MULTI-LABORATORY STUDY OF ACCELERATED MORTAR BAR TEST AND CONCRETE PRISM EXPANSION TESTS AT 38° AND 60°C

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Abstract

The main purposes of this study were to qualify a new 100 tonne stockpile of Spratt coarse aggregate used for ASR studies and for calibrating alkali-aggregate reaction test methods. About 60 laboratories volunteered to take part in this study, but at this time not all laboratories have reported.

The new stockpile of Spratt aggregate (No. 3) gave similar expansion values in both accelerated mortar bar and concrete prism expansion tests to those found with an earlier supply of the same aggregate (1992). The multi-laboratory variation of the accelerated mortar bar test at 14 days was found to be about 13%. This is similar to average values found in earlier studies (15.2%). In the concrete prism expansion test at 60°C, the use of a control sand with Spratt aggregate gave significantly lower multi-laboratory variation than was found with the same mixtures tested at 38°C or those made using locally available sands and tested at 60°C. The reason is currently unknown.

Keywords: Accelerated mortar bar test, Alkali-silica reaction, Concrete prism test, Multi-laboratory study

1 INTRODUCTION

The Spratt aggregate is used in Canada as a reference aggregate for the calibration of alkali-silica reaction test methods. This siliceous limestone was discovered to be deleteriously expansive in both the field and the laboratory in the early 1980's. In 1986, the Ontario Ministry of Transportation (MTO) established a 100 tonne stockpile of the material. This was used from then on as source of reliably expansive coarse aggregate for research into alkali-silica reactions. Over 50 studies have been conducted where the Spratt aggregate was used as at least one of the known reactive aggregates. MTO makes this material available free of charge for research purposes. The first stockpile was exhausted in 1991 when it was used for construction of an outdoor exposure site to evaluate long-term effectiveness of preventive measures [1]. A second stockpile (Spratt 2) produced from the same bench of the quarry was established in 1992. Results of studies into the expansion given by this second aggregate in multi-laboratory studies were published in 1996 [2,3,4]. By 2006, this stockpile was nearly exhausted and a third stockpile was established.

There were multiple purposes for this study:

- To qualify a new 100 tonne stockpile of Spratt coarse aggregate (Spratt 3) used for research into alkali-reaction studies and for calibrating alkali reaction test methods;
- To investigate the effect of the use of a standard non-reactive fine aggregate compared to the use of locally available non-reactive fine aggregates on expansion of concrete made with the Spratt aggregate;
- To look at the precision of a modified concrete prism expansion test where the temperature of storage was increased to 60°C from the normal/standard temperature of 38°C.

In early 2007, samples were prepared and shipped to about 60 participating laboratories in North America, Iceland, Norway, Brazil and Australia. The main purpose of this paper it to present a preliminary analysis of the data received to date from the participants in the interlaboratory study and to compare the above results to those of previous studies, thus providing a preliminary estimate of the validity of the new load of Spratt aggregate to serve as a control material for ASR studies. A full statistical analysis will be carried out at a later stage, i.e. when all data are received from the participants in this study.

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2 MATERIALS AND METHODS

2.1 Aggregates

The Spratt aggregate is a siliceous limestone from the Spratt quarry in Stittsville near Ottawa, Canada. This is a horizontally medium bedded limestone containing small amounts of chalcedony and black chert. The rock consists of calcite with small amounts of dolomite. The acid insoluble residue content is about 10%, by weight; it consists of very finely disseminated silica with traces of pyrite. The principle reactive component is thought to be the finely disseminated silica which is not visible with normal optical thin section methods of examination.

For the purposes of this study, a new stockpile of 5-20 mm stone was produced from the same area of the quarry as used for previous supplies (Figure 1). This material was placed into a conical stockpile with a conveyor belt after crushing and screening. From this pile, another linear stockpile was made using a front-end loader. This stockpile was built in about 5 layers each being about 300 mm thick. Three trucks were loaded from this stockpile by working from one end. A scoop was taken and placed in one truck. The next scoop was then placed in the second truck. The third scoop was placed in the third truck. The fourth scoop was placed in the first truck and so on until the trucks each contained about 32 tonnes. This was done to ensure that, as far as possible, each truck contained the same material and segregation was minimized. On arriving at the storage location, the truckloads were emptied on a clean asphalt pad and then using a loader the aggregate was transported and placed in a covered storage area. The loader operations were coordinated so as to mix the material as far as possible as it was placed in storage.

Fine aggregate for this study was obtained from a sand deposit (Masham) in Wakefield, Quebec. This sand was siliceous natural fluvial sand consisting of the fragments of disintegration of Precambrian granites and high-grade metamorphic gneisses. The principle minerals were quartz and feldspar with minor amounts of ferro-magnesian minerals and trace amounts of biotite mica. A 20 tonne load was delivered to the same storage facility as used for the Spratt aggregate in Toronto. This sand (called "control sand") was of low absorption and gave an accelerated mortar bar expansion (CSA A23.2-25A) of 0.035% at 14 days.

2.2 Sample Preparation

To ensure that, as far as possible, all the samples were the same, a large spinning riffler was used which is shown in Figure 2. This device consisted of a spinning turntable of about 4 m diameter supported on rollers and driven at constant speed with an electric motor and gearbox to give a rapid speed of rotation. On this were placed 32 containers at the outside edge. The containers were filled from a very slowly moving conveyor belt that was fed by a hopper containing the aggregate to be sampled. The belt discharged aggregate into the containers on the turntable. The speed of rotation of the conveyor belt was set so that it took many rotations of the sample containers under the flow of material falling off the conveyor belt to fill each container. Spinning rifflers are capable of removing the effects of segregation in a stream of material by the use of the multiple passes needed to acquire the sample. The process works best if the turntable rotates relatively quickly and the flow of material is slow so as to maximize the number of passes needed to obtain the sample. To fill the bags containing the coarse and fine aggregates, approximately 30 passes under the belt were required to obtain a sample of about 30 kg. Both the fine aggregate and the Spratt coarse aggregates were prepared in this way. Following sampling, the bags were selected randomly for each laboratory so as to further reduce systematic sampling error.

2.3 Test Program and Methods

Participants in this interlaboratory study were invited to engage in one or several of the different parts that are described below and summarized in Table 1.

Testing program - Part I

This part of the test program consisted in performing comparative accelerated mortar bar testing of the "Spratt 2" and "Spratt 3" limestone materials (both provided). Participants were asked to run the AMBT in accordance with either CSA A23.2-25A [5], ASTM C 1260 [6] or RILEM AAR-2 [7] test method, using a portland cement that met the requirements of the test method used. Expansion monitoring of the mortar bars were to be performed at regular intervals up to 28 days.

Testing program - Part II

In this part of the program, each participant had to make two concrete mixtures incorporating the "Spratt 3" material: mix 1, a mixture using the control sand (provided); mix 2, a mixture using a local non-reactive sand (i.e. to be provided by the participant) meeting the requirements of the standard procedure. Participants were asked to run the Concrete Prism Test (CPT) in accordance with either CSA A23.2-14A [8] or ASTM C 1293 [9] methods. Expansion monitoring of the concrete prisms were to be performed at regular intervals up to one year.

Testing program - Part III

This part of the study was optional. Additional amounts of "Spratt 3" material was sent to those interested so that larger concrete mixtures can be made in Part II to cast an additional set of three prisms for running the CPT in its accelerated version, i.e. at 60^{o}C. The test procedure for the accelerated CPT was identical to that of the conventional test, except that the test prisms in their containers are stored at 60^{o}C instead than 38^{o}C. Expansion monitoring of the concrete prisms were to be performed at regular intervals up to six months.

Methods

As described above, participating laboratories were able to use a variety of published test methods. For the Accelerated Mortar Bar Test (AMBT) either CSA A23.2-25A, ASTM C 1260 or RILEM AAR-2 versions of the test could be used. All methods are substantially the same. The CSA version is calling for the use of a w/c of 0.50 for crushed stone sand and metric sieves in the sequence 2.5 mm, 1.25 mm, 0.63 mm, 0.315 mm and 0.16 mm. ASTM is calling for a w/c of 0.47 and a sieve series of 2.35mm, 1.18 mm, 0.60 mm, 0.30 mm, and 0.15 mm. The cement used for making the mortar bars is also specified slightly differently but is unlikely to influence results in a meaningful way. RILEM permits the use of either a 40 x 40 x 120 mm bar or the North American 25 x 25 x 285 mm bar and is calling for a w/c of 0.47 and a sieve series of 2 mm, 1 mm, 0.50 mm, 0.250 mm, and 0.125 mm. For all test methods, the cement to aggregate mass ratio is 1: 2.25.

For the Concrete prism expansion test (CPT) either CSA A23.2-14A or ASTM C 1293 could be used. These tests are essentially the same other than the sieve series used for coarse aggregate grading and the requirements for the sand-to-coarse aggregate ratio. The ASTM method specifies the use of a coarse aggregate oven-dry-rodded unit volume of 0.70 ± 0.2 for all classes of coarse aggregates; on the other hand, CSA standard specifies the use of a fixed coarse-to-fine aggregate ratio of 60:40, by mass, for normal density aggregates.

3 RESULTS

As of January 2008, results had been received from 38 laboratories for the Accelerated Mortar Bar Test and from 18 laboratories doing the Concrete Prism Expansion test at 38°C. A smaller number of laboratories opted to conduct the Concrete Prism Expansion Test at 60°C with a total of 11 reporting data to an age of 6 months. A summary of the results is shown in Table 2 for the Accelerated Mortar Bar Test. In this Table, data obtained using the Spratt aggregate that was reported in 1996 are also shown. Table 3 shows the results for the Concrete Prism Expansion Testing together with data for a similar study reported in 1996. Results are also shown graphically in Figures 3 to 6, which are scatter diagrams. In scatter diagrams each laboratories data on a pair of materials is plotted on the graph together with the mean expansion for each material. This allows a graphical representation of the closeness of a pair of test data to the mean. It also allows an estimate of the type of bias characteristic of the test method. For instance, data which tend to fall in the top right and lower left quadrants in a linear fashion indicate a test with significant laboratory bias. Data that fall uniformly around the mean with equal points in each quadrant show a test with random variation and little systematic laboratory bias. Figure 3 shows significant systematic laboratory bias for the Accelerated Mortar Bar Test.

In calculating the standard deviations, outlying or suspect data has generally not been removed from analysis. The exception is for the Accelerated Mortar Bar Test where the data from the two sets where the RILEM 40 x 40 x 160 mm bars were used has not been used in calculating standard deviation. In this case, it is obvious (Figure 3) that the RILEM test expansion is not similar to that obtained with 25 x 25 x 285 mm bars. The reason for this is probably the longer transport path for alkalies to penetrate the bar and the less time of reaction of the aggregate with the alkalies of the immersion solution. This delays the onset of expansion. Jensen and Fournier [10] reported that, based on the results of various testing programs, the linear correlation factor converting expansion results from RILEM bars to ASTM bars varies from 0.54 to 0.65.

4 DISCUSSION

Table 2 and Figure 3 show data for the AMBT on the Spratt No. 2 and No. 3 aggregates. One set of Spratt No. 2 was tested in 1996 and a second set was tested in 2007 by similar numbers of laboratories. The aggregate was from the same stockpile. It can be seen that the mean expansion in 1996 at 14 days of 0.416 is virtually the same as the mean obtained in 2007 of 0.403. The standard deviations are also very close: 14% in 1996 versus 13% in 2007. It should be remembered that, with some exceptions, these two sets of data were reported by different laboratories using different technicians and different cements. The closeness of the data shows that the aggregate has not changed and that there does not seem to have been a change in the overall conduct of the test. There was the remote possibility that part of the original 100 tonne stockpile sampled and used in 1996 might have been segregated from that sampled 11 years later but this does not seem to be the case.

Table 2 also shows that the new stockpile produced in 2005 (Spratt No. 3) gave 0.382% expansion at 14 days and that compares very well with that for the stockpile represented by Spratt No. 2 that gave 0.403% expansion in 2007. This provides confidence that the new stockpile has similar levels of reactivity and expansivity to that of the earlier supplies. The material should be a reliable reactive aggregate to use for reference and research purposes.

The multi-laboratory variation of the accelerated mortar bar test at 14 days in solution is shown in Table 2 to be 10.9 % for Spratt aggregate No. 3 and 13.1 % for Spratt aggregate No. 2. This is similar to average values found in earlier studies [3, 4] of 15.2 %.

Figure 4 is a scatter diagram of 6-month concrete prism expansion at 38°C comparing the use of the control sand and the locally available non-reactive sand. This shows systematic bias as found with the AMBT shown in Figure 3. However, in this graph, there is a group of laboratories with relatively low expansion using their local sand compared to the expansion obtained with the control sand. For some reason, some, but not all of the local sands, result in reduced expansion which is probably not related to individual laboratory bias. The reason for this is not known and will be investigated as the study continues by research into the properties of the local sands. It is speculated that this may be due to either some natural air-entraining property of some of these sands or naturally higher porosity of these sands. In either case, the voids present might act as pressure relieve voids for the pressures induced by formation and hydration of alkali-silica gel. It should be noted that the control sand supplied to all laboratories was of exceptionally low porosity and that the average concrete expansion found when this sand was higher than that found when local sand was used in this study (Table 3) and also in the study in 1996 [2].

Figures 5 and 6 are scatter diagrams of 13 week and 6 month concrete expansion at 60°C, respectively. In these graphs it can be seen that, as found for testing at 38°C, the range in expansion when using local sand was significantly wider than when the standard sand was used. Regarding the levels of expansions obtained at 38 and 60°C, it was found that concrete prism expansion starts much faster at higher temperature but levels off quite rapidly (i.e. after about 2-3 months) due to alkali leaching from the test prisms; the consequence is that after about 6 months, the expansion at 38°C becomes greater than that at 60°C [11].

Figure 7 shows a plot of multi-laboratory standard deviation against mean concrete prism expansion. This shows that as mean expansion increases, multi-laboratory variation proportionally increases. This means that variation is probably best expressed by using the average coefficient of variation that will remain relatively constant over a wide range of expansion. This is normal for this kind of test and has been found in other studies and is also characteristic of the AMBT. It is noteworthy that prisms tested at 60°C with the standard sand show the lowest proportional variation. This is lower than the variation found with the same mixtures tested at 38°C, which appear to conform to the norm found with the mixtures using the local sand.

In earlier studies [2,12,13] of the multi-laboratory variation of the concrete prism expansion test at 38°C, the average coefficient of variation has been found to be about 23% and this value is published in the CSA and ASTM standards for these tests. The values shown in Table 3 are of the same order of magnitude although a little higher than predicted. As more data is received and data for later ages of storage is obtained, it is likely that more stable estimates of variation will be obtained.

5 CONCLUSIONS

The multi-laboratory variation of the accelerated mortar bar test at 14 days in solution was found to be about 11 and 13%. This is similar to average values found in earlier studies of 15.2 %.

The new stockpile of Spratt aggregate (No. 3) gave very similar expansion values in both accelerated mortar bar tests and concrete prism expansion tests to that found with a supply of the same aggregate established in 1992 and reported in multi-laboratory studies in 1996. This material should continue to be a reliable reactive aggregate to use for reference and research purposes.

In the concrete prism expansion test at 60°C, the use of control non-reactive sand with Spratt coarse aggregate gave significantly lower multi-laboratory variation than was found with the same mixtures tested at 38°C or those made using locally available sands and tested at 60°C. The reason is currently unknown.

Not all the data have been received from all laboratories and only data up to about 6 months in age has been received for concrete prism expansion. As a result, the data and conclusions given here should be viewed as preliminary in nature and are subject to change. At the conclusion of the study, a final report will be published.

The Spratt aggregate is available free of charge from the Ontario Ministry of Transportation for studies into alkali-silica reaction (to receive supplies contact Carole-Anne MacDonald at (+1) 416-235-3735 or CaroleAnne.MacDonald@Ontario.ca).

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TABLE 1: Test program for the interlaboratory study.

Test procedures / methods	Coarse Aggregate	Sand
Part I		
Accelerated Mortar Bar Test (AMBT) (CSA A23.2-25A, ASTM C 1260, or RILEM AAR-03)	Spratt 2	-
Accelerated Mortar Bar Test (AMBT) (CSA A23.2-25A, ASTM C 1260, or RILEM AAR-03)	Spratt 3	-
Part II		
Conventional Concrete Prism Test (CPT) (38°C) (CSA A23.2-14A, ASTM C 1293 or RILEM AAR-03)	Spratt 3	Control sand (provided)
Conventional Concrete Prism Test (CPT) (38°C) (CSA A23.2-14A, ASTM C 1293 or RILEM AAR-03)	Spratt 3	Local (provided by participant)
Part III		
Accelerated Concrete Prism Test (ACPT) (optional) (additional set of three prisms to be cast from Part II concrete mixture but tested at 60°C)	Spratt 3	Control sand (provided)
Accelerated Concrete Prism Test (ACPT) (optional) (additional set of three prisms to be cast from Part II concrete mixture but tested at 60°C)	Spratt 3	Local (provided by participant)

TABLE 2: Summary of results of accelerated mortar bar expansion testing in this study compared to earlier study in 1996 [3].

	Type of Spratt aggregate and age of testing	Number of Laboratories	Mean expansion %	Standard Deviation	Coefficient of Variation (%)
1996	Spratt No. 2 At 14 days	41 (5 labs rejected)	0.416	0.0621	14.9
2007, this study	Spratt No. 2 At 14 days	36 (2 labs rejected)	0.403	0.0526	13.1
!996	Spratt No. 2 At 28 days	41 (5 labs rejected)	0.676	0.1138	16.9
2007, this study	Spratt No. 2 At 28 days	36 (2 labs rejected)	0.696	0.1235	17.7
2007, this study	Spratt No. 3 At 14 days	36 (2 labs rejected)	0.382	0.0417	10.9
2007, this study	Spratt No. 3 At 28 days	36 (2 labs rejected)	0.585	0.0654	11.1

TABLE 3: Summary of results of concrete prism expansion testing at 38°C and 60°C in this study compared to earlier study in 1996 [2].

Time of expansion	Year	Temperature (°C)	Sand	Spratt (#)	Number of Laboratories	Mean value	Standard Deviation	Coefficient of Variation (%)
13 weeks	1996	38	local	2	19	0.079	0.0299	28.9
	2007	38	control	3	18	0.118	0.0296	25.1
	2007	38	local	3	18	0.099	0.0309	31.2
	2007	60	control	3	11	0.158	0.0310	19.6
	2007	60	local	3	11	0.129	0.0340	26.4
26 weeks	1996	38	local	2	19	0.137	0.0339	24.7
	2007	38	control	3	18	0.185	0.0455	24.6
	2007	38	local	3	18	0.160	0.0458	28.6
	2007	60	control	3	10	0.175	0.0309	17.7
	2007	60	local	3	10	0.143	0.0374	26.2

Figure 1: Stratigraphic level from which the Spratt 3 reference aggregate material was obtained.

Figure 2: Spinning riffler used for preparation of samples for multi-laboratory studies of aggregate test methods.

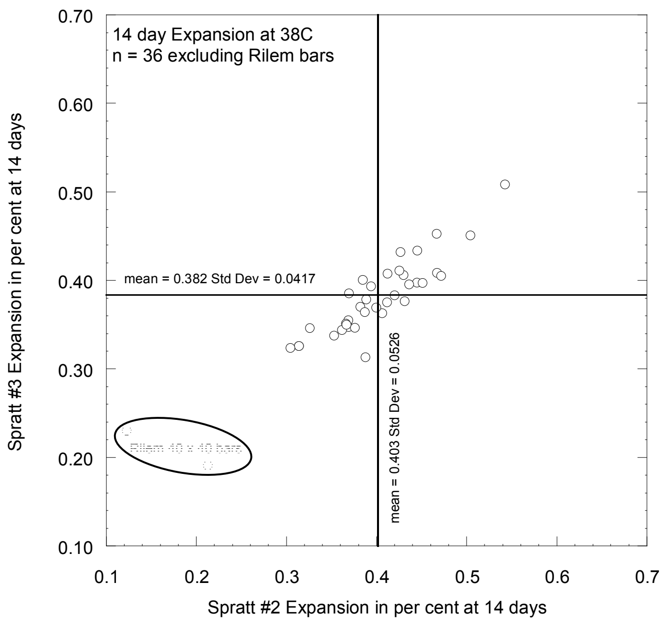

Figure 3: Scatter diagram for accelerated mortar bar expansion test at 14 days.

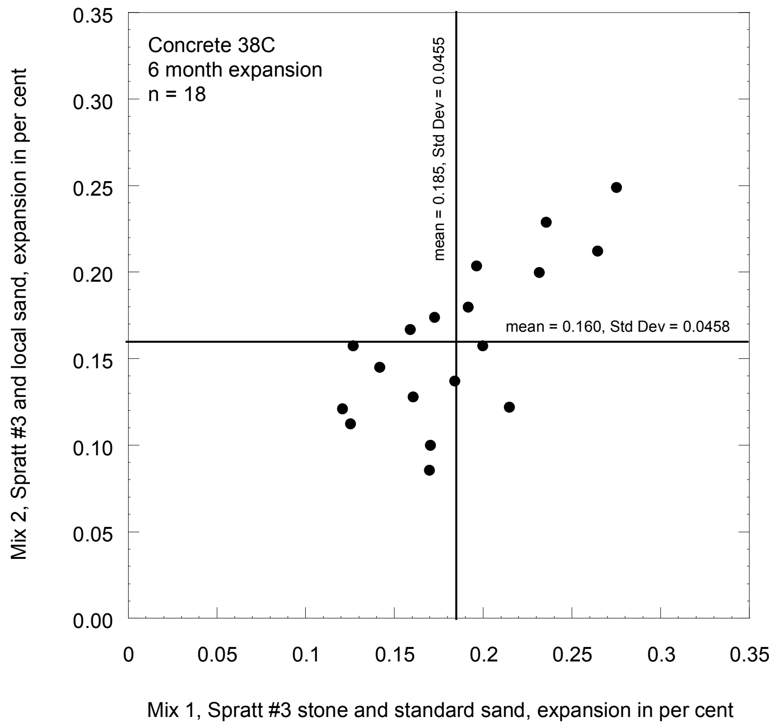

Figure 4: Scatter diagram for concrete prism expansion test (38°) at 6 months.

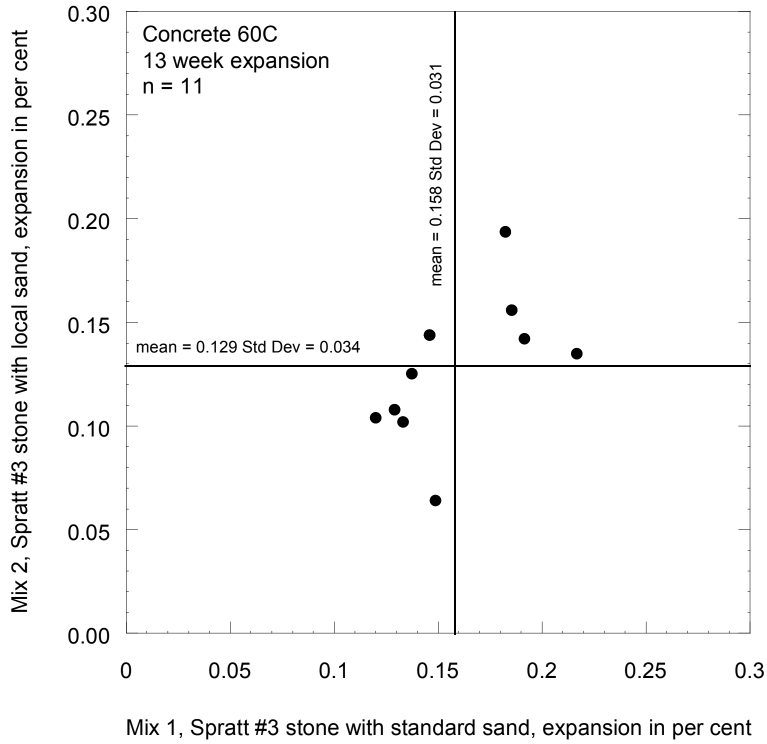

Figure 5: Scatter diagram for concrete prism expansion test (60°) at 13 weeks.

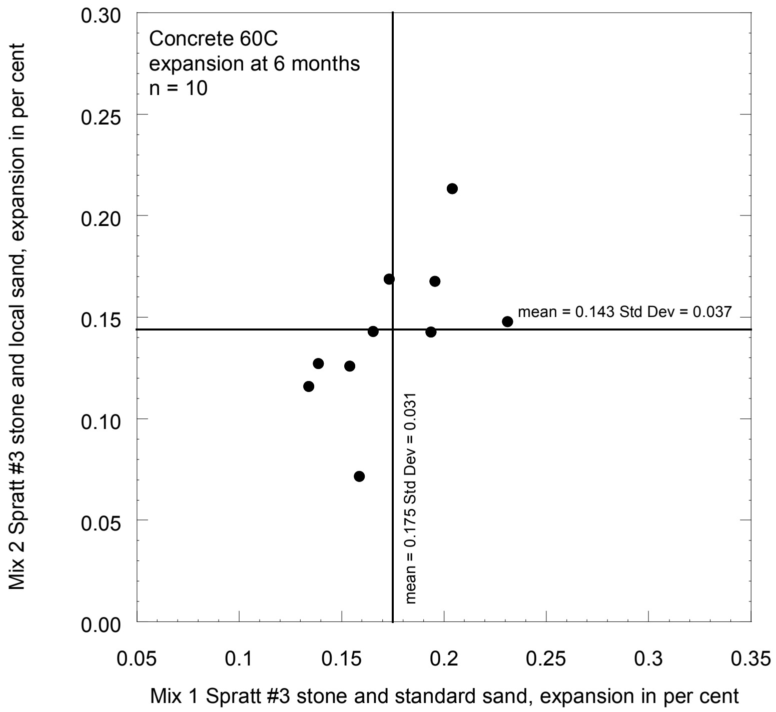

Figure 6: Scatter diagram for concrete prism expansion test (60°) at 6 months.

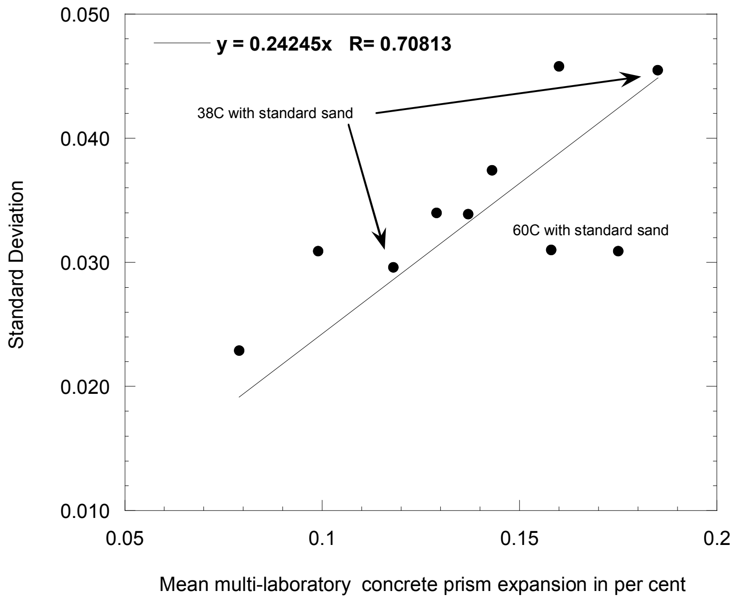

Figure 7: Standard deviation against concrete prism expansion.