TRIALS TO CORRELATE THE ACCELERATED MORTAR BAR TEST, THE STANDARD AND THE ACCELERATED CONCRETE PRISM TESTS

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Abstract

The accelerated mortar bar test (AMBT) is popular in the market especially because the results can be obtained at 16 days. However, field experiences showed that in some cases this method does not represent well the expected behavior. The concrete prism test (CPT) is known to have an excellent correlation with field performance but it takes a long time to analyse and classify aggregates. In order to accelerate CPT, researchers proposed to increase the testing temperature from 38ºC to 60ºC. This paper presents the comparative analysis by three methods (AMBT, CPT and ACPT) using six Brazilian aggregates. Petrographic analysis was also performed. The results show that the expansion behavior of the aggregates, when analyzed by AMBT and CPT, is quite different. ACPT showed a very good correlation with CPT at 90 days and 120 days and it seems to have a great potential to evaluate aggregates in the laboratory.

Keywords: concrete prism test (CPT), accelerated concrete prism test (ACPT), accelerated mortar bar test (AMBT), test methods, alkali-aggregate reaction (AAR)

1 INTRODUCTION

After 1940 with Stanton's work, several researchers have been trying to develop methods that can identify the potential reactivity of aggregates with the alkali hydroxides from the concrete pore solution. There are various methods that can be used for this purpose.

The main method that has been used in Brazil is the accelerated mortar bar test (AMBT) according to ASTM C 1260, especially because the results can be obtained at 16 days. However, field experiences have shown that, in some cases, this methodology does not represent very well the expected behavior.

The Concrete Prism Test (CPT) is generally consider the most reliable test for AAR but this test requires a long testing time (one year).

In 1992, Ranc and Debray tried to accelerate this method by increasing the testing temperature from 38 ± 2ºC to 60ºC. After this attempt, they realized that the test could be carried out in 3 or 4 months, and called it as Accelerated Concrete Prism Test (ACPT). Even though several researchers have been studying this method, it hasn't been normalized yet but it seems a promising test method [1]. This paper presents a comparison among these three test methods (AMBT, CPT and ACPT) using six different types of Brazilian aggregates: one granite from Embu das Artes (São Paulo state), two granite–gneiss from Recife (Pernambuco state), two basalts from Americana (São Paulo state) and Birigui (São Paulo state) and one quartzite from Três Lagoas (Mato Grosso state). Petrographic analysis was also performed for all the aggregates.

2 ACCELERATED MORTAR BAR TEST (AMBT)

The AMBT Test is somewhat similar to the NBRI Test proposed by Oberholster and Davies (1985) [2]. This test was developed because the old mortar bar test (ASTM C 227 procedure) was too long and nowadays it is proven that it is not reliable enough.

Studying 28 aggregates and correlating both tests, Oberholster and Davies (1985) [2] found out that even though the correlation was not very good (66%), aggregates could be classified as reactive or innocuous at 12 days. The limit initially proposed at 12 days was 0.11%.

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There are many procedures that can be used for the test, among them the ASTM C 1260. It consists, basically, in casting three mortar bars and soaking them into a 1N - NaOH solution at 80ºC throughout 14 days. Before being soaked in solution, the mortar bars are demolded after 24 hours and soaked into water at 80ºC for another 24 hours. AMBT can classify aggregates in reactive or innocuous in 16 days (i.e. 14 days in agressive solution). The limits and dates are:

- For expansions smaller than 0.10% at 16 days, aggregates are considered as innocuous;
- For expansions between 0.10% and 0.20% at 16 days, aggregates are considered as potentially reactive;
- For expansions greater than 0.20% at 16 days, aggregates are considered as reactive.

Nowadays the AMBT is considered as not as reliable as it should be, by some researchers. This test is severe and many aggregates that have good behavior in the field were classified as reactive, and some others that passed the test were found to induce cracking due to the alkali-aggregate reaction (AAR) in concrete [1].

Because of this problem the American Association of State Highway and Transportation Officials (AASHTO) and the American Concrete Institute (ACI - Comittee 221) proposed a decrease of the expansion limit for some aggregates, from 0.10% to 0.08% [3]. Some countries have proposed different limits and ways of performing the test. The limits proposed ranged from 0.10 to 0.15% for testing periods ranging from 12 to 30 days [4]. The committee from the Brazilian Standards Association-ABNT that studies AAR recently proposed that the AMBT should continue up to 30 days (i.e. 28 days in the aggressive solution), using the limit 0.19% as the value that distinguishes between potentially innocuous and potentially reactive aggregates. This Brazilian committee considered that all aggregates are reactive to a certain extent; when the reaction of an aggregate with cement alkalis does not reach the fixed limit, this aggregate is considered as potentially innocuous since the AMBT is not considered to be perfect and infallible.

Even though AMBT can classify aggregates in a very fast way, there are many factors that can affect the reactivity of some aggregate [3]. The main factors are:

- Alkali content of cement;
- Cement fineness;
- Size of aggregates;
- Water-cement ratio;
- Very agressive environment (i.e. high temperature, NaOH solution);
- Proportion of materials used in the mortar.

Usually, the AMBT should be the first method used to rapidly classify aggregates. However, other methods should be used that will result in a more reliable classification [4].

3 CONCRETE PRISM TEST (CPT)

The current version of the test, first published in 1994, uses a cement content of 420 kg/m^3 with the cement alkalis raised to 1.25% Na_2O_e by the addition of NaOH to the mixing water, and concrete prisms are stored over water in sealed containers at 38ºC. An expansion limit of 0.04% at 1 year is used to identify reactive aggregates and the same limit at 2 years to qualify preventive measures (CSA.A23.2-28A). The test method in its current form was adopted in 1995 as ASTM C 1293 [1].

According to Thomas et al. [1], there are no aggregates that pass the current test conditions and performance limits that have caused damaging alkali-silica or alkali-carbonate reaction in concrete structures [1]. It has been suggested however, that the test conditions may sometimes be severe as some aggregates with generally good field performance may be identified as being potentially reactive by the CPT. However, it has been acknowledged that these same aggregates may cause deleterious reaction if they are in concrete with higher alkali contents, such as the types of concrete commonly used nowadays in highway structures, which are often characterized by having relative high cement contents [1].

A problem that can occur in the accelerated tests is the leaching of the alkalis from the concrete or mortar prisms. In this method, due to the fact that the dimensions are 7.5 cm x 7.5 cm x 28.5 cm, the problem is relatively less prone to occur if compared with other tests such as the mortar bar test. However, it is important to take care of this problem, because it can provide distortion in the results [1]. Even thought there is an expansion limit to classify aggregates as reactive or not with the alkalis from the cement, it is quite difficult to classify some aggregates because at one year they can present an expansion near 0.04% [5].

4 ACCELERATED CONCRETE PRISM TEST (ACPT)

In the beginning of the 90´s, Ranc and Debray proposed an accelerated test method that could, in less than 8 months, identify and classify the reactivity of some aggregates with the alkali hydroxides from cement pore solution [5]. This test is similar to the Concrete Prism Test (CPT), but it is performed at 60ºC. A number of ACPT were carried out and it seems a powerful test to detect the reactivity of aggregates with cement alkalis. However, until now the test is not standardized [1].

An expansion of 0.04% at one year in the CPT corresponds to an expansion of 0.030% at 3 months and 60ºC in the ACPT. Therefore, testing with the ACPT for 13 weeks would lead to the same conclusion as for the CPT at one year for the majority of the aggregates that were tested. This was accomplished in 95% of the cases. Researchers, after new studies concluded that different testing periods and limits could be applicable for the test [6] (Table 1).

Even though many researchers have performed the ACPT test with good results, Fournier et al. alerted that in some cases leaching and the nature of the non-reactive sand used in a combination with the coarse aggregate under test can distort the results [5].

5 EXPERIMENTAL PROCEDURES

Six Brazilian aggregates were chosen for this research project. They were first subjected to petrographic examination and then to expansion testing using the CPT, AMBT and the ACPT.

5.1 Petrographic examination

The following aggregates were used:

Granite from Embu das Artes

The granite was used because it was classified by the AMBT test before the beginning of the study as innocuous. For this reason, it was considered as a standard aggregate.

Basalts from Americana and Birigui

These basalts, from the cities of Americana and Birigui (São Paulo state), were tested in order to investigate their potential reactivity.

Granite–Gneiss 1 and 2 from Recife

The granite–gneiss 1 has shown deleterious effects in many constructions at the city of Recife [7]. The worst problems have occurred in concrete foundations of buildings. This problem has alarmed the whole scientific community. To compare its behavior with another aggregate from the same city and with the same lithology, the granite–gneiss 2 was chosen.

Quartzite from Três Lagoas

This quartzite was chosen because there is proof that it can develop deleterious reactions with cement alkalis as can be seen on concrete test blocks, almost 40 years old, located in Ilha Solteira city (Cesp's laboratory).

5.2 Expansion testing in the laboratory

Accelerated Mortar Bar Test (AMBT)

The test was carried out according to the ASTM C 1260 up to 30 days. Basically, three bars with each aggregate were cast and cured in a moisture room for 24 hours. After the prisms were demolded, they were placed into water at 80ºC for more 24 hours. Afterwards, they were placed into a 1N solution of NaOH for 16 days. Readings continued during 30 days.

Concrete Prim Test (CPT)

The test was carried out using the ASTM C 1293 procedure. Basically, three prisms with each aggregate were cast and cured (in their molds) in the moisture room for 24 hours. The prisms were then demolded and placed in an environment of 38ºC and relative humidity of 100%.

Accelerated Concrete Prim Test (ACPT)

As well as for ASTM C 1293, three prisms with each aggregate were cast and cured in the moisture room for 24 hours. Then, the prisms were demolded and placed at 60ºC and relative humidity of 100%. Expansions measurements were carried out over a period of five months.

6 TEST RESULTS

Petrographic Analysis

According to the petrographic analysis the aggregates were classified as:

- **Granite - Embu das Artes:** Potentially reactive → quartz with undulatory extinction angle and microcrystalline quartz.
- **Basalt - Americana:** Potentially reactive → volcanic glass.
- **Basalt - Birigui:** Potentially reactive → volcanic glass.
- **Granite–Gneiss 1 - Recife:** Reactive → quartz with undulatory extinction angle and micro to cryptocrystalline quartz.
- **Granite–Gneiss 2 - Recife:** Potentially reactive → quartz with undulatory extinction angle and microcrystalline quartz.
- **Quartzite - Três Lagoas:** Potentially reactive → microcrystalline quartz.

Accelerated Mortar Bar Test (AMBT)

Figure 1 shows the AMBT expansions. According to the AMBT analysis the aggregates were classified as follows:

- **Granite - Embu das Artes:** the aggregate can be considered as innocuous at 16 days (14 days soaked in solution of NaOH – 1N). At 30 days (28 days soaked in solution of NaOH -1N), the mortar prepared with this aggregate reaches 0.10%.
- **Basalt - Americana:** it can be classified as potentially reactive at 16 days. At 30 days, the average expansion of the bars reached 0.28%.
- **Basalt - Birigui:** it can be considered as innocuous at 16 days.
- **Granite–Gneiss 1 - Recife:** can be considered reactive at 16 days.
- **Granite–Gneiss 2 - Recife:** It can be considered as innocuous at 16 days.
- **Quartzite - Três Lagoas:** The aggregate is innocuous at 16 days (14 days soaked in solution of NaOH – 1N). The quartzite mortar presents a sharp rise in expansion from 16 to 30 days.

Concrete Prim Test (CPT)

Figure 2 shows the expansions up to 12 months of test. According to the CPT analysis the aggregates were classified as follows:

- **Granite - Embu das Artes:** it can be considered as reactive since an expansion of 0.04% was reached at 360 days.
- **Basalt – Americana:** it can be considered as innocuous by the test at 360 days.
- **Basalt - Birigui:** it can be considered as innocuous by the test at 360 days.
- **Granite – Gneiss 1- Recife:** it can be considered as reactive with an expansion of 0.055% at 360 days.
- **Granite – Gneiss 2- Recife:** it is considered as reactive at 360 days with 0.04% of expansion.
- **Quartzite- Três Lagoas:** it is considered as reactive at 360 days with 0.04% of expansion.

Accelerated Concrete Prim Test (ACPT)

Figure 3 shows expansions of the ACPT until 5 months or 150 days. The results were analyzed at 90 days (3 months) and 120 days (4 months). According to the ACPT analysis, the aggregates were classified as follows:

- **Granite- Embu das Artes:** it is considered innocuous at 90 days with 0.03% of expansion. But in 4 months or 120 days, the aggregate could be considered reactive with an expansion of almost 0.05%.
- **Basalt – Americana:** it can be considered as innocuous.
- **Basalt - Birigui:** it can be considered as innocuous.
- **Granite – Gneiss 1- Recife:** it can be considered reactive.
- **Granite – Gneiss 2- Recife:** it is considered reactive at 90 days with 0.04% of expansion. In 4 months or 120 days, the aggregate can be considered reactive with an expansion greater than 0.05%.

- **Quartzite- Três Lagoas:** it is considered reactive at 90 days with 0.04% of expansion. In 4 months or 120 days, the aggregate can be considered reactive with an expansion greater than 0.05%.

Through these tests, it seems that 120 days is a better age to classify the reactivity of aggregates since those that are marginally reactive were close to the limit at 90 days. At 120 days, the reactivity of the aggregates can be distinguished with better reliability and after this age, the rate of expansion of all the aggregates stabilized to almost zero. Is seems that the test do not need to be continued after 120 days because of the stabilization of the expansions which are likely be caused by the leaching of the alkalis from the test prisms. Due to these facts, the period and limit chosen to perform the comparative analysis were 0.04% at 120 days.

7 ANALISYS OF DATA

After the end of three tests, a comparative analysis was performed. Figure 4 shows a comparison between the CPT at 12 months (360days) and the AMBT at 14 days in aggressive solution. It is possible to see that 4 in 6 aggregates (66%) are classified differently by the two methods. The results show that the behavior of most aggregates is very different when the methods are compared.

Because some aggregates (mainly granites) are slowly reactives, the Committee from the Brazilian Standards Association-ABNT proposed that the AMBT should continue up to 28 days in agressive solution and chose the limit of 0.19% as the value that distinguishes potentially innocuous and potentially reactive aggregates.

The comparison with CPT at one year and AMBT at 28 days in the aggressive solution shows that three in six aggregates (50%) are still classified differently (Figure 5). The result shows that the correlation with CPT is slightly better at this age, however, the behavior of the aggregates in the two tests continue to be very different.

After the comparison in both ages, it could be seen two types of differences: aggregates that passed in the AMBT and failed in the CPT (as the granites-gneiss 1 and 2 and the quartzite) and aggregates that were classified as potentially reactive in the AMBT and passed in the CPT (as the basalt from Americana).

Figure 6 shows a comparative analysis between the CPT at 360 days and the ACPT at 90 days. A regression analysis shows that a very good linear correlation exists with a correlation coefficient of 0.9639. It can be seen that just the granite from Embu das Artes had different classification by the two tests. Figure 7 shows a comparison between the CPT at 360 days and the ACPT at 120 days. At this age, all the aggregates had the same classification by the two tests. The regression analysis also shows that the correlation coefficient of 0.9725 is very good. It seems that 120 days is the best age to analyze aggregates by the ACPT, because at 90 days, some slowly reactive aggregates are quite near the limit.

Obviously, as the classification of the aggregates reactivity by the CPT is quite similar to the ACPT and very different from the AMBT, the comparison between ACPT and AMBT results is poor. When a comparison is done with AMBT at 16 days and ACPT at 120 days, 4 in 6 aggregates (66,7%, as well as in the CPT) were classified differently. When the AMBT is analyzed at 30 days, and using the limit proposed by the Brazilian committee, three aggregates are still classified differently. Table 2 shows the global comparison among all tests and some field results.

8 CONCLUSIONS

- Petrographic analysis is neither conclusive nor quantitative. Although all tested aggregates, in this case, were classified as either potentially reactive or reactive, expansions tests suggested that at least two aggregates can be classified as innocuous;
- AMBT is a fast and easy test to classify aggregates according to its potential alkali reactivity. However, there are cases where aggregates that pass this test show deleterious behavior in the field. The quartzite from Três Lagoas is an example of this case. For this reason there is a trend, in some countries, to increase the testing age of mortar bars in order to encompass these cases. The committee from the Brazilian Standards Association-ABNT recently proposed to use the limit of 0.19% at 30 days (28 days in the NaOH solution) as the value that distinguishes between potentially innocuous and potentially reactive aggregates;

- The CPT seems to be more reliable than the AMBT, when comparing its results with field performance (for the same aggregate). Some slowly reactive aggregates as granites and gneisses can be at 360 days very close to the limit (0.04%) that distinguishes innocuous or reactives aggregates. Due its slowly behavior, an analysis carefully should be done;
- The expansion of six Brazilian aggregates when comparing the AMBT (ASTM C 1260) and the CPT (ASTM C 1293) methods lead to different results. Four in six aggregates (66%) can be classified differently.
- When the AMBT is carried out until 30 days and the limit of 0,19% is used, a slightly better correlation is obtained but still not good enough.
- The behavior of an aggregate in the CPT and AMBT do not seem to be the same. After the comparison in both ages, it could be seen two types of differences: aggregates that passed in the AMBT and failed in the CPT (as the granites-gneiss 1 and 2 and the quartzite) and aggregates that were classified as potentially reactive in the AMBT and passed in the CPT (as the basalt from Americana).
- There is a quite good correlation between CPT and ACPT at 90 days and 120 days. The ACPT classifies slowly reactive aggregates with less difficulty at 120 days. After this age, the rate of expansion of all the aggregates stabilized to almost zero. Is seems that the test do not need to continue after 120 days and maybe the stabilization could be caused by the leaching of the alkalis from the prisms. However, this is based on a limited number of aggregates.
- The ACPT is not standardized, however it has a great potential to analyze the reactivity of aggregates in a fast and reliable way.

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Table 1: Limits proposed for ACPT [4].

Authors	Reference (CPT)	Proposed Limit at 60°C
Ranc and Debray (1992)	0.04% exp. at 8 months (38°C)	0.015% at 4 weeks, or 0.08% at 8 w
Bolotte (1992)	0.04% exp. at 8 months (38°C)	0.024% at 8 weeks
Murdock and Blanchette (1994)	0.04% exp. at 12 months (38°C)	0.02% at 8 weeks or 0.03% at 13 weeks
De Grosbois and Fontaine (2000)	0.04% exp. at 12 months (38°C)	• 0.04% at 13 weeks to carbonate rocks; • 0.025% at 13 weeks to igneous and metamorphic rocks.
Touma et al. (2001)	0.04% exp. at 12 months (38°C)	0.04% at 13 weeks

Table 2: Comparative analysis among all tests.

Aggregate	CPT 360 days	ACPT 90 days	ACPT 120 days	AMBT (ASTM C 1260)	AMBT (Brazilian standard)	Field	Petrographic analysis
Granite – Embu das Artes	Reactive	Innocuous	Reactive	Innocuous	Potentially Innocuous	?	Potentially Reactive
Basalt – Americana	Innocuous	Innocuous	Innocuous	Potentially Reactive	Potentially Reactive	?	Potentially Reactive
Basalt – Birigui	Innocuous	Innocuous	Innocuous	Innocuous	Potentially Innocuous	?	Potentially Reactive
Granite-Gneiss 1 - Recife	Reactive	Reactive	Reactive	Reactive	Potentially Reactive	Reactive	Reactive
Granite–Gneiss 2 - Recife	Reactive	Reactive	Reactive	Innocuous	Potentially Innocuous	?	Potentially Reactive
Quartzite – Tres Lagoas	Reactive	Reactive	Reactive	Innocuous	Potentially Reactive	Reactive	Potentially Reactive

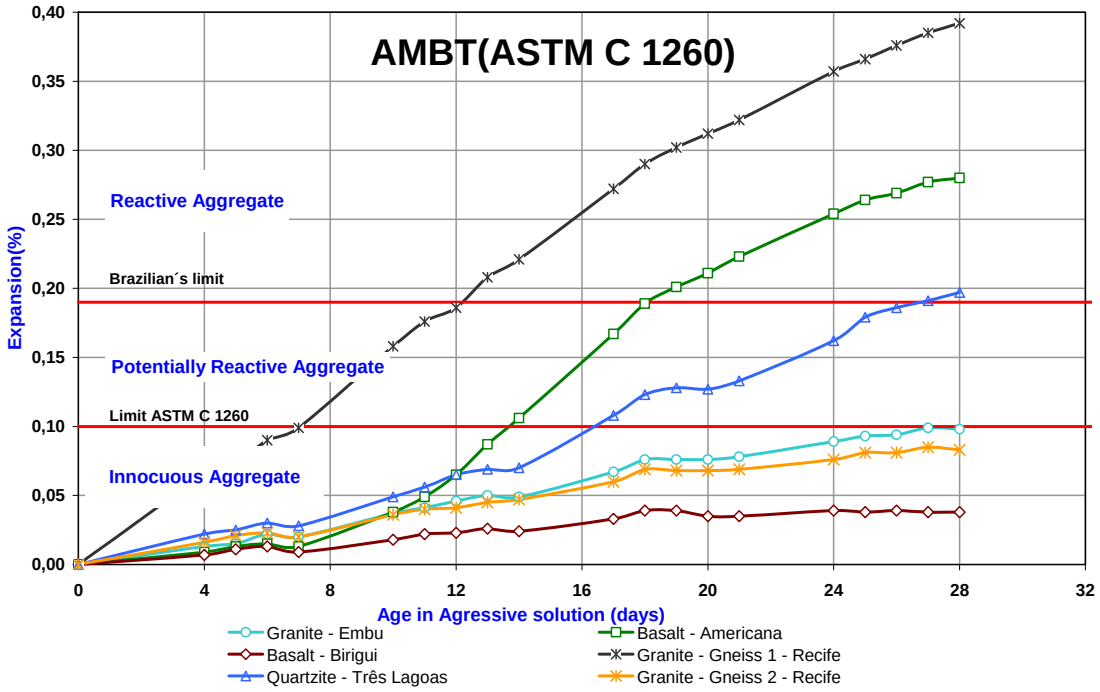

Figure 1: Accelerated mortar bar expansions as a function of time.

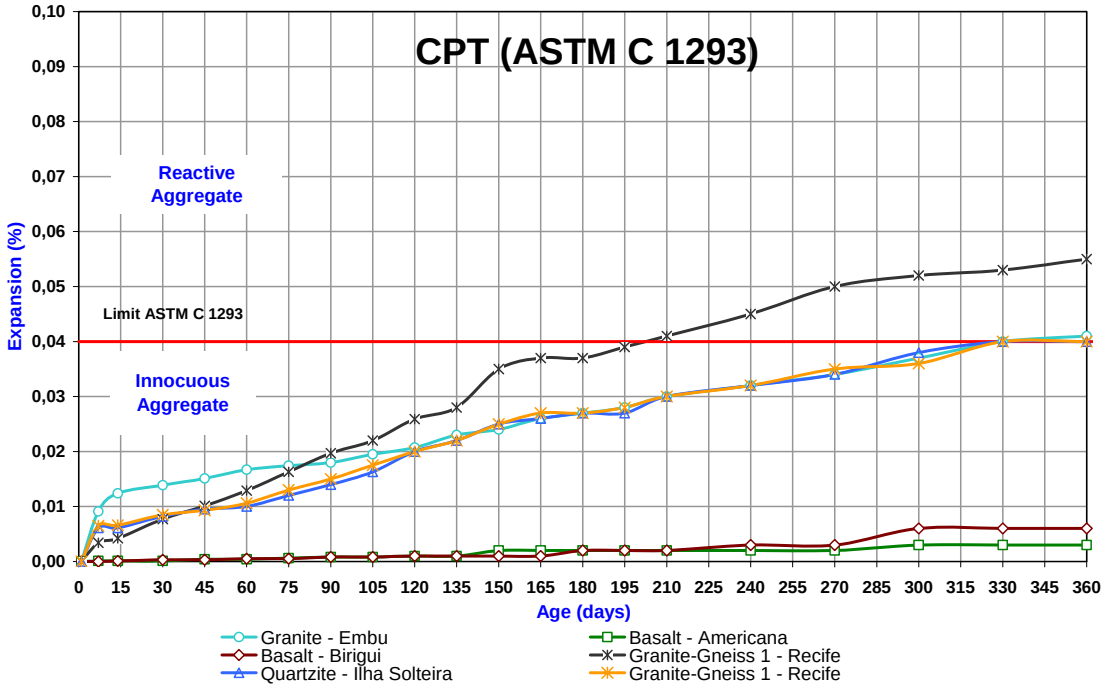

Figure 2: Concrete prism expansions as a function of time.

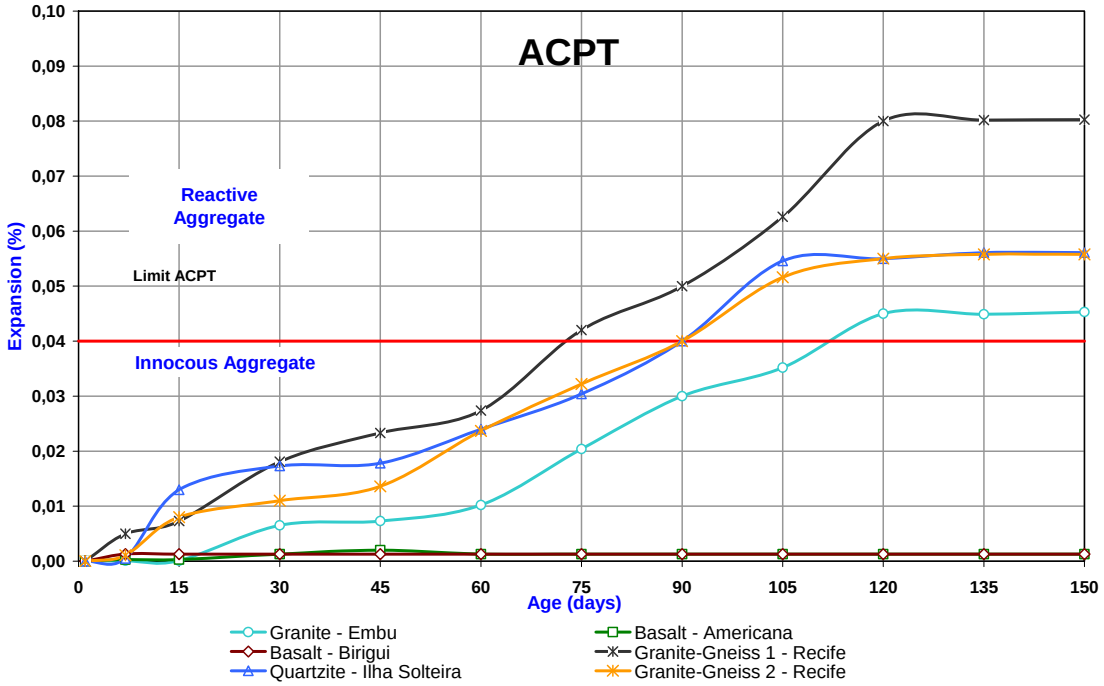

Figure 3: Accelerated concrete prism expansions as a function of time.

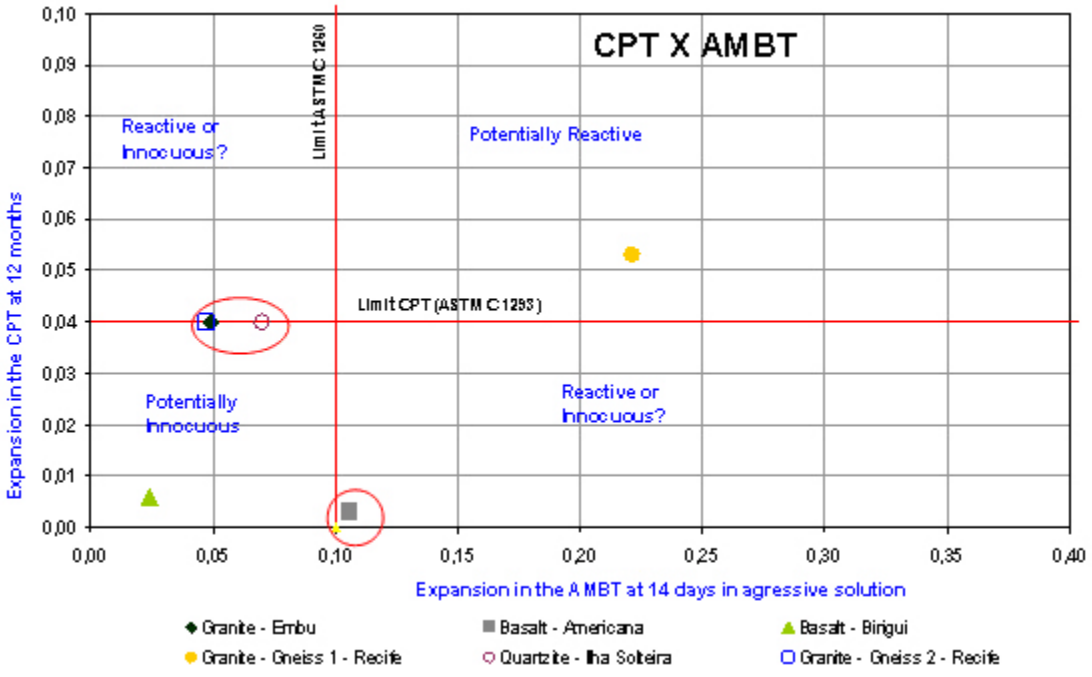

Figure 4: Comparative analysis of concrete prism (12 months) and accelerated mortar bar (14 days) expansions.

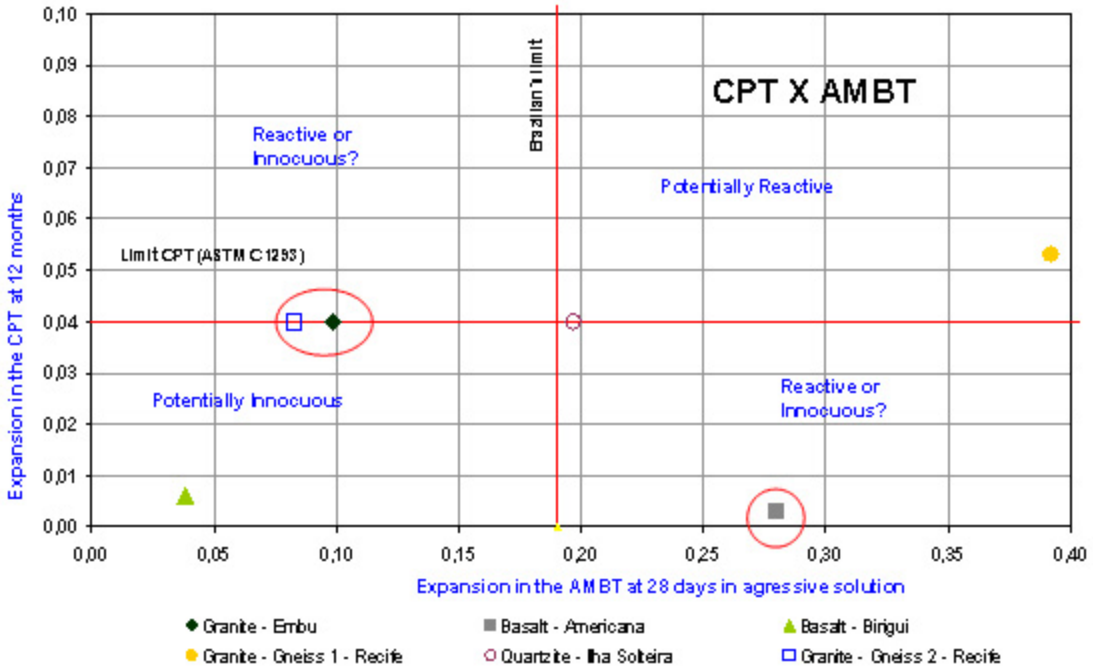

Figure 5: Comparative analysis of concrete prism (12 months) and accelerated mortar bar (28 days) expansions.

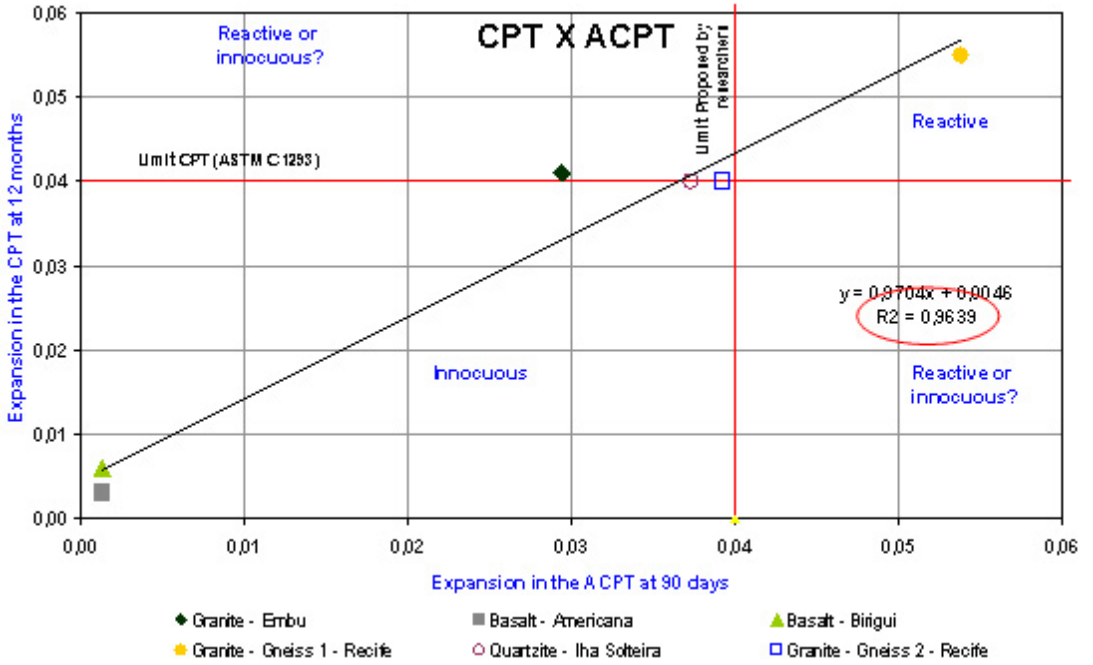

Figure 6: Comparison of concrete prism (12 months) and accelerated concrete prism (90 days) expansions.

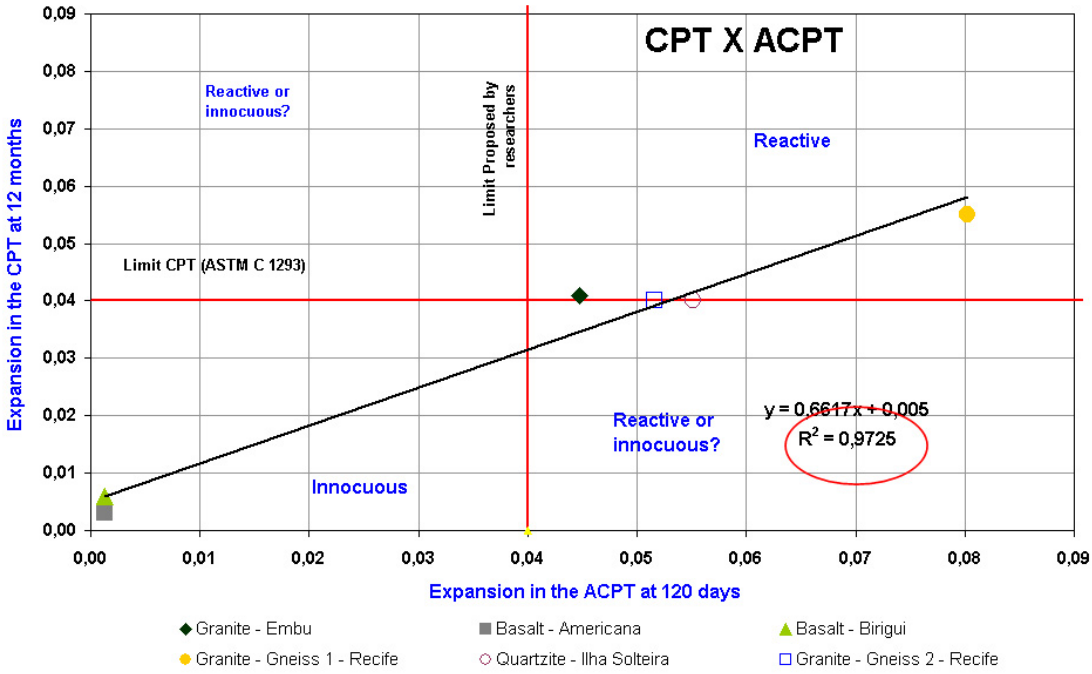

Figure 7: Comparison of concrete prism (12 months) and accelerated concrete prism (120 days) expansions.