AN ACCELERATED AND MORE ACCURATE TEST METHOD TO ASTM C1293: THE CONCRETE CYLINDER TEST

Stephen Stacey[1*], Kevin Folliard[1], Thano Drimalas[1], Michael D.A. Thomas[2]

[1]University of Texas at Austin, Austin, TX, UNITED STATES
[2]University of New Brunswick, Fredericton, New Brunswick, CANADA

Abstract

In recent years there has been a growing understanding that ASR test methods such as the accelerated mortar bar test (ASTM C1260/AMBT) and the concrete prism test (ASTM C1293/CPT) are producing unreliable results as compared with the long term exposure block data, and so a new more rapid and reliable test has been developed known as the concrete cylinder test (CCT). The keys to the CCT test method is preventing the leaching out of alkalis over the lifetime of the test, utilizing existing measurement practices and making onsite procurement and testing possible. Through the use of concrete cylinder molds we can create a closed system that insulates the specimen preventing leaching, while simultaneously promoting more direct linear expansion. The cylinders are pinned at the top and bottom surface, and cast 6 mm short from the top of the mold to leave room for water to pond and provide a source of moisture to the concrete cylinder. Results have shown that the CCT can produce final expansion values in a mere 15 weeks compared to the same mixture at 1 year for CPT. CCT removes the error associated with leaching, and allows for expansion seen in exposure blocks at the University of Texas at alkali levels lower than 1.8 kg/m^3, where mixture does not expand in standard CPT. CCT permits testing at these lower alkali thresholds to see if they would expand in the test providing the ability to evaluate actual "job mixtures," something that has never been possible with the AMBT, CPT, or any other ASR test method.

Keywords: Alkali Silica Reaction, Accelerated Concrete Cylinder Test, Low Alkali Testing, Mix Design Confirmation, Field Applicable

1 INTRODUCTION

The concrete cylinder test (CCT) was developed to produce a new accelerated and more reliable means of testing aggregates and mixtures with supplementary cementing materials for susceptibility to alkali-silica reaction (ASR). In recent years, there has been a growing understanding that ASR test methods such as the accelerated mortar bar test (ASTM C1260/AMBT) and the concrete prism test (ASTM C1293/CPT) are producing unreliable results as compared with the exposure blocks data which has led to the development of a more rapid and reliable test. This new test method developed at The Texas Department of Transportation and at the University of Texas has the potential to replace the currently adopted ASTM C1293. Recent work has gone into testing the authenticity of the new test method with the addition of several new sized specimens, temperatures and measurement practices adding to the pre-existing matrix of tests that have been conducted at both institutions. ASTM C1260 and ASTM C1293 have began to develop a greater number of false negatives with regards to long-term ASR exposure block expansion data. The reportedly lower expansion in CPT testing is directly correlated to the leaching of alkalis that occur over the 1 to 2 year testing period. This leaching out of alkalis during testing significantly reduces the level of expansion as shown in Figure 1 [1]. Work developed by Lindgård et al. has shown that there is a strong correlation between early onset alkali leaching with the prism test and final expansion and even more exaggerated leaching at elevated temperatures [2]. It is due to this loss of alkalis in the CPT that a correlation between long-term exposure block expansion and CPT does not line up, especially for mixtures containing SCMs. Figure 2 provides exposure block expansions vs. 2 year CPT data [3]. After 7.5 years, significant expansion has occurred in exposure blocks while the CPT data did not expand pass the 0.04% limit.

The CCT test has reported final expansion at a reduced testing duration (< 5 months) even with

* Correspondence to: Stephen.Stacey@utexas.edu

the addition of SCMs. The key developments of the CCT test over the CPT test is that the moisture solution remains in constant contact with the specimen and is not permitted to leave the system for the entirety of the test. By preventing the dissolution of alkalis out of the concrete specimens higher testing temperatures may be used and the testing period is significantly decreased.

2 MATERIALS AND METHODS

2.1 General

Ten concrete mixtures were selected with respect to the long-term exposure block data that is currently available at the University of Texas at Austin. The test specimens have been subjected to a range of temperatures (38, 50 and 60°C) in order to determine the shortest and most accurate testing time. Two different reactive fine aggregates were evaluated, as well as a class C fly ash, and lithium nitrate admixture. Nine variations of specimen sizes, holding conditions and measurement procurement have been developed in order to finalize a specimen size and conditions that portrays field expansion quickly, accurately and adaptability to users. In addition, a range of alkali loadings were evaluated to focus on mixtures that fail in outdoor exposure blocks but not in the CPT (primarily due to leaching issue).

2.2 Materials and Mixture Design

Aggregates

Aggregate selection was conducted by choosing the same fine and coarse aggregates that were used with respect to the previously cast exposure blocks that have now cracked but have passed the concrete prism test. One key component of the mixtures selected was the highly reactive siliceous fine aggregate (FA1) taken from West Texas, which has proven to trigger ASR in low alkali loading situations, as low as 1.7kg/m^3. The components of the sand are as follows: quartz (64.0 %) chert (17.1 %), and feldspar (11.5 %). Another fine aggregate selected proven to spur ASR was a mixed quartz and chert sand (FA2) taken from Robstown Texas.

The coarse aggregate (CA1) used in all the mixtures is known to be a non-reactive dolomitic limestone from San Antonio, TX. The aggregate is graded by sieving out three equal volumes of aggregate at: 1.27 cm, 0.9525 cm, and 0.475-mm through the use of a SIMCO Fractionator.

Cement and Fly Ash

An ASTM C 150 (ASTM C 150, Standard Specification for Portland Cement, 2005) Type I/II (CM1), and III (CM2) cement was used for CPT and CCT mixtures. Mixture proportions were determined according to ASTM C1293 where the cement content is fixed at 420 kg/m^3 and the water to cement ratio (w/c) was 0.42 by mass. The alkali contents of CM1 and CM2 are 0.52 and 0.78% Na_2O_{eq}, respectively. An ASTM C618 Class C fly ash was used for CPT and CCT Mixtures. The calcium oxide of this fly ash is 27%.

2.3 Methods for Assessment and Analysis

The CCT testing procedure follows the same mixing and concrete proportioning that is used for ASTM C1293 testing. The CCT apparatus essentially consists of casting concrete mixtures (including job mixtures) into plastic cylinder molds which are typically used for compressive strength specimens. A complete diagram of the CCT setup employed for testing is shown in Figure 3. Figure 4 presents a CCT measurement taking place while the specimen is set in the comparator stand. Figure 5 demonstrates the process employed at the University of Texas at Austin, where pins are cast on the tops and bottoms of the cylinder through the use of "Stace-molds". Concrete is cast into the cylinders in two layers; however, the concrete is placed in the upper half is cast 6 mm from the top of the cylinder mold, allowing for the ponding of a small amount of water just above the concrete cylinder. Two filter papers line the interior of the plastic cylinder prior to concrete placement to distribute the ponded water throughout and further reduce the tendency for drying of the cylinders. After the cylinders are cured for 24 hours, the extra water is added to the top of the cylinders, and a firm-fitting cap is then placed on top of the cylinder mold to effectively seal the specimen and prevent moisture loss.

The cylinders are then placed in their respective 38, 50 and 60°C ovens. Measurements are taken at 1, 7, 14, 28, 42, 56, 70, 91, 112, 140, 365, 548 and 730 days. A variety of 4 different CCT mold sizes and apparatuses were employed in the study, each with a like sized ASTM C1293 tested counterpart, as shown in Table 2. Sizes and holding conditions of the CCT specimens are as follows: 100 x 200 mm standard plastic compression molds, 100 x 200 mm Polyvinyl Chloride Pipe (PVC) molds with a 6.0 mm wall thickness, 150 x 150 mm cut down standard plastic compression molds and 150 x 305 mm standard plastic compression molds. The PVC pipe was chosen in the hopes that the thicker walls would provide additional restrictions to expansion in the radial direction and further propagate pure lateral expansion of the specimens. The aforementioned ASTM C1293 exposed specimen sizes are as follows: 100 x 200 mm, 150 x 150 mm, 150 x 305 mm, 75 x 75 x 285 mm and 115 x 115 x 285 mm.

The increase in specimen sizing was done to investigate the size effect on reducing the leaching out of alkalis as seen in the field. Increasing the specimen sizing has been proven to lower the permutable alkali thresholds and therefore capture excessive expansion in the laboratory with the current Norwegian 38°C CPT [4]. Likewise, the CCT and ASTM C1293 direct sizing correlation was done to show the influence on alkali confinement within the specimen vs. permissible leaching of alkalis out of the concrete system.

3 Results

3.1 CCT and ASTM C1293

Ten concrete mixtures were cast to evaluate concrete mixtures in the concrete cylinder test that have shown to fail in the field and pass the concrete prism test. Figure 6 shows the expansion for ASTM C1293 and CCT samples for Mixture 3, which has a total alkali loading of 1.25%. This graph shows the trends of typical ASTM C1293 testing, but also draws several important features of the CCT test. First, the different temperatures to which the samples were exposed greatly effects the speed at which final expansion is attained. The specimens exposed to 60°C, prove to have rapid expansion, as compared with the 50°C specimens, which reach final expansion in about twice the time. The samples in the 38°C ovens are taking nearly 6 times as long to reach final expansion as compared with the 60°C samples. Figure 6 also shows that specimens contained in CCT at the higher 50 and 60°C temperature clearly reaches final expansion at a much faster rate than its 1293 counterpart. After a period of 28 days limited additional expansion is seen from the CCT contained samples held at 60°C. Another key point to be taken from Figure 6 is that larger samples exposed to ASTM C1293 conditions continue developing expansion even at higher temperatures. For this reason, more work has been performed investigating larger samples sizes to decrease alkali leaching with the hopes of detecting ASR susceptibility in low alkali loading job mixtures.

Figures 7-9 provide the ASTM C1293 and CCT expansions for mixtures 1-3 that contain different alkali loadings which have all shown to expand and crack in outdoor exposure blocks. Figure 7 shows that expansion is not occurring for either CPT or CCT testing regime. This is a very low alkali loading (2.2 kg/m^3); however, it has been seen to crack in the field. It may be that more time is needed to see if these mixtures expand in the CCT. Similar to mixture 1, mixture 2 which has an alkali loading of 3.3 kg/m^3 which has not expanded after 250 days. However, these first two mixtures were repeated (mixtures 4 and 5 in Table 1) to include larger 150 X 300 mm compression molds and a method of ensuring water was ponding in the samples every week. Due to the difficulty in measuring the larger pinned specimens, embeddable strain gauges were placed in the 150 X 300mm cylinders to assure the accuracy and repeatability of the results. The new method of ensuring ponding of water weekly has shown to be beneficial as shown in Figures 10 and 11. Expansion is occurring for both the gauge pins and embedded strain gauges. Both Figures 10 and 11 provide a direct comparison between the expansion through the use of gauge pins with CCT setup with overlaid strain gauge expansion measurements for that same mix in both CCT and 1293 conditions. The embedded strain gauge does show a slightly lower expansion at 60C, when compared to the standard CCT measurement with gauge studs for mix 5, Figure 11. However, Figure 10 proves that the embedment gauge's expansion is larger than the standard CCT measurement gauge process. This is attributed to the improvements that have been made to the CCT test with respect to perfectly sealing and wetting the specimen. Figure 10 also shows a minor dip around the 18-day mark. This was done in order to address the concerns of potential coefficient of thermal expansion effects, which proved minor with respect to ASR expansion. Currently research is being performed in order to measure temperature effects with respect to expansion on CCT strain gauged specimen measurements. Figure 6 provides the expansion measurements for mixture 3 which is boosted to 1.25%. The benefits of the CCT are shown in this graph. The CCT mixtures have a quicker onset of expansion and higher ultimate expansion when compared to ASTM C1293. An issue with testing CPT at 60C was lower expansions due to increased leaching at the elevated temperature. This has been minimized with the CCT as shown in Figure 6.

Figure 12 provides the CPT and CCT expansions for mixture 7 which contains 100% lithium. Previous CPT testing [4] showed this mixture passing the test at 2 years. However, this exposure block after 10 years has expanded and cracked. Mixture 7 tries to capture any expansion using the CCT. After 365 days, this mixture has not expanded past the 0.04% expansion limit using the CCT. Mixture 8 contains a mixture with 35% Class C fly ash which passed the CPT test [6], but expands in outdoor exposure blocks. After 365 days, this mixture has not expanded to failure with CPT, but CCT has nearly failed at 0.039% expansion. Mixture 10 was cast with a full boost up to 1.25% based on 100% cement mixture. Figure 13 shows this mixture expanding past the 0.04% expansion limit after 91 days which is encouraging since the CPT did not expand after 2 years.

4. DISCUSSION

The CPT is generally regarded to be the more reliable of the two main ASR test methods; yet, there are some notable shortfalls of this test. Research has indicated that there is significant permissible alkali leaching, which only increases with time over the fairly lengthy testing periods (1 to 2 years). The CCT apparatus proves to hold the alkalis within the concrete system and drastically shorten the length of the testing to reaching final expansion especially with boosted mixtures . More work continues to be done with measuring larger sized specimens and ensuring that the moisture and alkalis are not permitted to leave the system. With data proving that larger samples produce more expansion over time, more energy has been spent towards testing larger 150 X 300 mm specimens for future CCT testing. Embeddable strain gauges have been implemented in both 150 X 300 mm CCT and 1293 specimens in order to assure the accuracy and repeatability of the expansion results.

In evaluating aggregate reactivity with mixtures boosted to 1.25%, the CCT has shown that it could decrease the length of the test duration. Figures 5 and 9 show the benefits for testing aggregates in the CCT. Elevated temperatures do have a quicker onset of expansion. Figure 11 shows the possibility of using the CCT for mixtures containing SCMs. The use of double boosting the mixture has shown greater expansions compared to just boosting the cement portion of the mixture.

The most difficult item for the CCT mixtures has had trouble with is picking up mixtures with low alkali loadings. Mixture 1 which has an alkali loading of 2.2 kg/m^3 has not shown expansion to date but future monitoring will be conducted to see if this mixture expands. Mixture 2 which has an alkali loading of 3.3kg/m^3 has shown expansion in both gauge studs and embeddable strain gauges. Further monitoring will help determine the effectiveness of the CCT on lower alkali loadings.

5. CONCLUSION

The concrete cylinder test (CCT) addresses both the issue of leaching and the excessive test duration that have limited the use of the CPT in practice. It has been shown that the CCT can produce final expansion values in a mere 15 weeks compared to the same mixture at 1 year for the CPT [1]. With the use of concrete cylinder molds, this test method may easily be used for on site job mixtures. In addition, with leaching no longer being a source of error with this method, the test could be utilized with mixtures that have lower alkali thresholds. However, this test method has not shown to be able to pick up very low alkali mixtures (2.2 kg/m^3) which do show cracking in the field.

6. REFERENCES

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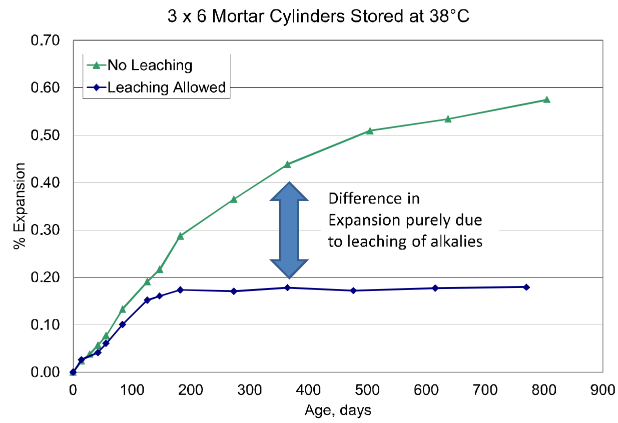

FIGURE 1: Alkali Leaching Expansion Data.

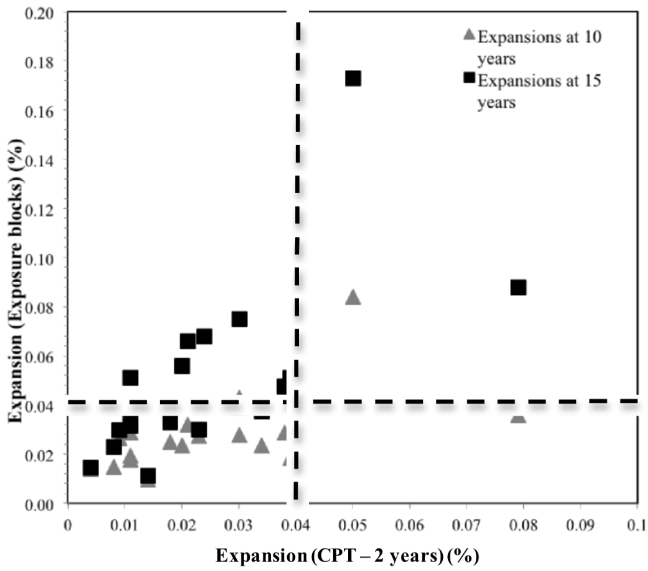

FIGURE 2: CPT Results at 2 years as compared with exposure blocks at 10 to 15.

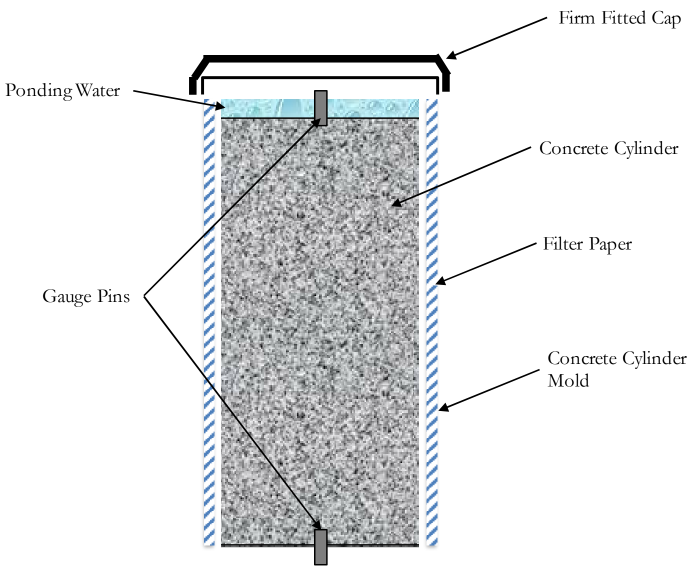

FIGURE 3: Diagram of CCT Setup.

FIGURE 4: Top View of CCT in Comparator Stand.

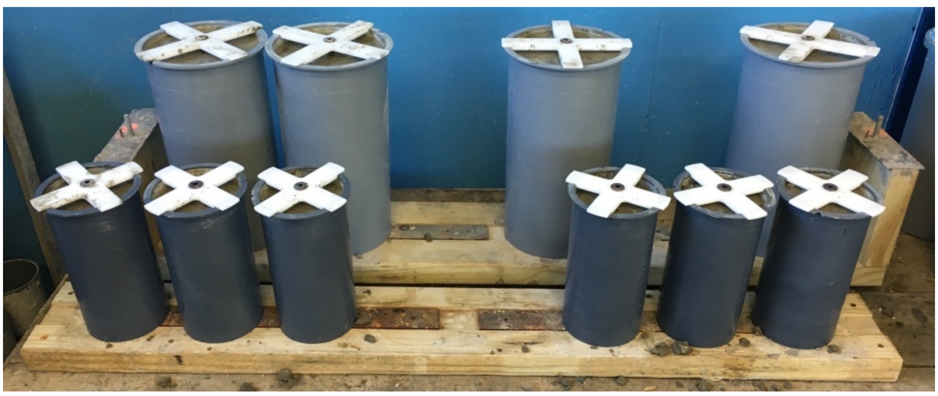

FIGURE 5: Photo of CCT specimens in the "Stace-molds" apparatus (105x305 mm in back and 100x200 mm in the front).

TABLE 1: Mixtures evaluating the CCT testing at the University of Texas.

Mix No.	Fine Aggr.	Coarse Aggr.	Cement	SCM's	Admixtures	Alkali (%)
1	FA1	CA1	CM1	-	-	0.52
2	FA1	CA1	CM2	-	-	0.78
3	FA1	CA1	CM2	-	-	1.25
4	FA1	CA1	CM1	-	-	0.52
5	FA1	CA1	CM2	-	-	0.78
6	FA2	CA1	CM2	-	-	1.25
7	FA1	CA1	CM2	-	100% LiNX	1.25
8	FA2	CA1	CM2	35% Class C	-	1.25
9	FA2	CA1	CM2	-	-	1.25
10	FA2	CA1	CM2	35% Class C	-	1.25 (Double Boost)

TABLE 2: Specimen Sizing for CCT and 1293 with Companion Notes.

CCT or 1293	Temperature [°C]	Cylinder or Prism	Dimensions [mm]	Notes
CCT	38, 50 & 60	Cylinder	100 x 200	Easiest to Measure
	38, 50 & 60	Cylinder	100 x 200	6mm wall thickness for added restriction
	38 & 60	Cylinder	150 x 150	Sealing proved difficult
	38 & 60	Cylinder	150 x 305	Difficult to handle
1293	38 & 60	Cylinder	100 x 200	Performed as direct size control to CCT
	38 & 60	Cylinder	150 x 150	Performed as direct size control to CCT
	38 & 60	Cylinder	150 x 305	Difficult to handle
	38, 50 & 60	Prism	75 x 75 x 285	Standard 1293 Size for control
	38 & 60	Prism	115 x 115 x 285	Larger to test effects of leaching

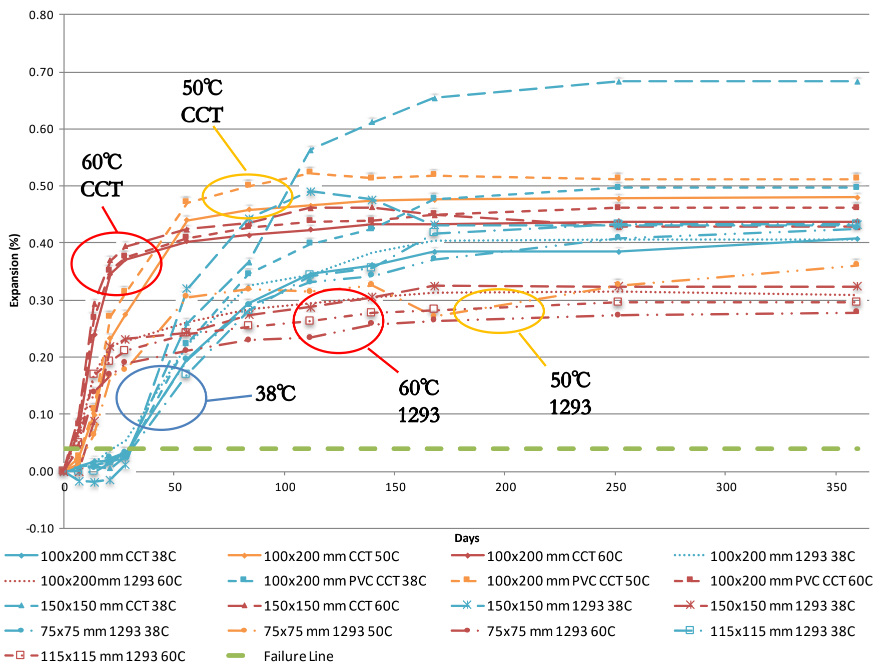

FIGURE 6: Mix 3 Expansion over Time CCT and 1293 Specimens at 38, 50 and 60°C.

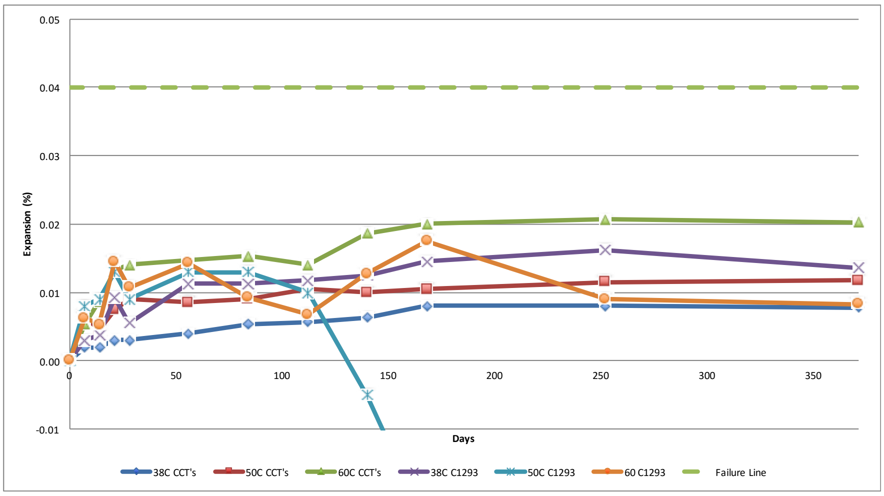

FIGURE 7: ASTM C1293 and CCT expansion measurements for mixture 1.

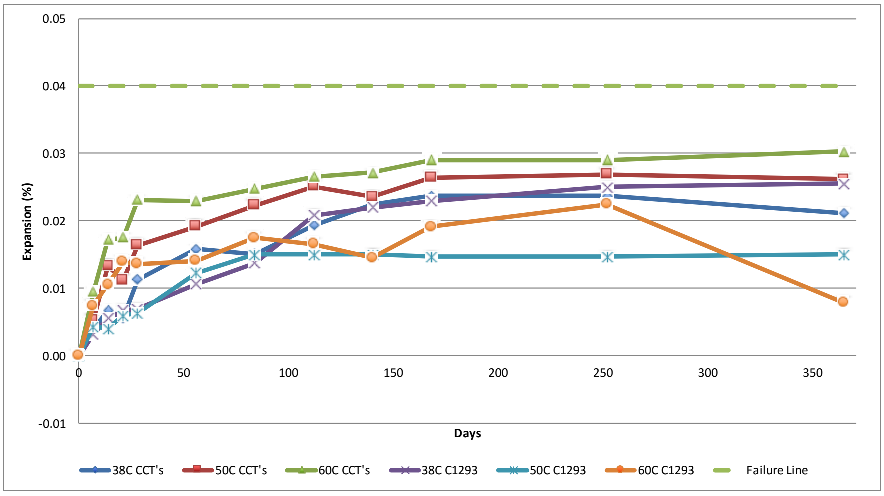

FIGURE 8: ASTM C1293 and CCT expansion measurements for mixture 2.

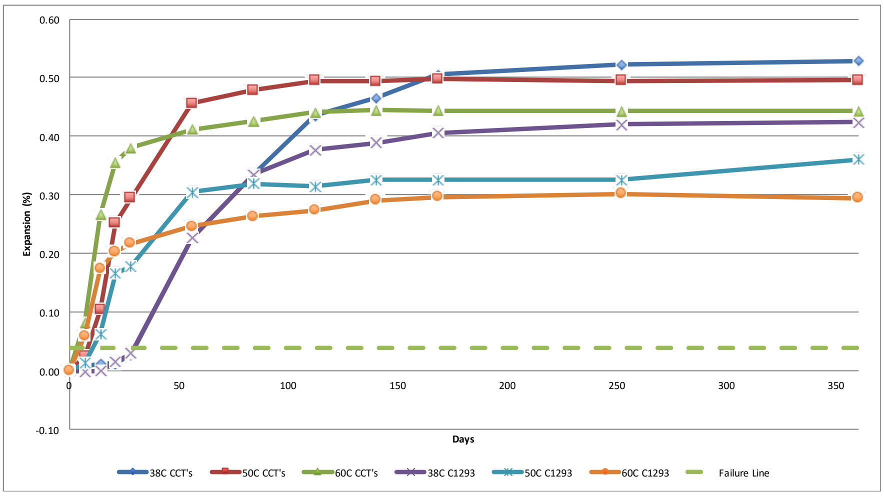

FIGURE 9: ASTM C1293 and CCT expansion measurements for mixture 3.

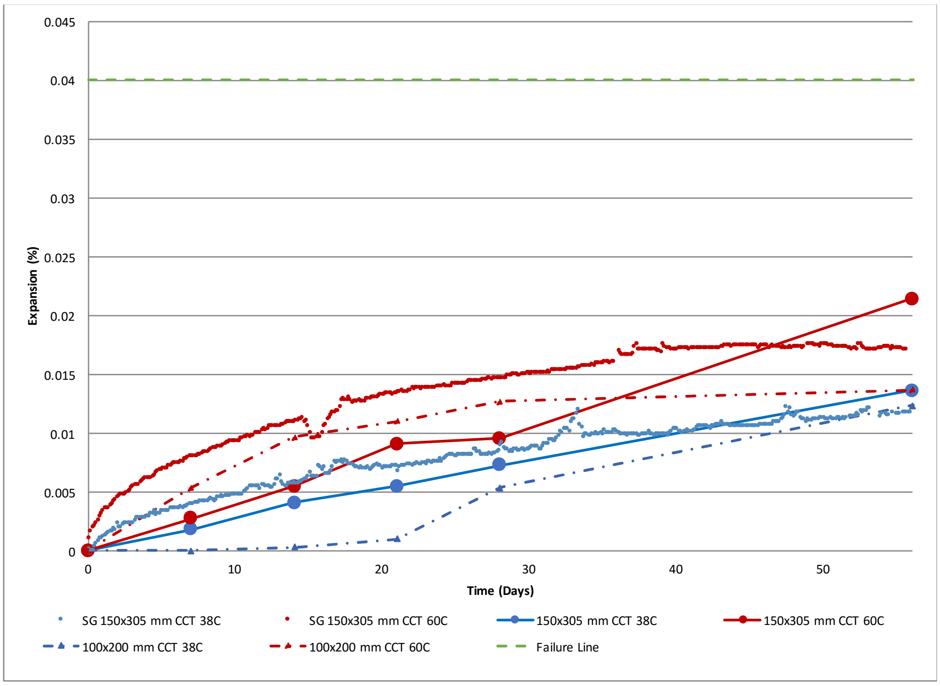

FIGURE 10: Mix 4 Expansion over Time CCT and 1293 with Strain Gauge (SG) Overlay for Completeness.

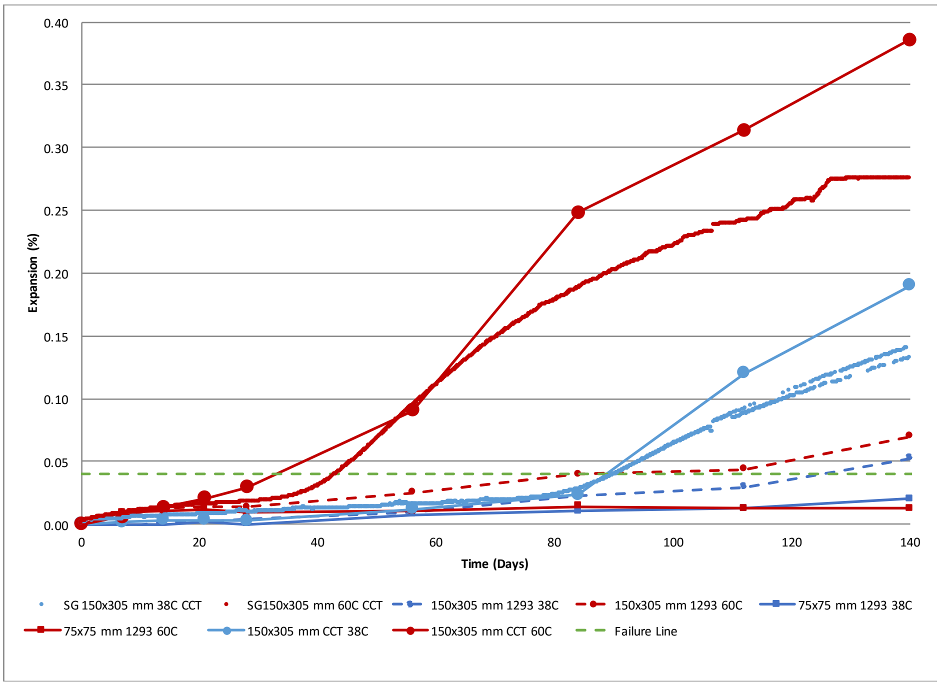

FIGURE 11: Mix 5 Expansion over Time CCT and 1293 with Strain Gauge (SG) Overlay for Completeness.

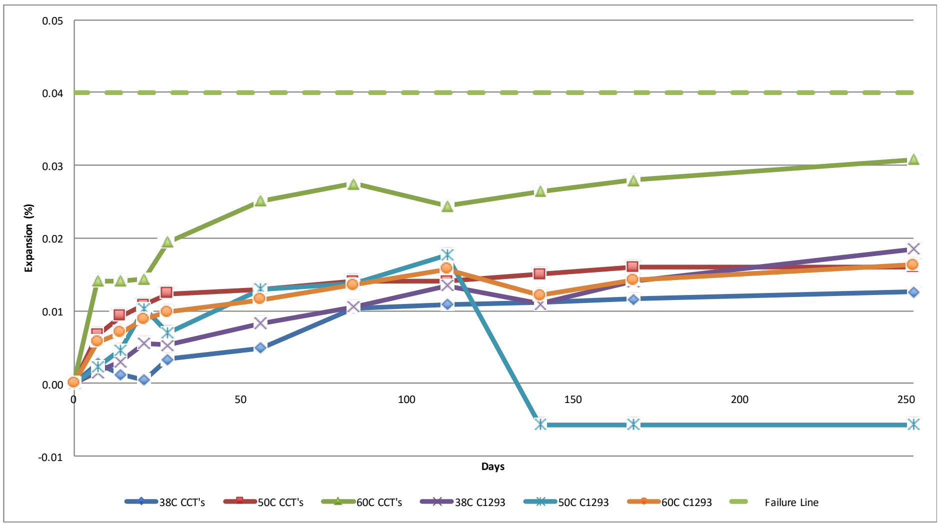

FIGURE 12: ASTM C1293 and CCT expansion measurements for mixture 7.

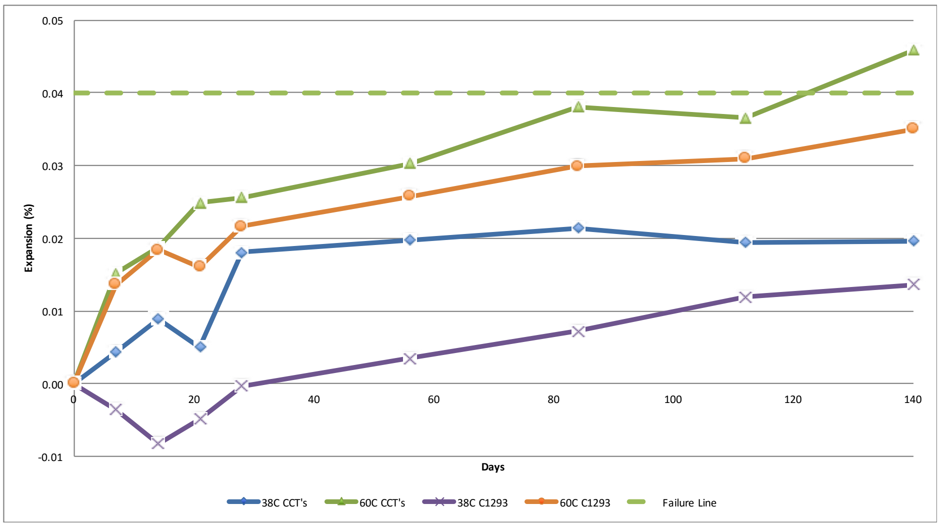

FIGURE 13: ASTM C1293 and CCT expansion measurements for mixture 10.