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Expansions due to the Alkali-Aggregate Reaction - Process Finite or Infinite?

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Resumo/Resumen/Abstract

Expansões Devidas a Reação Álcalis Agregados- Processo Finito ou Infinito?
Ao se observar a evidencia de Reação Álcalis Sílica em uma estrutura de concreto, construída sem ater-se à necessidade de ter-se tomado o cuidado técnico, a grande questão é:

- Quando a reação-expansão cessa?

Dentro do cenário teórico a resposta seria simples:

- Quando não houver álcalis disponíveis!

Entretanto isso não se traduz simplesmente para determinar a época em que as expansões se estabilizam, e as decorrentes manutenções seriam minimizadas.
Diante disso o Autor faz uma proposição para o estabelecimento de ensaios para uma determinação estatística para a busca da época onde as expansões se estabilizassem.
Essa proposição é feita com base em ensaios já realizados

¿Expansiones Decurrentes de la Reacción Álcali-Agregado- Proceso Finito o Infinito?
Mediante la observación de las pruebas de reacción álcali sílice en una estructura de hormigón, construida sin pegarse a la necesidad de haber adoptado medidas defensivas antes de la construcción, la gran pregunta es:

- ¿ Cuando cesa la reacción-expansión?

Dentro del escenario teórico la respuesta sería simple:

- Cuando no hay ningún álcalis disponibles!

Sin embargo esto no se traduce simplemente para determinar el tiempo cuando las expansiones se estabilizam y se minimizaría el mantenimiento resultante.
Por eso que el Autor hace una propuesta para el establecimiento de una determinación experimental-estadística por pruebas para la búsqueda de la fecha donde las expansiones si fueron estabilizados. Esta propuesta se hace en base a las pruebas ya realizadas

Expansions due to the Alkali-Aggregate Reaction - Process Finite or Infinite?
By observing the Alkali Silica reaction evidence in a concrete structure, built without the adoption of defensives actions/measurement, the big question is:

- When the reaction-expansion ceases?

In a theoretical scenario the answer would be simple:

- When there are no alkalis available!

However this doesn't translate simply to determine the time when the expansions oil stabilizes, and the resulting maintenance would be minimized. Due to that the Author presents a proposal for the establishment of a statistical-determination tests for the search of the time where the expansions if were stabilized. This proposal is made on the basis of tests already performed

Keywords: AAR-Alkali Aggregate Reaction, expansion, strain, gel, ambient, accelerate curing, mitigation, maintenance.

1 Introdução

Since the ' 30 (Stanton), the phenomenon of Alkali Aggregate Reactions is known and various testing methods have been developed to meet the Alkali Aggregate Reaction, its extensions, damage, and very fruitful, ways to minimize the effects of expansive reaction, before they can happen. It is a complex phenomenon, that is influenced by various parameters.

The temperature, the alkaline concentrations, the concrete permeability and other physical parameters play a role in the chemical process, while the mechanical part is dominated by the complex microstructure of the concrete, and the formation of crack patterns, and the mechanical boundary conditions.

The expansion observed at the structural level is notably caused by the opening of cracks in the concrete. They form a network which can be observed as map cracking on the surface of the affected structures, but before map cracking can be observed, micro-cracks will have opened at the micro-structure level. These cracks tend to naturally orient themselves with the load applied to the concrete. ASR displays a strong anisotropic behavior, which could be explained by preferential orientations of the cracks.

From these it can be observed that very little or almost nothing has been developed by the technical-scientific community, about:

- what to do when the expansive phenomenon, in a esttrutura of concrete where no mitigating actions adopted at the time of construction, and

- When the expansive phenomenon ceases?

These two issues, especially the second, has technical and economic impacts of great magnitude. One can imagine a powerhouse of a hydroelectric plant in a process of expansion, with periodic interruptions (without a broad view of the scenario), for maintenance, vericalizations etc. .. Otherwise the possible amendment of the linearity of a building due to the same process.

2 Mitigating Measures

Various defensives measures are recommended normally, such as:

Alkali-silica reaction can be controlled using certain supplementary cementitious materials. In proper proportions, silica fume, fly ash, and ground granulated blast-furnace slag have significantly reduced expansion due to alkali-silica reactivity. In addition, lithium compounds have been used to reduce ASR.

There are some technical recommendations to build with non-reactive aggregates, and a potentially reactive aggregate would ideally be replaced with a non-reactive one. This is not always possible. Non-reactive aggregates may be economically unavailable or delays in finding, testing, procuring, and transporting non-reactive aggregates for a specific project may cause unacceptable delays to the construction

Some methods has been applied to field structures suffering from ASR-affected expansion and cracking, such as the use of silanes, such as the topical application of lithium, such as methacrylates compounds, showing some promise in reducing ASR-induced expansion and cracking

Otherwise, various measurements of expansions has been adopt and computational mathematical models developed to predict the rate of expansion, also. This however, was not perpetuated through systematic reading of long period, in order to allow a re-analysis and/or a re-calibration of models.

In the case of alkali-silica reaction, the reaction can occurs much later, possibly years after the concrete is placed. Large aggregate particles (large, that is, compared with cement-sized pozzolan) generate a significant volume of gel which then takes up water and expands within the hardened, mature concrete

Concrete deterioration due to alkali –aggregate reaction (AAR) and alkali-silica reaction (ASR) is difficult to model because concrete itself has a highly complex structure that includes random heterogeneous components In addition, modeling the reaction is hampered by imperfect knowledge of the mechanisms and requires a technique that bridges concrete science and structural engineering and that goes up and down across multiple scales of length. Thus AAR and ASR modeling remains a difficult task and relatively little work has been done to simulate expansion and structural damage resulting from the reaction

A recent publication [1] mention:

> *"….At present we do not have the technical understanding to reliably predict when the alkali-silica reaction will end or even ascertain for a specific concrete if it has ended. Consequently, one must expect that the expansion and deterioration of the original pavement will continue and may significantly reduce the effective life of the overlay..."*

3 Proposal

With the objective of trying to estimate the stabilization of expansions (which can be considered as termination of the phenomenon), there was developed a methodology and testing for this attempt. This has the purpose of establishing parameter for the estimation of maintenance costs for affected structures.

This publication inform about the methodology-attempt to evaluate the period to cease expansions.

4 Conceptual Base for the Development of Test

Two important aspects were considered:

- ✓ Most expansion tests for assessing the reactivity of aggregates, from a certain time, show a curve-asymptotic behavior over time, and;
- ✓ The expansive phenomenon is accelerated under the conditions of temperature and humidity, and the expansion curve shows a development similar to that of the test above.

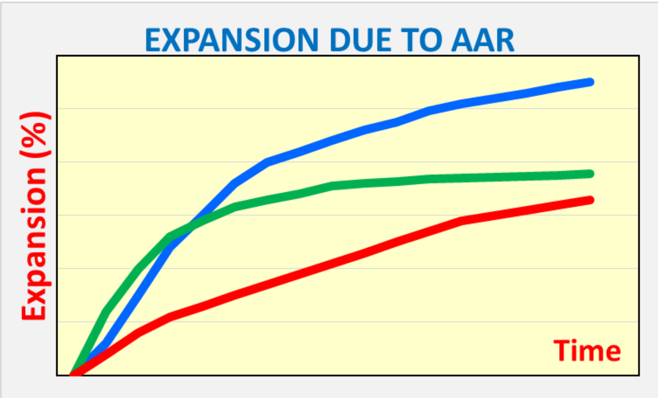


Fig. 1 – Typical curves of expansion due to AAR

5 Objective

The goal was to try to get through tests that accelerate the expansion phenomenon, specifically through exposure of specimens randomly obtained from drilled cores at structures, in a wet environment, to 3 different temperatures and through the measurements of the expansions (strains), supported the concept of regression, determine the time to cease expansions, in the environment in which they are the structures. For such maximum expansions are selected measures to each exposure temperature, admitting that from these expansions will not be maximum measured values greater, throughout its exposure time, as conceptually illustrates the following figure. For such maximum expansions are selected measures to each exposure temperature, admitting that from these expansions will not be maximum measured values greater, throughout its exposure time, as conceptually illustrates the following figure.

The test procedures are not standardized but was set in a context of Service Simulation type, in order to simulate potential conditions that allow through statistical-mathematical holders evaluate with some confidence the eventual expansion potential, existing in the structural elements affected; Considering the originality of the test (in the World, and only in Brazil) was expected that adjustments could be made during the course of the test, and this really was performed; The readings has continued to observe, statistically, the stabilization of the expansion.

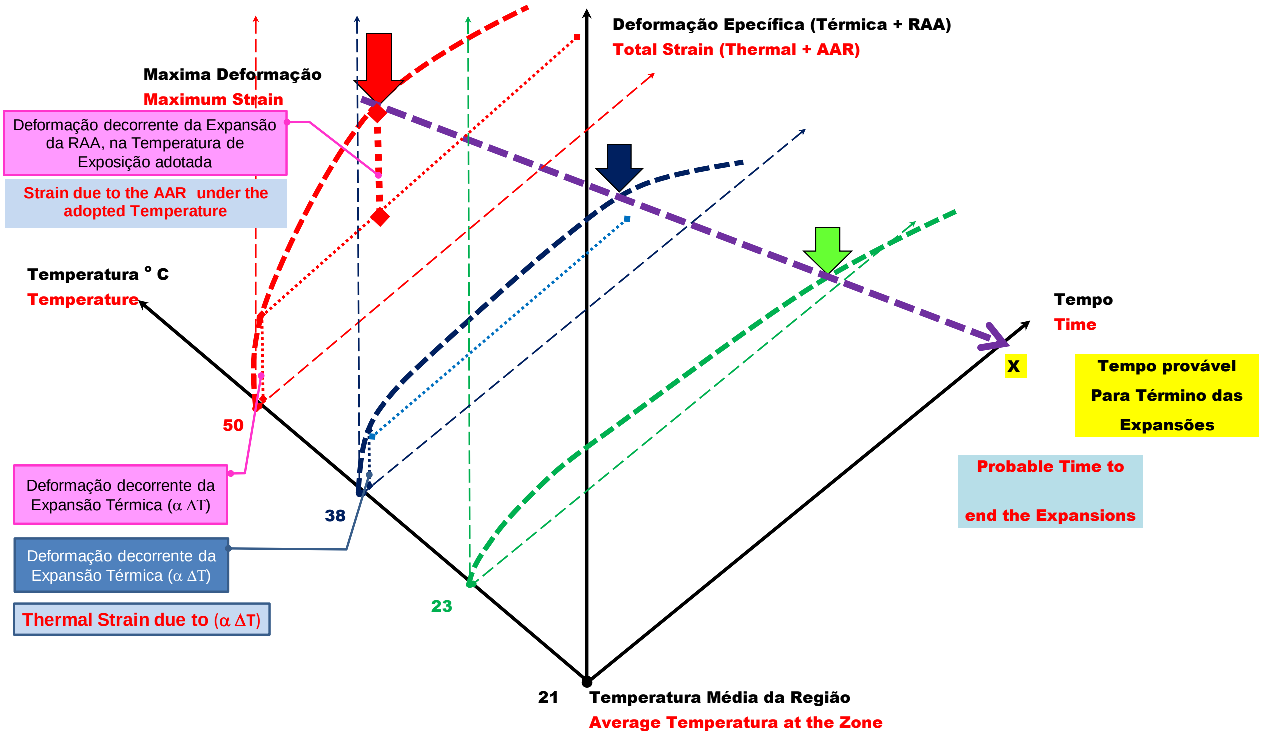


Fig. 2 – Objective of the Tests to try observed the time to AAR end

The tests began in March 2009 in the CESP laboratories at Ilha Solteira and the main adjustment was set related to the highest temperature, that was initially adopted to 55°C, but some damage has occurred in the strain-meters, and due to this the temperature was reduced to 45°C.

6 Test Procedures

Measurements of changes in lengths allow assessing the potential of expansion that can occur on structural elements represented by the specimens drilled from the structures were stocked in the following conditions

Condition	Temperature °C	Humidity (%)	Number of Specimens
A (Normal)	21 ± 0,5	≥ 75	3
B- Accelerated 23	23 ± 1,0	≥ 75	3
C- Accelerated 38	38 ± 1,0	≥ 75	3
D- Accelerated 45	45 ± 1,0	≥ 75	3

7 Apparatus and Instruments

Containers — were used containers, tanks, similar to those used in the accelerated mortar bar test (ASTMC-C-1260)

Fig. 3 – Example of container tank for storage of the specimens and the support about 5cm over the bottom to keep the required ambient

The containers had adequate dimensions to support at least 3 specimens of cylindrical specimens, 150 mm diameter and 300 mm in height, attached to their strainmeters. Could be adopted individual containers for each body and proof and the respective meter, provided that the conditions and maintain humidity and temperature, required. The containers were constructed with corrosion resistant material. The specimens should not be in direct contact with the water

Figs. 4 – Drilled cores, preparation of the specimens and the specimens ready to test

Strain meters- There were used pairs of strain-meters, fixed externally and diametrically opposed to each specimens. The meters had ability to measure, too, the temperature reading with 0.5 ^{O}C tolerance.

Base rings: There were used metallic rings, not affected by corrosion, with inner diameter of 160 mm, and appropriate external to allow fixing the strain meter). Screw contact with the surface of the specimens, cannot be by punching, but by slender support shoe.

Figs. 5 – Ambient for "curing" the specimens during the tests*:* Specimens at 38ºC and a 45ºC were heated with steam air (as left), and specimens at 23ºC were warmed in a water bath

(a) (b) (c)

Figs. 6 – Instrumentation system adopt: a) Specimen instrumented with strain meters b) Digital recorder c) Data Logger

Data logger and Record: System of strain and temperature-reading terminals adopted for the readings

Hydrometer: the moisture from each of the tanks controlled in order to meet the established required.

Samples: 150 mm diameter and with a minimum length of 400 were core drilled from the structural in such a way as to allow the taking of specimens of 150 mm diameter and 300 mm long. The remaining parts, the cores, were stored for possible additional evaluations.

Specimens: Specimens in the required dimensions were prepared from drilled cores, by cutting with diamond disk, with top and bottom orthogonal to the axis of the cylinder

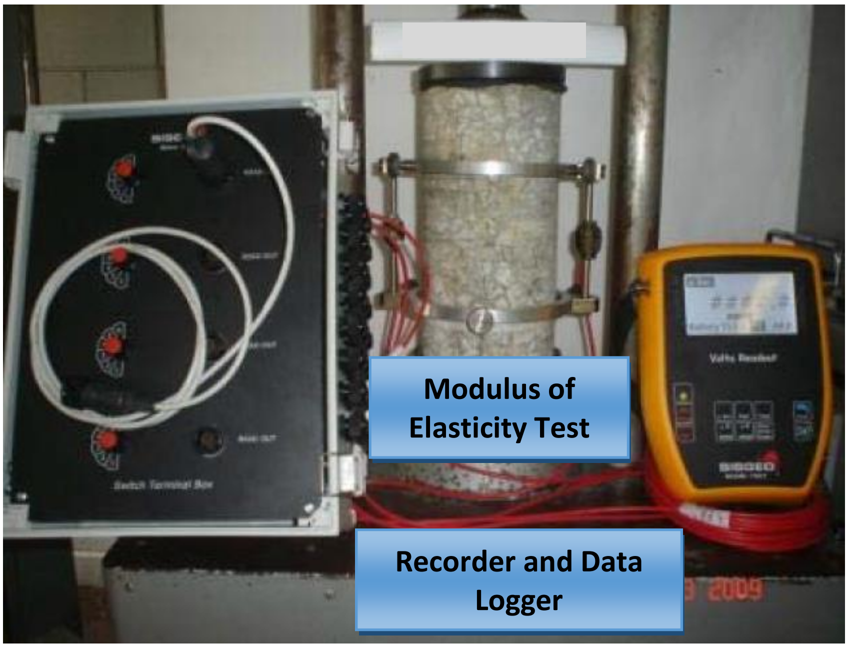


Fig. 7 – Specimen under Modulus of Elasticity Test and the Digital recorder and Data Logger

Figs. 8 –Formation of gel due to AAR, on the surface of the specimens during the test period, and the borders of reaction around the aggregates

8 Test Procedure

The system was verified in order to check the response of reading and fixing the meters to the specimens, soon after the preparation, identification and installation. The system and the specimens kept in air-conditioned constant temperature around 23 + 0.5 oC for 48 hours. After that, immediately, the deformation and temperature recorded.

The specimens, after this reading, were placed in established environments for testing, shortly after that there was another reading of deformation and temperature every meters, installed, each diametrically on the specimens. Strains and temperature data were compared with the adoption of an average coefficient of thermal expansion of concrete with aggregates of similar mineralogy of concrete used in the evaluation. *Note: it was considered granite as aggregates and cement content around 400 kg/m3, with a 10% tolerance*.

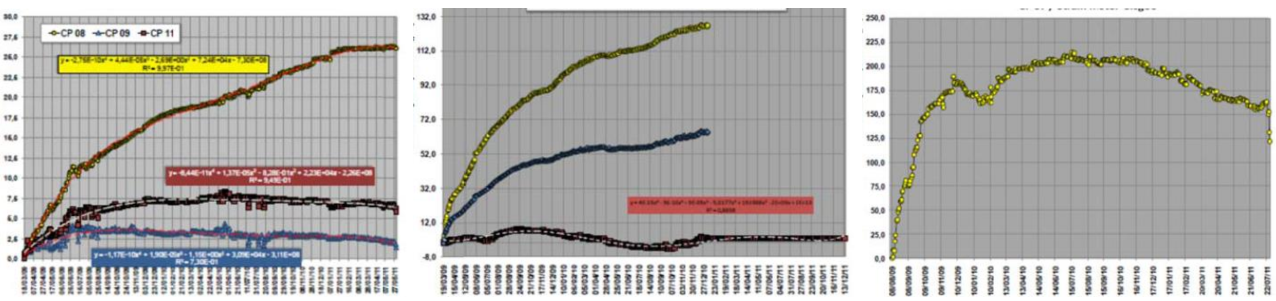
Every day, for 5 days straight there were recorded the readings of moisture, temperature and strains. These readings of the first 5 days were compared with the initials for any anomalies. As initial anomalies not occurred the readings were spaced for each week, during the first 3 months, every fortnight to 6 months monthly subsequent period and subsequent.

The readings were finalized after the confirmation of stabilization of strain readings (compatible with the minimum reading as obtained). Temperature and humidity conditions were systematically verified. The accompanying charts have been adopted to evaluate the gradients and expansion or stabilization of deformations.

9 Data Results

At the end of each test, each specimen, were used for determination of the modulus of elasticity under compression, whereas a ruptures strength of approximately 30MPa, was considered. After the completion of the test of the modulus of elasticity, the specimen was tested until the rupture. Portions of the fragments of each specimens, were used for Microscopy and Petrography in such a way as to characterize the scenario of the AAR and possible attacks by sulfates. With another part of the fragments of the specimens tests were conducted to determine the specific weight and absorption.

The overall result is shown in figures 9.



Figs. 9 – Readings of the individual strain-meters under exposure at 23^{o}C; 38 ^{o}C and 45 ^{o}C

According to what the tests show, following the methodology proposed, it appears that the expansions shown a stabilzation tendency. Assuming the average temperature of 21° C in the region, as constant, it was estimated that the maximum value of expansions it would be obtained in days after the start up of the test.

The results since March 2009 to December 2011 were evaluated and the following comment can be set

- The ratio for expansions at a temperature of 23° C (next to the environment of the structure) were less than 20 μstrain in the first period (2009) of observations which allowed to comment that these (maximum deformation) were much lower than those initially adopted in mathematical models (50 μstrain/year). And that became a prime benefit of conducting the tests, as it confirmed the reducing of remaining expansions;
- The behavior displayed by the values of the strains shows a growth decelerated in the first phase, followed by a stabilization and subsequent reduction. A possible model to represent this behavior is the Gauss curve, used to represent the hydration of cementitious systems as the reference [2] "**Modeling Hydration of Cementitious Systems",** published in the Journal of the American Concrete Institute Materials ACI, March-April 2012. The model assumed the following function

$$\varepsilon = \varepsilon_{máx}.e^{a(t-t')}$$

  In this function (ε), is the unitary deformation calculated by regression, ε_{max} is the maximum calculated unitary deformation, and **e** is the Euler number, *a*=2.71828, and **t** is the time elapsed until the unit considered deformation and t' is the elapsed time until maximum unitary deformation be obtained. Once found the function that is representative of the behavior observed, it is possible to estimate ages for various scenarios, both for the average temperature of the region, of 21° C, as for other possible scenarios with higher or lower temperatures**.**

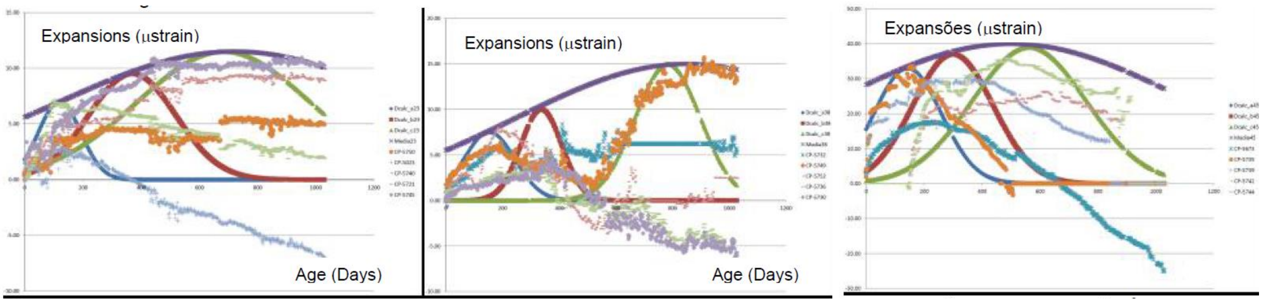
- Expectation about the Mistakes: The experience with the application of this procedure indicates an expected error of about 10%. This expectation can change slightly depending on the dispersion of results, since the cores were taken from regions of the structure subjected to different States of compression, normal stress levels of heat stroke, which affects temperature, and degree of moisture

10 Data Analysis

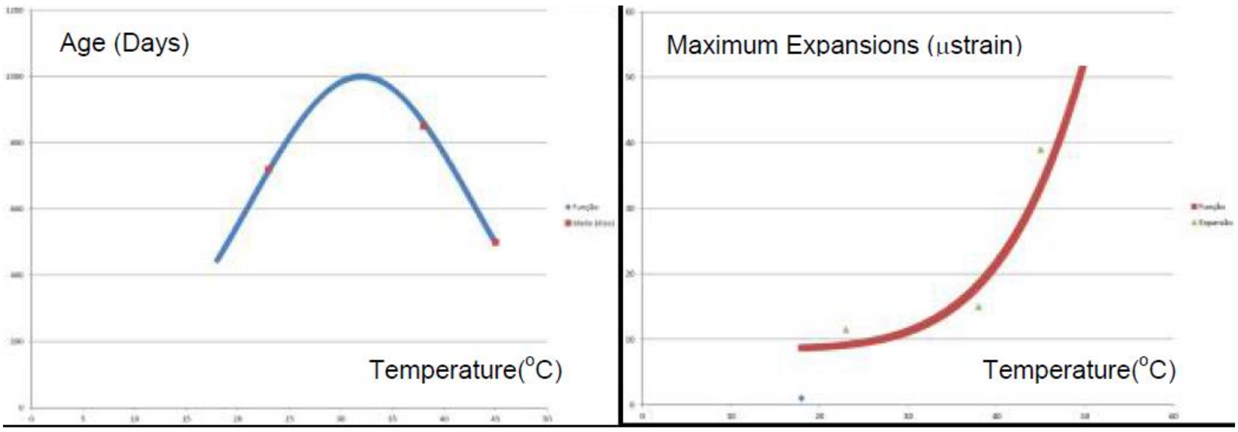
Using the function chosen it was proceeded to data analysis, for each of the specimens tested, for use at temperatures of 23, 38 and 45 degrees Celsius. Although some dispersion, caused by the complexity of conducting the tests, in controlled temperature conditions over many months, the occurrence of various expansion cycles in each specimen. This behavior is compatible with the characteristics of alkali-aggregate reaction, since the formation of cracks increases ease of attack and change qualitatively the expansions.

Assuming the average temperature of 21 degrees Celsius in the region as if it were constant, the estimation of the maximum value of expansions was obtained two years after the start of the trials

(720 days) as shown in figures 10 and 11, having reached the maximum average value around 10 μstrain



Figs. 10 – Expansions under exposure at a temperature of 23ºC ; 38ºC and 45ºC



Figs. 11 – Estimated time with reference to exposure temperatures (left) and maximum expansions observed referred to exposure temperatures

11 References

[01] DEPARTMENT OF THE AIR FORCE HEADQUARTERS AIR FORCE CIVIL ENGINEER SUPPORT AGENCY entitled- Engineering Technical Letter (ETL) 06-2: **Alkali-Aggregate Reaction in Portland Cement Concrete**;

[02] Modeling Hydration of Cementitious Systems", published in the Journal of the American Concrete Institute Materials ACI, March-April 2012