ALKALI SILICA REACTION IN CONCRETE: KINETIC MODELING THE START OF THE EXPANSION. PART 2- COMPARISON OF MODEL ESTIMATES WITH EXPERIMENTAL DATA

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Abstract

This paper compares expansion model estimates and experimental data. In a previous paper, a diffusion controlled topochemical model fitted to isothermal curves yielded kinetic parameters (induction time and kinetic constant). Linear regression of their Arrhenius plots modelled the constants dependence on temperature, allowing to predict induction times at given temperatures and times in laboratory. Comparing expansions thus estimated with experimental values at 37 ºC in mortar-bars immersed in 1M NaOH solution ASTM C 1260 adapted test, the expansion start matched the modelled induction time. The experimental and modeled expansion after that time follow different patterns. The model may use known correlations for correcting for different alkalinities and humidity's,.

The model possibilities were checked with published data on ASR-affected concrete . The estimates matched real values despite high errors in statistical processing and environment data. Improvements are proposed for reducing errors, in modeling major factors , and application to other cases.

Keywords: Alkali-Silica Reaction, prevision, model, induction time

1. INTRODUCTION

In a previous paper [1] the authors discussed relevant aspects for model selection leading to the choice of Unreacted Shrinking Core model, with spherical interface and induction time, and the experimental conditions used and data collected at 50, 60 , 70 and 80 ºC in mortar-bars immersed in 1M NaOH solution for fitting the model. A final comparison with test data at 37.2ºC was also carried out.

Experimental data obtained with the same set up and procedures of the ASTM C 1260 test at this temperature were compared with estimates from the models at 37.2 ºC. The induction time displays a better fitting for the model with spherical interface, but further expansion follows a completely different pattern. Possible improvements were further discussed in Gonzalez 2010 [2] and Gonzalez et al. 2011 [3]. This second part presents only the comparison of the model obtained with experimental data.

2. EXPERIMENTAL

The expansion test at 37.2ºC was planned and carried out to evaluate the estimated expansions using the model by comparison with experimental data, independent from the data used for fitting. The setup was analogous to ASTM C 1260 test. The temperature reading was made with higher accuracy, as the projected estimates from the model ha shown a large sensitivity. Readings of the three specimens were made sequentially and averaged. The data collected is presented graphically in Figure 1.

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3. RESULTS AND DISCUSSION

Low temperature test comparison and discussion

Figure 1 displays as void circles data measured in tests at several temperatures, used to evaluate the model parameters as described in Part I [1], and as losanges the test at 37.2 ºC. The estimated curves are represented as continuous lines at the corresponding temperatures. The model assumes null expansions below induction time, followed by a diffusion controlled regime.

There is good agreement between data and estimated lines for higher temperatures, above the induction time, better seen in Figure 6 of Part I. At 70 and 50 ºC some deviations occur to the same side, displaying a biased behavior due to a misfit of the model or to a systematic error that may be due, e..g.., to a small deviation of the test setting temperature, even within the allowance of the test itself.

Figure 1 shows that induction time is fairly well predicted by the model, which was the explicit aim of the work, but further expansions beyond it follow a linear pattern instead of the typical downward curved, so that modelling higher expansions are not validated. This linear trend was confirmed in another experiment at 45ºC. This clear change of pattern between higher temperatures and lower was not studied. It may possibly be due to an alteration of controlling mechanism from only diffusion to partly reaction; its confirmation however requires an independent experimental program, and the balance between benefits and effort required is not clearly positive.

The model considers null expansions at ages before induction time, which is obtained by projecting back the diffusion controlled model in which fitting very low expansions were excluded. For the aimed purpose of estimating induction time as an indication of service life, this is enough.

However the tests results show an intermediate zone, where expansions are already in the microcracking range, where acceleration is taking place (expansion lines curved upwards), but is not yet in the diffusional controlled regime. This zone can extend as high as 0.06% expansion at the higher temperature. Considering the rapid expansion increase close to the 0.04% level (widely accepted as critical for fissuration) induction time is tentatively identified with the initial pre-fissuration period. In this intermediate zone, the transition is less pronounced at higher temperature, and better outlined at lower, probably because of some overlapping of transformations at higher rates (i.e., temperatures).

Figure 1 details also this pre-cracking period, for the test at 37.2ºC, for estimated isotherms ±1ºC and ±2ºC, pointing out the appearance of gel and its nigration to the solution. There is an initial regime, until 0.012%, curved downwards, followed by an accelerated expansion, curved upwards up to 0.028%, ending as a sudden expansion (assumed to be cracking; it was not possible to confirm visually, due to rugosity of the surface). These observations agree with several authors' remarks that this area below 0.02 % is important to understand and model [4], both for aggregates and the cement paste to start micro-cracking[5].

Below the intermediate zone the initial expansion tendency is blocked by the material reaction, and the expansion proceeds with downward curvature, better evidenced at lower temperatures . The pre-fissuration period expresses probably, thus, a balance between expanding and retracting forces developing inside the reactive particles and cement paste.

An interpretation of what happens depends on the phenomena considered to happen, and would certainly need a much more extended program to clarify the possibilities allowed by the currently accepted expansion models. Considering one of the mechanisms, of solid expansion, just for reference, expansion in the test beginning is relatively fast (assuming the data is accurate enough to describe it), and is followed by a leveling period, probably when expansion is counteracted by the material reaction to deformation, accumulating stresses. Goltermann [6, 7] modeled this procedure considering the expansions located in the spherical particles periphery, and developing compressive tangential stresses and radial tensile sresses. It is interesting to note that the reported appearace of gel on the specimens surface and inside the solution also provides evidence for the "alternative" transsolution model theory.

The outline of this region as it is, drawn from raw data, must be pondered by accuracy considerations. Although it seems logical that the expansion curve starts here, phemonenologically, and it is obvious interesting to relate the early processes here to later on at higher expansions, this part of the curve requires more sensitive readings (not necessarily with other equipment). Probably a controlled low temperature bath would stabilize reading conditions enough for the higher accuracy needed; better reading procedures must be established and discussed before using this potential. There is already a large involvement of research in or very close to this area, when setting up criteria for AAR-4.

Tentative comparison with field data

The model was tentatively applied to a case reported in literature, of a concrete railway sleeper with symptoms of incipient ASR after 11 years of service [Santos Silva 2008] [8]The alkalinity was estimated from the composition of the cement used by Helmuth 1993 correlation[9]. The correction of the effect of temperature and humidity proposed in Part I [1] assumed for these environment variables values taken from published general meteorological data reported. The use of these data was in this particular case justified by the structure location, in covered place. The correction leaves certainly a lot of margin for improvement, but that analysis in a more general, wide context, is out of the scope of the present research work. The estimates agree with the data, as depicted in Figure 2, but are affected by significant errors. Improvements of the prediction precision are proposed elsewhere [2] .

The model is especially adequate to estimate the service life when the start of significant strains is critical, as well as to define time intervals for inspection, and covers only the problems due to material properties degradation. It is inadequate to foresee strains within the pre-cracking period and, after cracking, when relatively large strains are allowed. In these cases, there are completely different interactions, between concrete and reinforcement bars, and between the different components of the construction. Procedures to improve the accuracy of the estimates are suggested and discussed in Gonzalez 2010.

4. CONCLUSIONS

The expansion tests performed show that the expansion starts immediately, although only reaching a significant level (across the limit of 0.04% usually assumed for the start of visible cracking) after a slower period which in this communication is treated as an induction time. The kinetic parameters of a model with induction time are best fitted to data from isothermal tests, between 50 and 80ºC. The fitting is better for the unreacted shrinking model with induction time and spherical interface. The kinetic parameters were modeled themselves in relation to temperature by regression in an Arrhenius plot.

The induction time prediction, original aim of the work, presents a fair match with data for an expansion curve at 37.2 ºC. The model considers null all expansions during this period, although this pre-cracking period may be relevant for expansion predictions. After induction time, the data at 37.2 ºC display an expansion pattern completely different from the previous model estimates (other well known models also don´t follow this pattern).

Tentatively the model was applied to a concrete structure with incipient ASR. The positive comparison evidenced however significant errors of statistical data treatment (that might be improved with a better experimental design aimed at that purpose), and the modeling and definition of the effects and of environmental data, enhancing the need of further improvements.

A possible advantage of the model now proposed, with spherical interface, is to define a dependence on the aggregate particles size that, if confirmed experimentally, might constitute a basis to transfer data from mortar bar test results to concrete, with larger aggregate particles. This model considers the behavior of the material in itself, independently of size and interaction of the concrete structures, setting a general limit to service life. It allows to predict the period of time in which the initial concrete properties are kept within acceptable low limit. When service life is constrained by very small strains that might occur within the induction (pre-cracking) period, or allow large strains well above incipient cracking, other models should be tried and used.

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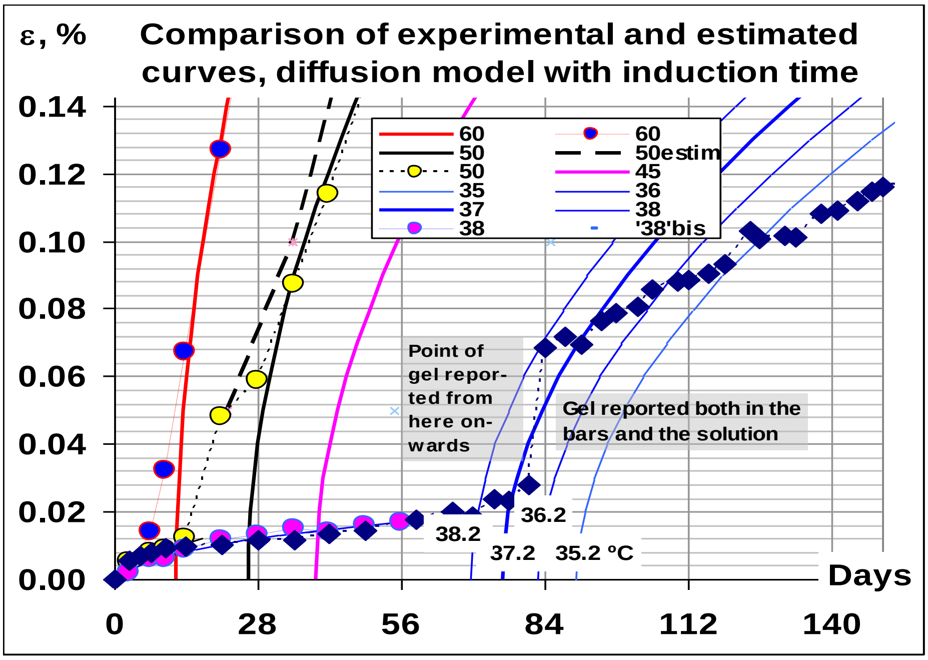

Figure 1 Detail of the pre-cracking period, covered by present model only for its total duration, assumed as induction time, with null expansion before it. At higher temperatures, this period is less well defined.

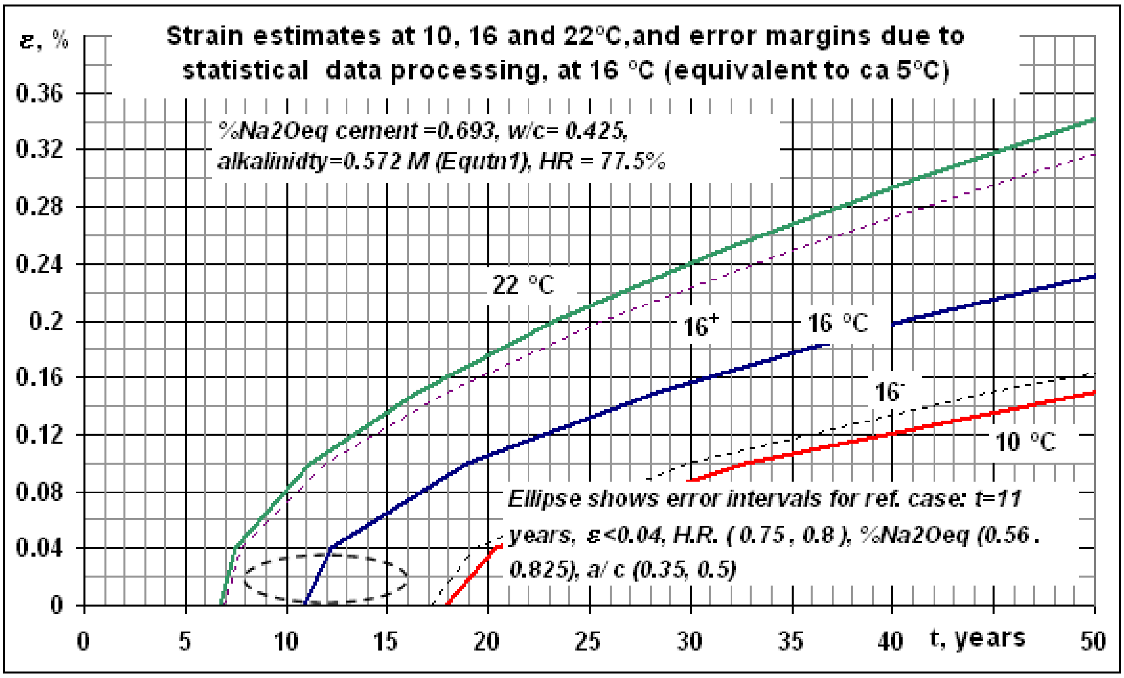

Figure 2 Prediction by the model in the case of a concrete structure. Prediction of strain at different temperatures (10, 16 and 22ºC); the error margins in temperature (16^{+} , 16^{-}) are indicated by dashed lines.