMBT suggests the aggregate was potentially deleterious. Comparing all of the AMBT expansion values to the CPT expansion values; it was found that only two AMBT mixtures resulted in a pass-pass relationship with the CPT results. The 14- and 28-day expansion values of the 23C and 38C AMBT mixtures produced this pass-pass relationship.

4 DISCUSSION

Decreasing the normality of the NaOH solution to 0.75 N resulted in a higher expansion at both 14 and 28 days compared to the control. Further decreasing the normality to 0.5 N resulted in a lower 14 day expansion, but a higher 28 day expansion when compared to the control. The length change at both 14 and 28 days in mortar bars stored in NaOH solutions that had a normality greater than 1 N was similar to that of the control. The increase in reactivity of the same aggregate when tested at lower normality solutions was caused by a pessimum effect [24], which ultimately resulted in a higher expansion at a lower alkali content. The pessimum effect seen in the AMBT results may also explain the low reactivity in the CPT. Further research on the CPT with this aggregate at various alkali loading levels needs to be completed to ensure whether this aggregate is actually innocuous.

Reducing the temperature below 80 °C resulted in a decreased amount and rate of expansion in all temperatures tested. Decreasing the temperature to 60 °C resulted in a reduction in the 14 and 28 day expansion by 35% and 19% when compared to the mortar bars test at 80 °C, respectively. There was no measured expansion at 14 days for the mortar bars stored at 38 °C and 23 °C. No expansion was observed at 28 days in the mortar bars stored at 23 °C, and an expansion of 0.02% was observed at 28 days in the mortar bars stored at 38 °C. However, when stored long enough, mortar bars stored at both 23 °C and 38 °C eventually reached an expansion of 0.01%, thus indicating that even at low temperatures this aggregate may still be potentially deleterious in the long-term.

Using the aggregate in an as received state resulted in an increase in variability in both the expansion values, as well as the measured standard deviation. Expansion at 14 days was increased by 12.5% when compared to the control. At 28 days, the expansion was also increased in the as received aggregate mortar bars when compared to the control. However, this increase in expansion was generally lower (10.9%) than at 14 days. Furthermore, the standard deviation amongst the twelve mortar bars was higher than that of the control. This increase in expansion and variation amongst the individual mortar bars was likely caused by an increase in the amount of fine aggregate particles (<600 μm) in the as received aggregates than the ASTM C1260 grading requirements. Previous research has indicated the particle size influences the amount of expansion caused by ASR [11, 25, 26]. However, in that research it was found that the 1.25-2.50 mm size range influenced the expansion the most [11]. In this research the increase in expansion and variation amongst the individual mortar bars was likely caused by an increase in the amount of fine aggregate particles (<600 μm) in the as received aggregates, as seen in Table 2. Furthermore, the increase in standard deviation can be attributed to the inherent variability in the grading of the aggregate in an as received state. Although standardized procedures for aggregate sampling were followed during aggregate sampling, these natural variations in aggregate gradation influenced the total expansion in the mortar bars.

Comparing both the 14- and 28-day expansion values for all of the mixtures tested in the AMBT to the CPT results, it can be seen that the majority of the mixtures failed the AMBT but passed the CPT. Only two different mixtures, 23C and 38C, passed both testing procedures. It can be seen that modifying the normality of the NaOH or changing the aggregate gradation in the AMBT does not result in a pass-pass relationship when compared to the CPT. However, it was observed in the AMBT that decreasing the normality to 0.75 N resulted in a higher expansion at 14-days, while the highest 28-day expansion was observed in mortar bars tested at 0.5 N. This pessimum effect could result in an increase in expansion in the CPT when tested at alkali contents lower than 1.25%. It is recommended that a parametric study on the amount of available alkalis in the CPT be done.

5 CONCLUSIONS

This research reassessed several testing parameters of the AMBT method for a locally sourced, siliceous river gravel. The testing parameters studied were the normality of the NaOH solution, storage temperature, aggregate grading, and the alkali content of the cement. The following conclusions were made from this research:

- The original development of the AMBT was optimized through testing six different quartz or silica bearing aggregates. Maximum expansion was observed in five of the six aggregates at the conditions that have been prescribed in ASTM C1260. It is reported that this test method typically results in the highest expansion values, thus a worst case scenario. Results from AMBT on a locally available, siliceous river sand from this study indicated that conditions in ASTM C1260 may not always be the worst case scenario, thus the potential for misclassifying aggregates in either the innocuous or potentially deleterious category.

- A pessimum effect was observed in the AMBT, with a maximum expansion at 14-days in 0.75 N NaOH solution. At 28-days, maximum expansion was measured when mortar bars were tested in a 0.5 N NaOH solution. This result may indicate a pessimum effect may be present when this aggregate is tested in the CPT as well. Results from the CPT indicated this aggregate is innocuous, but had a high degree of reactivity when tested in the AMBT, particularly at lower normalities of NaOH. Therefore, due to these variations in aggregate reactivity caused by alkali loading, a parametric study on several aggregate types should be done in order to determine the appropriate alkali loading in both the AMBT and CPT to ensure maximum expansion.
- Modifications to the AMBT resulted in only two mixtures that passed both the 14-day AMBT and 1-year CPT expansion limits. Significant expansions were observed in all normalities of NaOH tested, aggregate preparation, and in temperatures 60 °C or higher. This indicated that the aggressiveness of the test method may result in an incorrect classification of an aggregate when compared to the more reliable CPT.
- However, further testing on both the AMBT and the CPT should be done in order to assure an accurate assessment of an aggregate and correlation between the test methods is confirmed. While it is typically reported that the CPT is the most accurate laboratory test method [23], there has been recent research indicating aggregates that pass the CPT have shown significant expansions in both field performance and long-term testing on field exposure sites [27].

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TABLE 1: Typical composition of fine aggregates.

Component	Mineral Examples	Amount (%)
Fine-grained basic to intermediate volcanic rocks	Basalt, andesite, dacite, crystalline rhyolite	44
Medium- to coarse-grained basic to intermediate igneous rocks	Granodiorite, diorite, gabbro	34
Quartzite and microcrystalline silica	Quartzite, microcrystalline silica, chert	8
Glassy volcanic rocks	Rhyolite, Tuff	1
Other	Iron oxides, quartz, feldspar, pyroxene, opaques	13

TABLE 2: Cement composition.

Constituent	Amount (%)
SiO_2	19.61
Al_2O_3	4.38
Fe_2O_3	2.76
CaO	62.21
MgO	2.72
Na_2O	0.28
K_2O	0.84
Na_2O_{eq}	0.83
LOI	2.6
C_3S	60.16
C_3A	6.95
C_2S	10.83
C_4AF	8.39

TABLE 3: Mixture identification.

Mixture ID	Aggregate grading	Normality of NaOH	Temperature	Number of bars
Control	ASTM C1260	1 N	80 °C	4
0.5N	ASTM C1260	0.5 N	80 °C	4
0.75N	ASTM C1260	0.75 N	80 °C	4
1.25N	ASTM C1260	1.25 N	80 °C	4
1.5N	ASTM C1260	1.5 N	80 °C	4
1.75N	ASTM C1260	1.75 N	80 °C	4
23C	ASTM C1260	1 N	23 °C	4
38C	ASTM C1260	1 N	38 °C	4
60C	ASTM C1260	1 N	60 °C	4
AR	As received	1 N	80 °C	12

TABLE 4: Aggregate grading.

		ASTM C1260 graded	As received
Passing	Retained on	Mass (%)	Mass (%)
12.5 mm	9.53 mm	0	0.04
9.53 mm	4.75 mm	0	4.62
4.75 mm	2.36 mm	10	18.36
2.36 mm	1.18 mm	25	11.87
1.18 mm	600 μm	25	12.05
600 μm	300 μm	25	31.09
300 μm	150 μm	15	19.33
150 μm	Pan	0	2.64

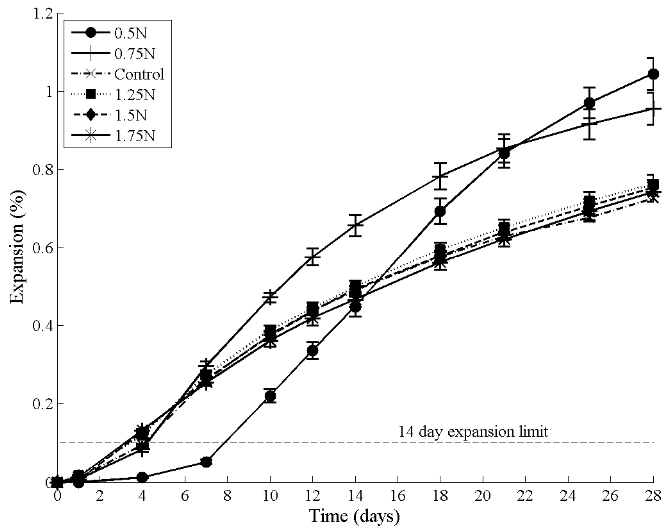

FIGURE 1: Expansion as a function of time for ASTM C1260 graded mortar bars with differing levels of NaOH normality.

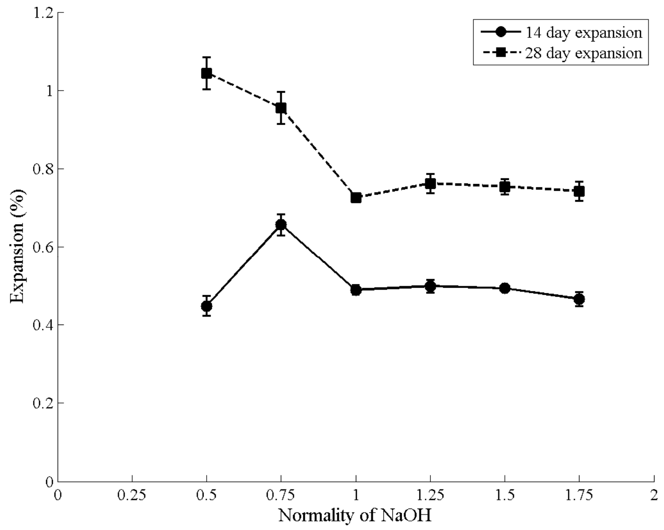

FIGURE 2: 14- and 28-day expansion at various levels of NaOH normality on ASTM C1260 mortar bars.

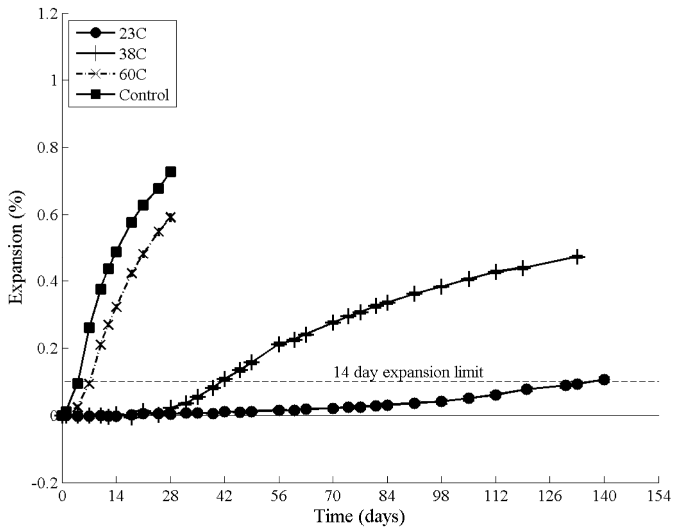

FIGURE 3: Effect of temperature on expansion values of ASTM C1260 mortar bars.

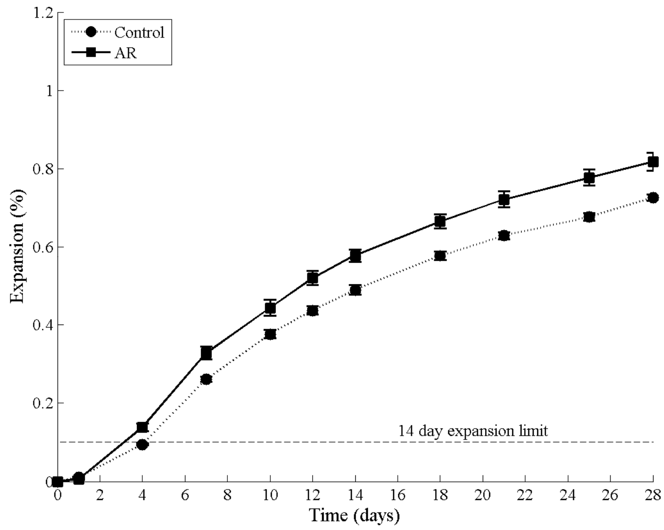

FIGURE 4: Effect of gradation on expansion values of ASTM C1260 graded and as received fine aggregates.

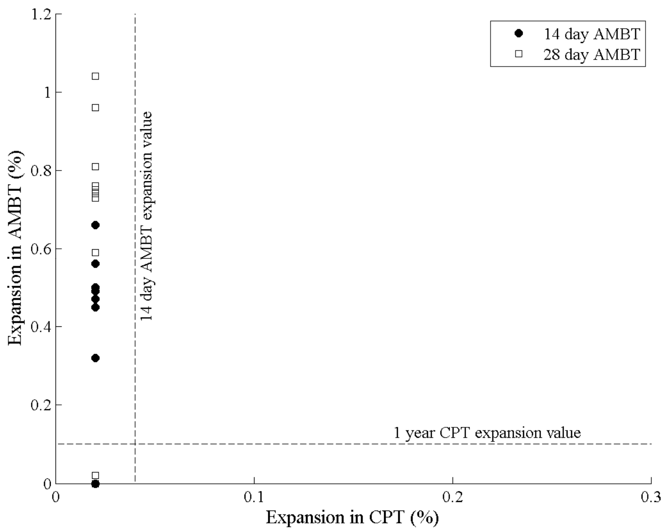

FIGURE 5: AMBT vs CPT results.