INTER-LABORATORY COMPARISON OF EXPANSIONS FROM THE AUTOCLAVED CONCRETE PRISM TEST

Stephanie G. Wood[1*], Margaret L. Kimble[2], Nathan D. Klenke[1], Bryce Fiore[3], Jennifer E. Tanner[3], Eric R. Giannini[1]

[1]The University of Alabama, Tuscaloosa, AL, USA

[2]GEI Consultants, Inc., Denver, CO, USA

[3]University of Wyoming, Laramie, WY, USA

Abstract

A widely-accepted test method for determining the alkali-silica reactivity of aggregates is the ASTM C1293 concrete prism test (CPT). Of all the standardized test methods designed for this purpose, the CPT shows the best correlation with field behavior. However, the one-year test duration renders the CPT unappealing.

The autoclaved concrete prism test (ACPT), was developed to reduce this testing time. The ACPT uses concrete prisms like those in the CPT but with higher alkali loading. Prisms are conditioned in an autoclave for 24 hours at 133 °C. Early results show a good correlation to known aggregate field performance.

To determine repeatability of the ACPT, The University of Alabama (UA) and the University of Wyoming independently tested four aggregates from Wyoming paired with a known non-reactive counterpart. Results indicate a better inter-laboratory correlation with coarse aggregates than with fine aggregates, with UA consistently obtaining higher expansions for fine aggregates tested.

Keywords: alkali-silica reaction, autoclave, expansion, interlaboratory study, test repeatability

1 INTRODUCTION

The concrete prism test (CPT) specified in ASTM C1293 [1] and CSA A23.2-14A [2] is a widely-accepted test method for determining the potential for alkali-silica reaction (ASR) in aggregates due to its strong correlation with field behavior. However, the CPT requires one year to obtain results with normal concrete and two years when testing the effectiveness of mitigation measures, restricting the use of the test in actual construction applications.

In an effort to reduce testing duration, Ranc and Debray [3] introduced the accelerated CPT in which prisms are stored at 60 °C for a shorter duration rather than the standard 38 °C for one year. More recently, it has been observed that expansion rates in the accelerated test can be reduced significantly compared to those observed in the standard test due to specimen drying and alkali leaching [4]. Such reductions in expansion may result in incorrect evaluations of aggregate reactivity. The accelerated test has yet to replace the standard CPT.

A number of autoclave test methods were developed to address the testing duration issue, most notably those by Tamura [5], Nishibayashi et al. [6], and Fournier et al. [7]. Some of those methods demonstrated promise, but none have come into wider use or been standardized. Additionally, though not a new concept, the use of autoclaving to quickly determine aggregate alkali-silica reactivity has mostly been limited to testing fine aggregates in mortar specimens rather than using concrete or job mixtures. This is also one of the limitations of the ASTM C1260 (AMBT) [8] because some coarse aggregates perform differently when crushed into fine aggregate.

The autoclaved concrete prism test (ACPT) was developed at The University of Texas at Austin in hopes of expediting ASR testing in concrete specimens while providing results that relate to field behavior and CPT results [9].

The purpose of this study is to evaluate the repeatability of the ACPT. To do so, The University of Alabama (UA) and the University of Wyoming (UW) tested four coarse and fine aggregates from Wyoming against the same known non-reactive counterpart and compared expansions.

* Correspondence to: wood010@crimson.ua.edu

2 MATERIALS AND METHODS

2.1 General

Aggregates used in this project were sourced from various locations in Wyoming and demonstrated a range of reactivities based on results acquired from the Chinese accelerated mortar bar test (CAMBT), ASTM C1260, and ASTM C1293 testing [10]. Crushed limestone from San Antonio, Texas served as the control non-reactive aggregate – both coarse and fine. Chemical analysis of the ASTM C150 Type I/II cement from Wyoming is provided in Table 1. The equivalent alkali content (Na_2O_{eq}) was 0.71% by mass of cement.

2.2 Materials and methodology

Aggregate abbreviations, source locations, mineralogies, and reactivity classifications are listed in Table 2. Two of the aggregates tested, GP and KR, were classified as highly reactive, one aggregate, HP, as non-reactive, and another aggregate, BR, as moderately reactive based on results of CAMBT, AMBT, and CPT testing.

The specimen size (75 x 75 x 285 mm) and coarse aggregate gradations in this study matched those specified in ASTM C1293. The fine aggregates were graded in accordance with ASTM C1260. The w/cm between the two laboratories differed with UA using a w/cm of 0.42 and UW using a w/cm of 0.45. Additionally, a polycarboxylate superplasticizer was employed by UW to improve workability of the fresh concrete. The Na_2O_{eq} of all mixtures was boosted to 3.0% by mass of cement using sodium hydroxide (NaOH). Mixture proportions were obtained following the absolute-volume method [11], using a cement content of 420 kg/m^3 and bulk volume of coarse aggregate equal to 0.70.

Mixing procedures varied between the two laboratories. For comparison, the two procedures, are described in Table 3 along with the procedures for aggregate preparation and curing. After mixing, slump was measured in accordance with ASTM C143 [12], and three 100 x 200-mm cylinders for compressive strength testing were cast from each mixture for quality assurance. Each mixture created four prisms for expansion testing.

Curing methods also diverged slightly between the two laboratories. After mixing, UA allowed the prisms and cylinders to remain in molds for 24 hours in the laboratory before they were demolded and moist cured until testing – 24 hours for the prisms and 27 days for the cylinders. Alternatively, UW immediately began moist curing prisms and cylinders in molds for 24 hours before demolding, wrapping prisms in moist felt, and moist curing for an additional 24 hours.

After curing, concrete prisms were measured using a length change comparator before being conditioned in a commercially available autoclave for 24 hours at 133 °C (0.20 MPa gage pressure). Figure 1 shows concrete prisms inside the autoclave. Prisms were placed upright inside the chamber in a wire basket so that they were not resting on the embedded metal studs. The wire basket sat upon a steel plate which was suspended above a water reservoir used to create a steam environment. Deionized water was used rather than tap water to enable measurement of leached alkalis during the test. A schematic of the autoclave chamber interior is provided in Figure 2.

Concrete prisms were removed from the autoclave once the unit reached 90 °C and were subsequently cooled upright in a tap water bath over a period of approximately 1 hour until prism temperatures reached 23 °C.

Prisms were once again measured using the length change comparator at 23 °C, and expansions were calculated. The proposed expansion limit for the ACPT is 0.08%; any aggregates with expansions at or above that value are considered potentially reactive. Results from the two laboratories were compared to results from the AMBT and to each other.

Compressive strength testing was performed on the concrete cylinders from each mixture in accordance with ASTM C39 [13] at 28 days and results were compared between the two laboratories.

3 RESULTS

Expansion results from each laboratory were first compared to expansions observed in the AMBT. Figure 3 shows results from the UA laboratory versus AMBT, and Figure 4 shows the same comparison with results from the UW laboratory. All four of the fine aggregates emerged as reactive in both laboratories. Although UW provided CPT expansions for the tested aggregates, they had performed a non-standard version of the test, combining coarse and fine fractions of a potentially reactive aggregate rather than pairing the potentially reactive coarse aggregate with a non-reactive fine aggregate and vice-versa. Therefore, results from the ACPT and CPT cannot be effectively compared.

Figure 5 compares autoclaved prism expansions obtained by the two laboratories. The non-reactive coarse aggregate, HP, would be classified as non-reactive based on the ACPT results at both

laboratories; however, the fine fraction of this aggregate far exceeds the 0.08% proposed expansion limit at both laboratories. Expansion results were more similar between the two laboratories for test coarse aggregates than they were for test fine aggregates. Table 4, showing the intra- and inter-laboratory coefficients of variation (CVs), better illustrates these comparisons. Inter-laboratory CVs of coarse aggregate expansions ranged from 11 to 22%. The CVs of fine aggregate expansions demonstrated a much greater range from 12 to 42% with KR exhibiting the highest and most outlying value.

Table 5 shows the average compressive strengths measured at 28 days for each mixture, along with intra-laboratory CVs. Strengths were generally 50% higher for specimens cast at UA. The mixture with the least difference in compressive strength between the two laboratories was GP fine, with the UA specimen strengths 17% higher than the UW specimens; this was also the lowest-strength mixture tested at UA.

4 DISCUSSION

Though expansion limits for the ACPT and AMBT are different and expansion values themselves cannot be directly compared, the ACPT was able to classify fine aggregate reactivities that agree with the AMBT; this was the case with results from both laboratories. Additionally, Figures 3 and 4 show similar plotted groupings for KR and HP as well as GP and BR for both laboratories. This indicates that better repeatability of the ACPT may be possible with more agreement between the laboratories concerning aggregate preparation, mixing procedure, and curing method. It was unexpected that the non-reactive aggregate, HP, appeared to be reactive as a fine aggregate in the ACPT. Results from the ACPT should be compared to results from the standard CPT, particularly in the case of the HP fine aggregate, to gain a better sense of the reliability of the ACPT at the temperature, duration, and alkali loading currently used in the test.

Of greater concern was the fact that tests run at UA consistently resulted in greater expansions than tests run at UW. One possible explanation for UA observing higher expansion values than UW, particularly when testing the fine aggregates, relates to the non-reactive coarse aggregate used in the study. Both laboratories observed excessive dust on the coarse aggregate, but UA washed the aggregate prior to mixing while UW did not. UW was only able to achieve sufficient workability by using a higher w/cm and a superplasticizer. Previous research has shown that the use of a polycarboxylate superplasticizer does not affect concrete expansions due to ASR [14], and its use by UW is not considered a contributor to the observed disparity in expansion results.

The reason for the substantially lower 28-day compressive strengths obtained by UW is also undetermined. Initially, it was thought that the reason could be attributed to the dusty non-reactive coarse aggregate or honeycombing of the concrete mixture. It remains unclear why UA consistently achieved much higher strengths for coarse aggregate mixtures using a coarse aggregate from the same source. Furthermore, although the w/cm used by UW was higher, the difference in w/cm used by the two laboratories was not great enough to account for the large differences between compressive strengths.

5 CONCLUSIONS

From the work performed in this study, the following conclusions can be made:

- Reactivity classifications of the four fine aggregates tested in the ACPT generally agree with those obtained in the AMBT.
- The correlation between coarse aggregate expansions was much stronger than the correlation between fine aggregate expansions between the two laboratories. A possible reason for this disparity is excessive dust on the non-reactive coarse aggregate, as one laboratory washed the aggregate before mixing and one did not.
- Compressive strengths measured at UA were generally 50% higher than compressive strengths measured at UW. The reason for this is unclear and is likely not due to the dust on the non-reactive coarse aggregate or the relatively small difference in w/cm.
- It may be possible to achieve lower inter-laboratory CVs and similar compressive strengths if all processes, including aggregate preparation, mixing procedure, and curing method, were the same between laboratories, especially considering the overall good intra-laboratory CVs obtained at both test sites.

Other methods for evaluating the efficacy of the ACPT are currently underway at UA, including autoclave water and pore solution analysis and petrographic analysis of the concrete prisms. Future studies should include an inter-laboratory comparison of expansions using a larger number of samples and aggregates with more diverse mineralogies and reactivies. It is also suggested that certain

variables of the test, such as temperature, duration, and alkali loading, be re-examined and adjusted, perhaps based on mineralogies of the aggregates in question. UA intends to recreate some of the approximately 50 mixtures already tested using a different non-reactive counterpart to determine its influence, if any, on expansion outcomes.

6 REFERENCES

[1] ASTM C1293-08b (2015): Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction, ASTM International, West Conshohocken, PA, 2015, www.astm.org.

[2] CSA A23.2-14A, Potential expansivity of aggregates (procedure for length change due to alkali-aggregate reaction in concrete prisms at 38°C), Concrete Materials and Methods of Concrete Construction/Methods of Test and Standard Practices for Concrete, Mississauga, ON, Canada, 2004, pp. 246-256.

[3] Ranc, R., & Debray, L. (1992): Reference test methods and a performance criterion for concrete structures. In *The 9th International Conference on Alkali-Aggregate Reaction in Concrete*, July 1992, London, Volume 2.

[4] Ideker, J. H., East, B. L., Folliard, K. J., Thomas, M. D., & Fournier, B. (2010): The current state of the accelerated concrete prism test. *Cement and Concrete Research*, *40*(4), pp. 550-555.

[5] Tamura, H. (1987). A test method on rapid identification of alkali reactivity aggregate (GBRC rapid method). In *Proceedings of the 7th International Conference on Alkali-Aggregate Reaction in Concrete,* 1986, Ottawa, ON, Canada, pp. 304-308.

[6] Nishibayashi, S., Yamura, K., & Matsushita, H. (1987): A Rapid Method of Determining the Alkali-Aggregate Reaction in Concrete by Autoclave. *Concrete Alkali-Aggregate Reactions,* ed. P.E. Grattan-Bellew. Noyes Publications, Park Ridge, New Jersey, pp. 299-303.

[7] Fournier, B., Bérubé, M. A., & Bergeron, G. (1991): A rapid autoclave mortar bar method to determine the potential alkali-silica reactivity of St. Lawrence lowlands carbonate aggregates (Quebec, Canada). *Cement concrete and aggregates*, *13*(1), pp. 58-71.

[8] ASTM C1260-14, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method), ASTM International, West Conshohocken, PA, 2014, www.astm.org.

[9] Giannini E.R.; Folliard, K.J. (2013): *Determining Alkali-Silica Reactivity of Aggregates Using a Rapid Autoclaved Concrete Prism Test*, SN3235, Portland Cement Association, Skokie, IL, USA.

[10] Kimble, M., Fertig, R., Jones, A., & Tanner, J. (2013): "Evaluation of ASR Potential in Wyoming Aggregates" Final Report, Federal Highway Administration, Wyoming Department of Transportation, FHWA-WY-13/04F, pp. 156.

[11] ACI 211.1-91, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete.

[12] ASTM C143/C143M-15, Standard Test Method for Slump of Hydraulic-Cement Concrete, ASTM International, West Conshohocken, PA, 2015, www.astm.org.

[13] ASTM C39/C39M-15a, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, 2015, www.astm.org.

[14] Leemann, A., Lothenbach, B., & Thalmann, C. (2011): Influence of superplasticizers on pore solution composition and on expansion of concrete due to alkali-silica reaction. *Construction and Building Materials*, *25*(1), pp. 344-350.

TABLE 1: Chemical analysis of cement.

Oxide	Oxide Notation	Weight %
Silicon Dioxide	SiO_2	20.09
Aluminum Oxide	Al_2O_3	4.68
Iron Oxide	Fe_2O_3	3.34
Calcium Oxide	CaO	62.10
Magnesium Oxide	MgO	1.42
Sodium Oxide	Na_2O	0.14
Potassium Oxide	K_2O	0.87
Total Alkali Equivalent	Na_2O_{eq}	0.71
Loss on Ignition		2.76

TABLE 2: Descriptions and classifications of aggregates. Reactivities are based on results from the CAMBT, AMBT, and CPT.

Abbreviation	Source Location	Mineralogy	Reactivity
KR	Cheyenne, WY	Granite, rhyolite	Reactive
GP	Greybull, WY	Granite, rhyolite, quartzite	Reactive
HP	Cody, WY	Granite, rhyolite, quartzite	Nonreactive
BR	Powell, WY	Granite, rhyolite	Moderately Reactive

TABLE 3: Difference in procedures followed by the two laboratories.

The University of Alabama (UA)	University of Wyoming (UW)
Aggregate Preparation	
1. Grade aggregates in accordance with ASTM C1293 for coarse and ASTM C1260 for fine. 2. Wash aggregates on sieves and allow to air dry. 3. Mix aggregate sizes together in concrete mixer and sample to determine moisture content.	1. Grade aggregates in accordance with ASTM C1293 for coarse and ASTM C1260 for fine. 2. Mix aggregate sizes together and sample to determine moisture content.
Mixing Procedure	
1. Add all aggregate and half of the mixing water (with NaOH added). 2. Mix for 1 minute. 3. Stop mixer and add all of the cement. 4. Mix for 30 seconds. 5. Add the remaining water over a 30-second period while mixer is running. 6. Mix for 2 minutes. 7. Stop and cover mixer. 8. Rest for 3 minutes. 9. Mix for 2 minutes.	1. Add some of the coarse aggregate and some of the water. 2. Begin mixing. 3. Add the remaining coarse and fine aggregates and water. 4. Mix for 3 minutes. 5. Stop and cover mixer. 6. Rest for 2 minutes. 7. Mix for 2 minutes.
Curing	
1. After casting, allow prisms and cylinders to remain in the laboratory under a sheet of plastic for 24 hours. 2. Demold prisms and cylinders and move to moist curing room for 24 hours for prisms and 27 days for cylinders.	1. After casting, moist cure prisms and cylinders in molds for 24 hours under a sheet of plastic. 2. Demold prisms and cylinders, wrap prisms in saturated felt, and return specimens to the curing room for 24 hours for prisms and 27 days for cylinders.

TABLE 4: Average prism expansions with intra- and inter-laboratory coefficients of variation.

Test Aggregate	Test Site	Average Prism Expansion, %	Intra-Lab CV, %	Inter-Lab CV, %
KR Coarse	UA	0.084	24.03	19.77
	UW	0.060**	9.43	
	UW	0.068	2.50	
KR Fine	UA	0.336	4.49	42.15
	UW	0.154	5.29	
GP Coarse	UA	0.127	4.76	19.44
	UA	0.124	10.92	
	UW	0.087	4.17	
GP Fine	UA	0.366	3.23	13.89
	UW	0.280	2.50	
HP Coarse	UA	0.065	2.36	11.34
	UW	0.051*	-	
HP Fine	UA	0.277	2.82	20.26
	UW	0.192	4.64	
BR Coarse	UA	0.109	2.79	22.13
	UW	0.073	4.92	
BR Fine	UA	0.362	1.96	14.95
	UW	0.270	3.75	

** Two prisms tested.
* One prism tested.

TABLE 5: Concrete cylinder compressive strengths at 28 days from both laboratories with intra-laboratory coefficients of variation.

Test Aggregate	UA		UW	
	Avg. Strength, MPa	CV, %	Avg. Strength, MPa	CV, %
KR Coarse	36.7	2.6	16.4*	-
	31.9	5.6	14.9*	-
KR Fine	38.1	1.2	15.5**	9.1
	36.8	1.6	-	-
GP Coarse	33.9	1.7	18.5*	-
	35.0	1.4	-	-
GP Fine	26.7	2.7	22.2	2.3
HP Coarse	-	-	-	-
HP Fine	37.5	1.1	16.2**	1.0
	-	-	17.3	3.7
BR Coarse	34.6	2.0	19.0	2.1
BR Fine	35.4	1.4	12.9**	9.9

** Two cylinders tested.
* One cylinder tested.

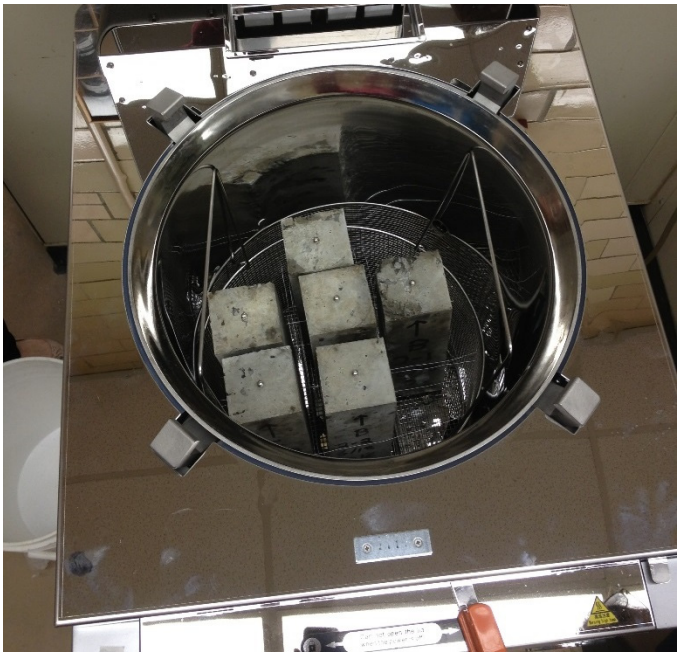

FIGURE 1: Concrete prisms standing upright inside the autoclave.

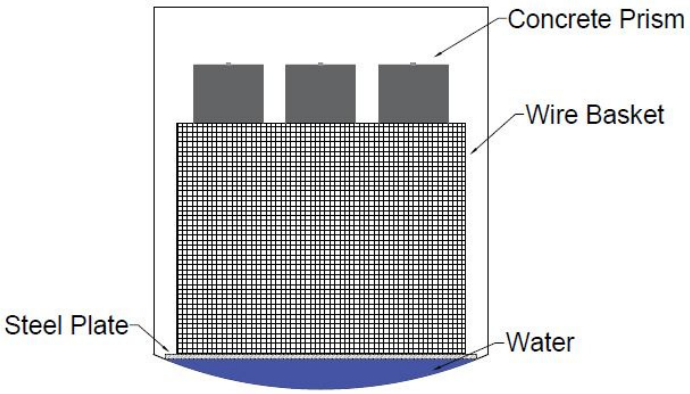

FIGURE 2: Schematic of the autoclave interior with concrete prisms inside.

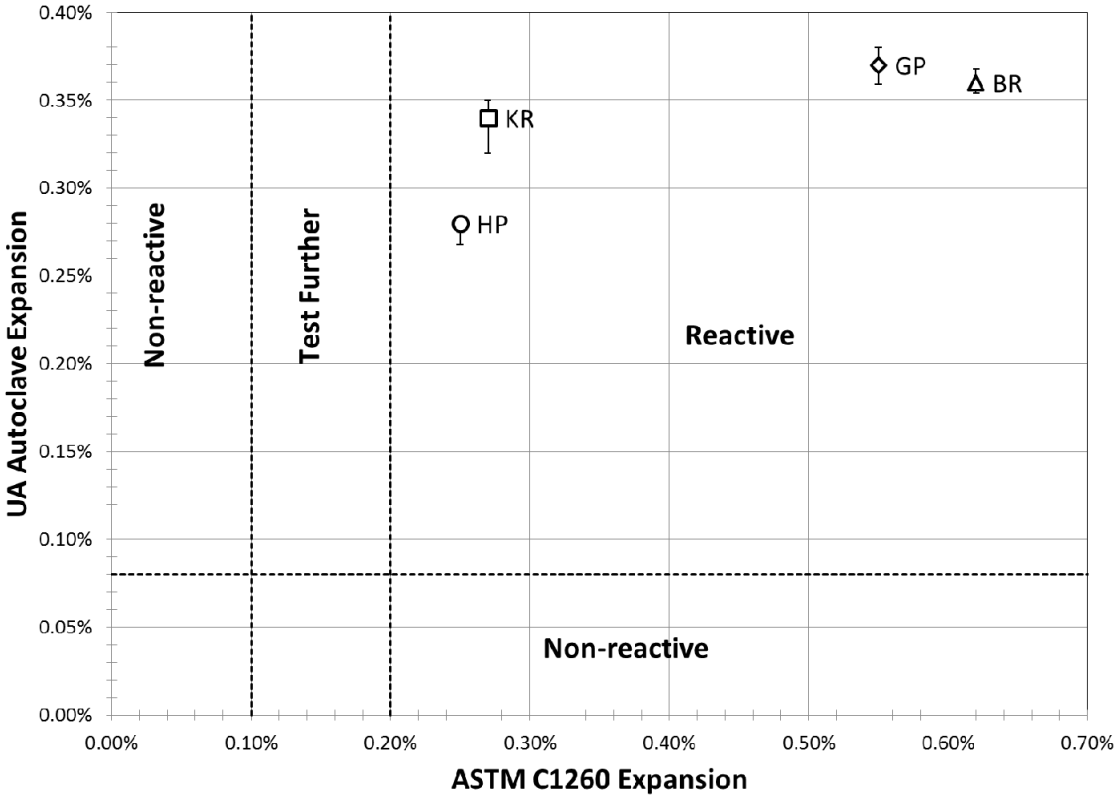

FIGURE 3: ACPT expansions vs. AMBT expansions for fine aggregates tested at UA. The dashed lines indicate recommended values for classifying aggregates as potentially reactive or reactive in the AMBT and a proposed threshold for classifying aggregates as reactive in the ACPT.

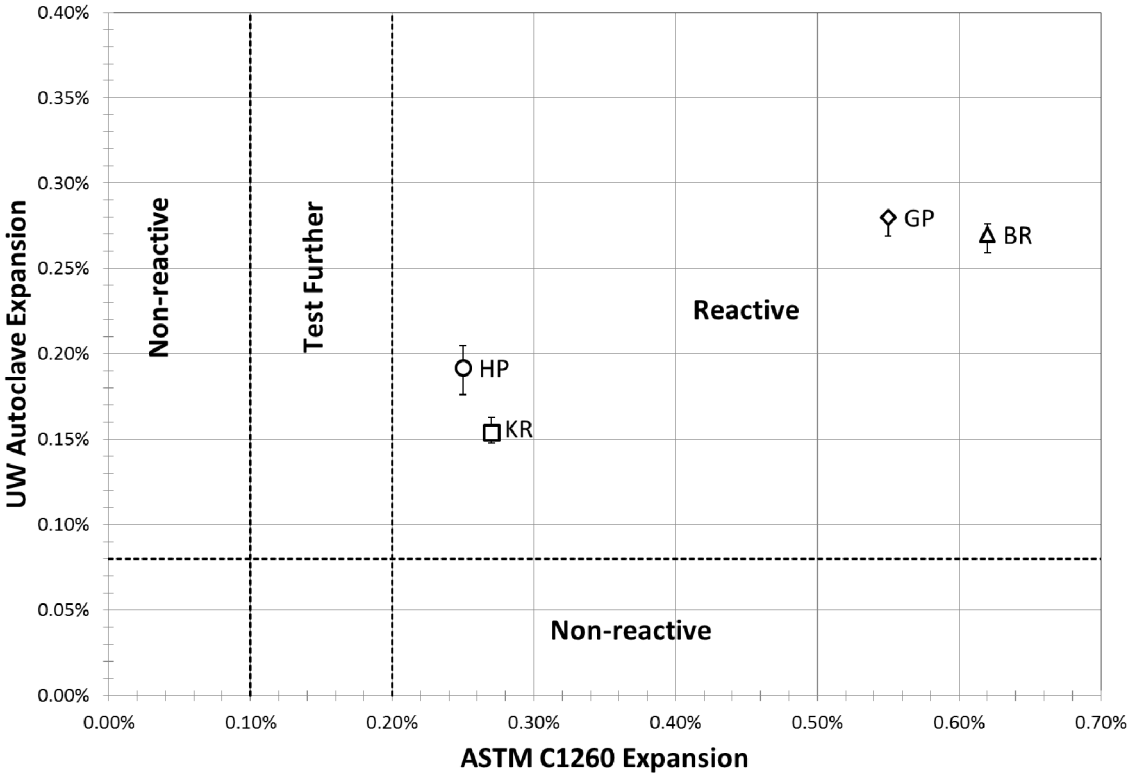

FIGURE 4: ACPT expansions vs. AMBT expansions for fine aggregates tested at UW. The dashed lines indicate recommended values for classifying aggregates as potentially reactive or reactive in the AMBT and a proposed threshold for classifying aggregates as reactive in the ACPT.

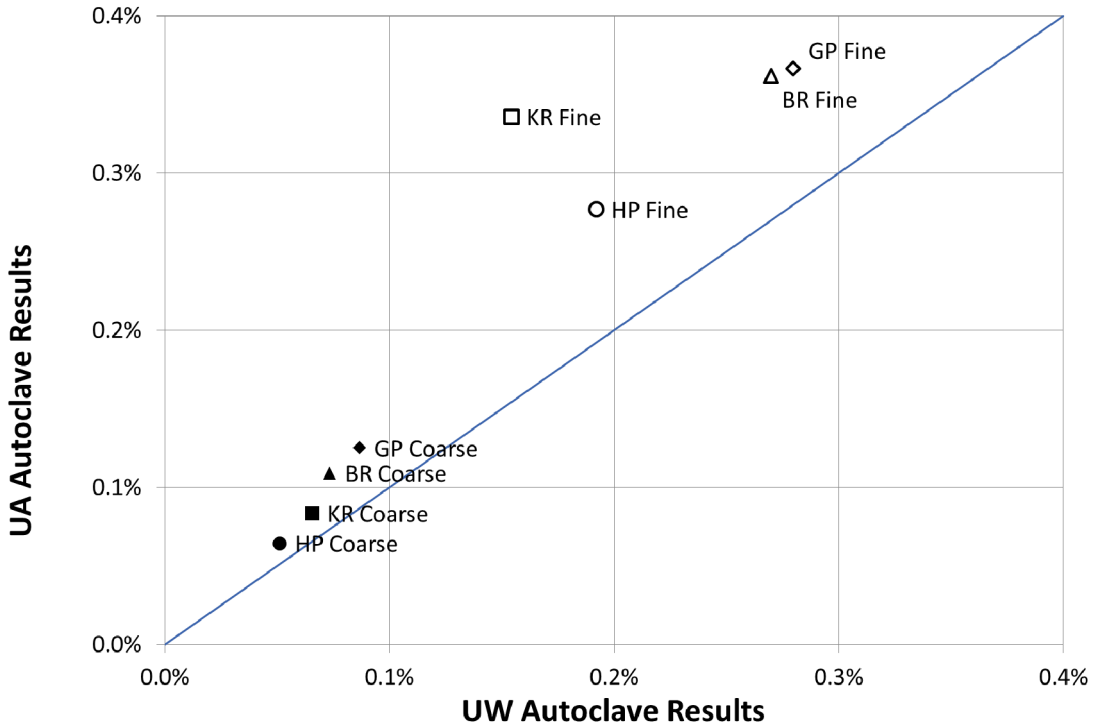

FIGURE 5: Comparison of autoclaved prism expansions between UA and UW. The diagonal line indicates what would be a perfect correlation of expansions between the two laboratories.