COMPARISON OF EXPANSION TESTS FOR ALKALI-REACTIVITY OF AGGREGATES, BASED ON A KINETICS APPROACH – PART II – EXPERIMENTAL RATES FOR DIFFERENT TYPES OF AGGREGATES

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Abstract

In a previous paper, a kinetic based comparison between expansion tests for alkali aggregate reactivity was carried out. In this paper, the same assumptions and models allow to check the comparison with results with real aggregates varying in alkali reactivity. Using the same approach, for each aggregate, expansion rates for three expansion tests are estimated, corrected for alkalinity and depicted as an Arrhenius plot. The relationship used data from NF P18-590, ASTM C 1260 and ASTM C 227 tests and shows linear Arrhenius plots for several aggregates, aligned almost parallel to the line obtained for test criteria. Aspects related to the different experimental conditions on test-methods and their effects are discussed. The proposed conclusion is that both standards and aggregate results, at the given conditions, are not inconsistent under the kinetic point of view. Some suggestions are made for improving the accuracy of the relationship obtained.

Keywords: Expansion tests, alkali reactivity, ASR, kinetics

1 INTRODUCTION

In a previous paper [1] it has been presented a kinetic based procedure to compare several expansion tests for determining alkali aggregate reactivity, based on linear expansion measurements and corresponding criteria. Assumptions made were that a near linear expansion occurs for quasi reactive aggregates (defined in this two part series as aggregates with reactivity close to the upper limit of nonreactive field), a linear relation between reaction and expansion, a first order dependence of expansion or reaction rate on alkalinity, given by the hydroxyl content, and an Arrhenius-type dependence of reaction rate on temperature. These assumptions are not new; they have been considered in several studies of the ASR kinetics or expansion modelling.

For quasi reactive aggregates, reaction rates were estimated from tests criteria limits and ages, considering the linear expansions corrected for alkalinity effect from the first order assumption, and representing in Arrhenius plot the corrected rates thus found. The linearity of this plot, considered as a criterion for kinetic consistency between tests, was verified for ASTM C 1293 [2], ASTM C 1260 [3] and NF P18-590 [4] expansion tests. Several tests beyond these three were found to match this criterion, within certain variation. The effect of other lesser factors was evidenced in the case of particle size, for which the Norwegian AMBT test [5] [6] mentions different criteria and it is supposed that similar variations should occur for other factors. A logical issue is the handling of abstract information from criteria, defining hypothetical behaviour as if dealing with virtual aggregates. How far from reality are these assumptions ? This issue was tested against existing data on three tests with real aggregates: five siliceous sands, five limestones, four granites, two quartzites and one schist. The expansion tests considered were the ASTM C 1260, the NF

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P18-590 and the ASTM C 227 test, the last runs under conditions similar to the ASTM C 1293, using a somewhat lower cement alkalinity (0.89% Na_2Oeq.). The data collected allowed to check the validity of the expansion linearity assumption, before being treated the same way as in previous tests, and representing corrected rates of expansion in Arrhenius plots.

2. EXPERIMENTAL

Santos Silva 2005 published [7] experimental results of tests ASTM C 227 [8] , ASTM C 1260 [3] and NF P18- 590 [4] carried out on 17 portuguese aggregates (5 siliceous sands, 5 limestones, 4 granites, 2 quartzites and 1 schist) with varying reactivity where possible. In case of ASTM C 227, alkalinity was fixed at 0.9% Na_2O_{eq} , cement basis, by addition of NaOH during the mortar preparation.

These tests are widely known, a summary of the main relevant features and parameters being presented as Tables 1 and 2 in the first part of this two paper series, and they will not be commented here unless referring to additional details.

3. RESULTS

3.1. Expansion Results

The results for the three expansion tests are presented in Table 1. The results of the tests are depicted for intermediate and final readings in Figure 1 for the ASTM C 1260 test. As it is possible to see, using the ASTM C 1260 criterion, only one sand is markedly reactive; one is non-reactive just close to limit and the other three are above, but still close to the test lower limit (0.1% at 14 days) referred to as quasi-reactive limit. A limestone, by the same criterion, is classified as reactive; another has reactivity between high and low limit (closer to quasi reactivity) and the other three are particularly inert. The reading precision for very low expansions, in these latter three, compare to expansion values, and the corresponding data is thus irrelevant. Granites present a similar problem of low expansion, although not as low as the inert limestones, but their expanding nature in long-term tests require judgement. All of them are in the non-reactive area below the lower limit, two with a linear expansion pattern while the other two show a downward curvature pattern. One quartzite is clearly reactive, while the other's expansion curve overlaps the lower limit line, being above at 14 days (dubious reactivity according to the test). The schist data fall in the non-reactive area, though close to the lower limit. All these last three aggregates follow a general linear expansion pattern. Regarding expansion linearity, granites 3 and 4 are remarkably linear from the origin. The four lower reactivity sands, the two higher reactivity limestones, the quartzites and the schist all present a fair linearity but only after an expansion of about 0.02%, a varying threshold commonly referred to in literature as linked to the start of microcracking, namely of cement paste, e.g. in Nonat [9].

3.2. Data Processing to rates/equivalent ages and their Arrhenius plots

The obtained data was submitted to the same procedure presented in a first part of this work [1]. Average expansion rates were maintained where linearity starts at 0.02%. The rates were also converted to equivalent times, although not required in this situation, to keep a uniform procedure (the values themselves have no special meaning, being just a projected trend in the case of the granites). Finally, the corrected rates for alkalinity were plotted in the equivalent age format in Arrhenius plots. For comparison, in the plots are included the data for the three tests compared in [1]; the limits due to the temperature allowances of ASTM C 1260 and 1293 tests were not considered, due to the high number of lines.

The Arrhenius plots thus obtained are presented in Figures 2 and 2A. For easier comparison, regression and correlation coefficients are listed in Table 1.

4. DISCUSSION

The main purposes of this part of the work are to check if the proposed procedure depicts a “kinetic consistency” between results from different expansion tests for real aggregates, i.e., if they lead to linear Arrhenius plots and also to compare the plots for real aggregates with the plots derived for quasi reactivity criteria conditions as shown in [1].

The sands show a general good alignment, parallel to the criteria line. The reactive sand 5 is the less good case, with R^2= 0.989. Non-reactive limestones depart from parallel alignment, but limestones 4 and 5 show a good parallel alignment. Granites follow a similar pattern, though being very low reactive, granites 3 and 4 depicting a good alignment; the others departing from general behaviour mainly for longer testing ages. Quartzites and the schist align very well as parallel lines. In summary, all aggregates except the reactive sand 5, the three very non-reactive limestones, and the two downwards curved granites follow the expected alignment in Arrhenius plot. The exceptions are also the aggregates departing more from linear expansion and quasi reactivity, both conditions assumed in the procedure development.

Considering only the “aligned” cases, slightly in the reactive field fall the lines for sand 4, limestones 4 and 5 and quartzite 2, while, slightly on the non-reactive field fall the lines of sand 1, granites 3 and 4, and the schist; quartzite 1 line overlaps the criteria quasi reactive condition. This behavior essentially agrees with the expansion curves, in reference to the lower, quasi reactive limit of ASTM C 1260, as shown in Figure 1. The fact that these aggregates have an Arrhenius plot with same slope as the criteria line has an interesting connection with another reactivity criterion, the Threshold Alkali Limit (TAL). Indeed, as parallel aligned aggregates present the same slope, such real aggregate present rates, for the different tests considered, proportional to rates derived from quasi reactive criteria applied to same tests. For each aggregate, the departure from quasi reactivity may be quantified by such a proportionality constant (or its logarithm, in Arrhenius plot by an additive, translational term). As a first order dependence on alkalinity was assumed, this departure may then be expressed also as equivalent alkalinity ratio. In other words, for all tests, at a certain alkalinity ratio to the standard alkalinity, the aggregate should behave as critically reactive; this is the principle backing the TAL definition [10] [12]. Unfortunately, the initial program was not designed to yield results allowing to check such possibility, so to confirm this conclusion an adequate experimental program would be required. (note also that the present results have applied only to aggregates not very far from quasi reactivity).

5. CONCLUSIONS AND RECOMMENDATIONS

This paper shows that a kinetic consistency may exist between the ASTM C 1293, ASTM C 1260 and NF P 18-590 expansion tests at the adopted criteria level and at the respective test results, carried out with the same aggregates. The comparison done assumes constant expansion rate for quasi-critical reactivity and the effect of the main factors (alkalinity, humidity and temperature) yielded by models found in literature. The criterion of consistency adopted was the linearity of the Arrhenius plot of the reaction rate after correction by the effect of the other factors to a same comparison basis.

A similar alignment was found for the expansion rate with available data for ASTM C 227, ASTM C 1260 and NF P 18-590 tests, for most of the tested aggregates, covering different reactivity. In others, the linearity for quasi reactive aggregate may be observed mainly above an expansion of about 0.02%. The apparent energies of activation for the real aggregates are nearly the same as the one found from tests criteria, as the alignments for real aggregates and criteria are about parallel (comparing with Figure 1 –ASTM C 1260 test - , quartzite 2 is the more reactive, and schist is non reactive, whilst quartzite 1 alignment overlaps the limit line for criterion).

The proposed approach, presents interesting results, but is over-simplified in its assumptions and lack of precision, difficult to avoid in such a complex reaction. It evidences a global coherence between data, regardless of the effect of possible factors variations, some of which were not even considered, and the different interpretations and behaviour referred to ASR. That may be possible because kinetics is concerned only with the performance of the controlling reaction, and some factors´ influence may be not controlling.

The quality of the assumptions may be improved in many aspects, namely:

i) by improving all the used models, regarding

quantification of alkalinity resulting from several interactions in concrete environment,

variation of alkalinity due to leaching and reactions,

effects of variation of humidity.

ii) by extending the proposed approach by inclusion of other expansion tests, specially those which use the linear expansion, and data from expansion tests of other aggregates in different tests. If results are positive, extend to tests based on different properties.

iii) by improving the accuracy of reading experimental data, namely expansion and temperature and, when relevant, alkalinity and its evolution .

ACKNOWLEDGEMENTS

The authors thank the financial support provided by Fundação para a Ciência e Tecnologia (FCT), through the project EXREACT (PTDC/CTM/65243/2006).

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Table 1- Aggregates expansion results (%) in alkali-reactivity tests

Aggregate	ASTM C 1260 (14 d)*	NF P18-590 (5 d)**	ASTM C 227 (181 d)***
Sand 1	0.090	0.075	0.011
Sand 2	*0.101*	0.090	0.019
Sand 3	*0.122*	0.090	0.021
Sand 4	*0.147*	**0.166**	0.022
Sand 5	**0.294**	**0.201**	0.018
Limestone 1	0.001	0.016	0.008
Limestone 2	0.003	0.024	0.023
Limestone 3	0.006	0.033	0.020
Limestone 4	**0.140**	**0.390**	0.022
Limestone 5	**0.227**	0.208	0.017
Granite 1	0.019	0.046	0.036
Granite 2	0.027	0.046	0.018
Granite 3	0.035	0.042	0.005
Granite 4	0.031	0.041	0.001
Quartzite 1	0.091	0.095	0.023
Quartzite 2	**0.247**	**0.266**	0.034
Schist 1	0.072	**0.111**	0.009

* Non-reactive < 0.1 < Potentially reactive < 0.2 < **Reactive**.

** Non-reactive < 0.15 < **Reactive**

*** Non-reactive < 0.1 < **Reactive**

Table 2. Linear regression of data in the Arrhenius plot for inverse of equivalent time. (x=1/(2.303 R T)

Data	Regression line of 1/teq , *	R^2
Test Criteria	= -20644.8 x+11.663	0.9998
Sand 1	= -19490.8 x+ 11.090	1.0000
Sand 2	= -17940.4 x+ 10.002	0.9993
Sand 3	= -18200.1 x+ 10.122	1.0000
Sand 4	= -19242.3 x+ 10.649	0.9983
Sand 5	= -20667.6 x+ 11.922	0.9892
Limestone 1	= -15391.4 x+ 7.377	0.7182
Limestone 2	= -13591.1 x+ 6.600	0.7055
Limestone 3	= -15027.1 x+ 7.600	0.8107
Limestone 4	= -21852.2 x+ 12.675	0.9945
Limestone 5	= -20956.1 x+ 12.057	0.9956
Granite 1	=-14337.3 x+7.468	0.8834
Granite 2	=-16343.9 x+8.670	0.9687
Granite 3	=-19545.8 x+10.511	0.9999
Granite 4	=-23348.0 x+12.666	0.9962
Quartzite 1	=-17777.4 x+9.882112	0.998526
Quartzite 2	=-19632.2 x+11.38299	0.999903
Schist 1	=-20834.1 x+11.63536	0.999812

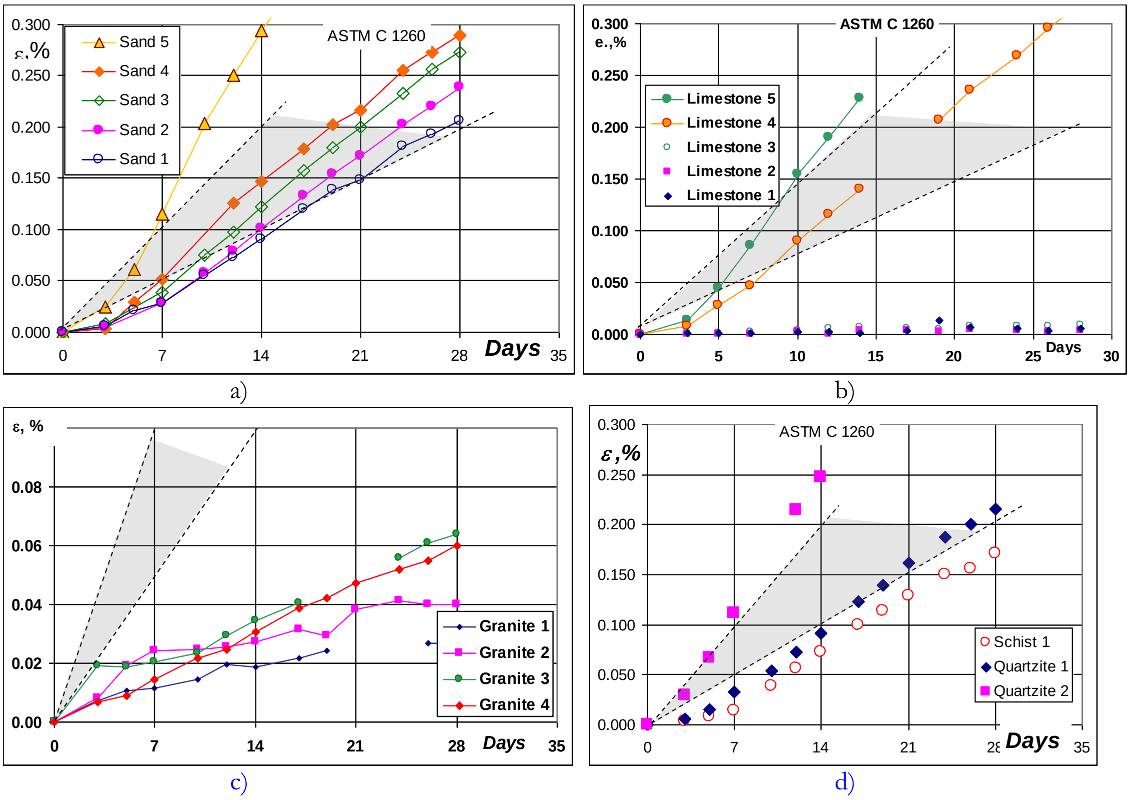


Figure 1 - Results of ASTM C 1260 for sands (a), limestones (b), granites (c), quartzites and schist (d) . Portuguese aggregates.

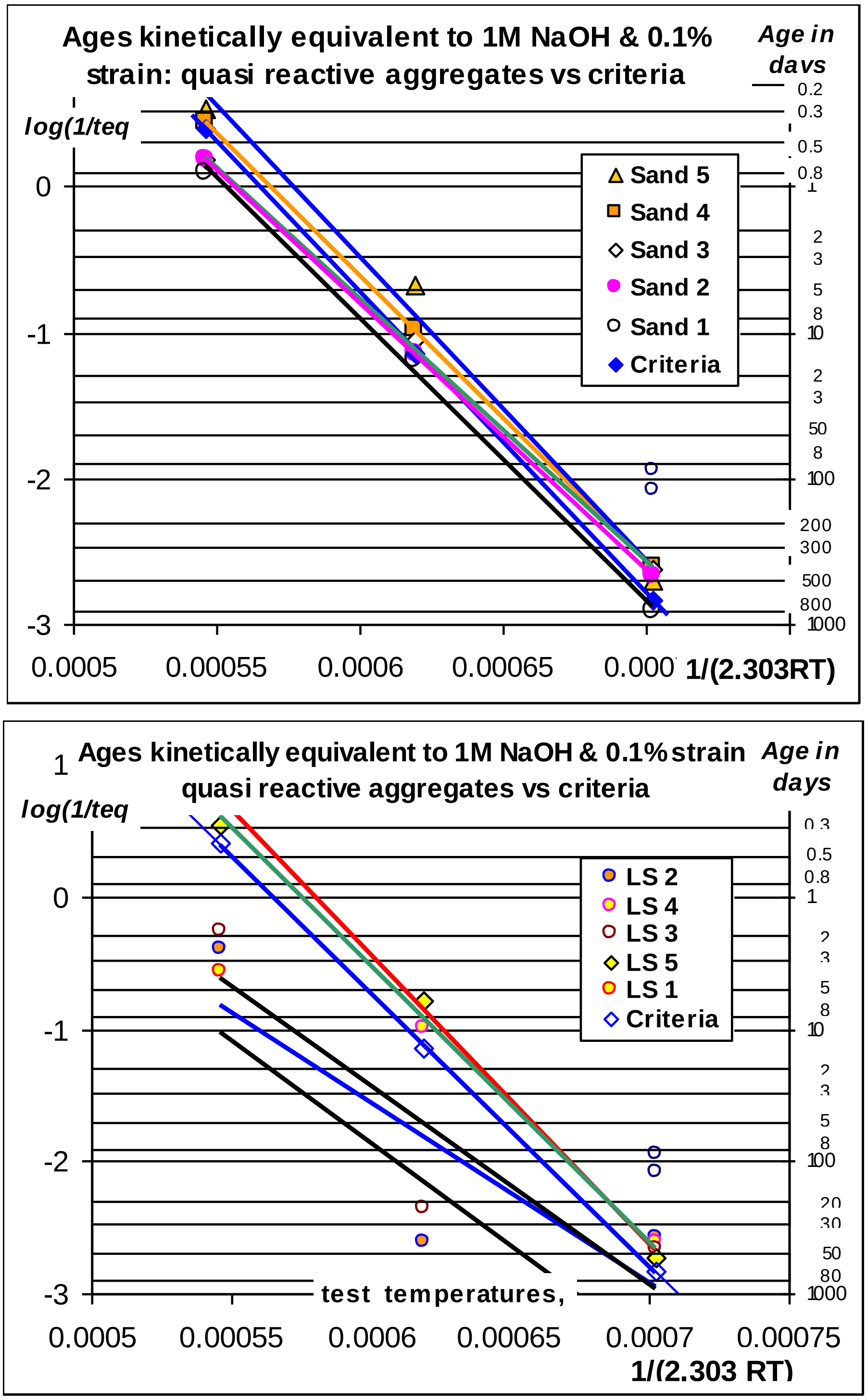
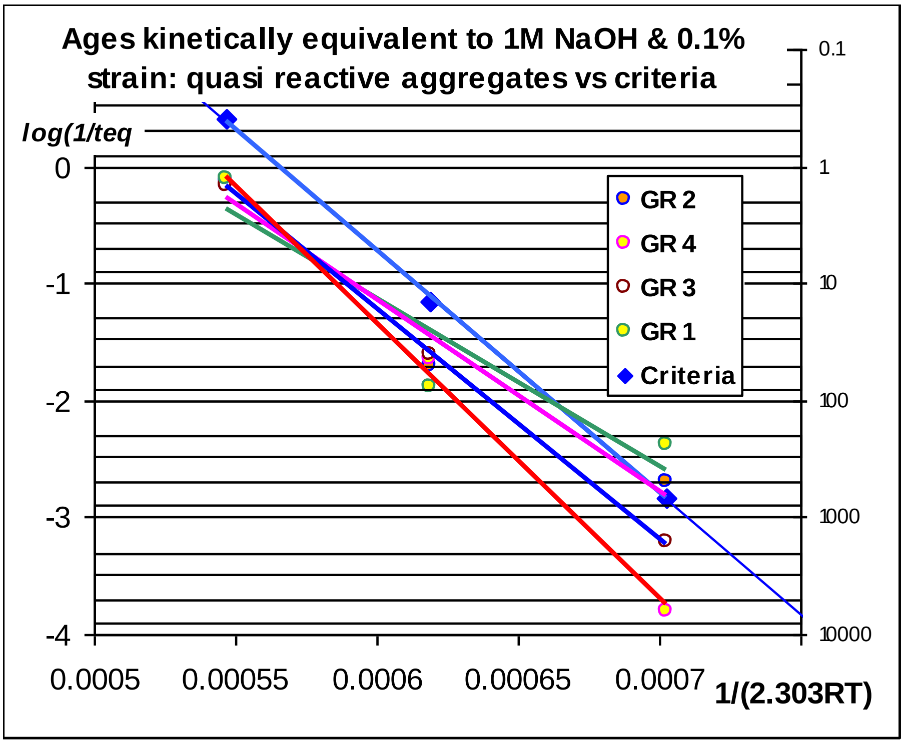


Figure 2 - Arrhenius plot for results of ASTM C 1260, ASTM C 227 and NF P18-590 tests with same sand (upper), and limestone (lower) aggregates tested in Figure 1, in comparison with same tests estimated from quasi reactive criteria in Figure 1, represented as filled diamonds. The regression and correlation coefficients obtained for the respective lines are presented in Table 3.



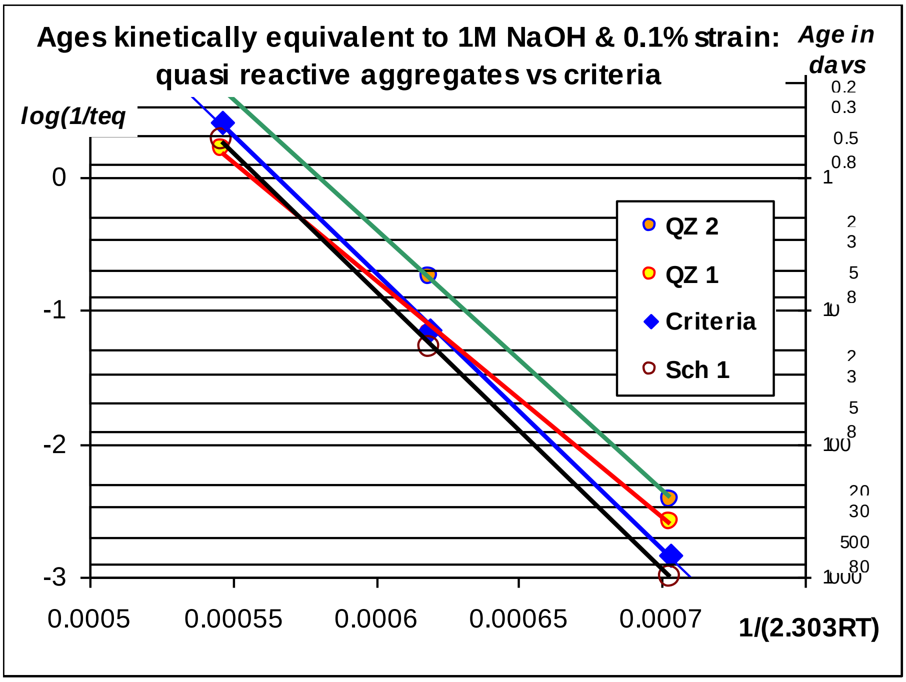


Figure 3 Arrhenius plot for results of tests ASTM C 1260, ASTM C 227 and NF P18-590 with same four granite (uppert) and 2 quartzite and one schist (lower) aggregates tested in Figure 1, in comparison with same tests estimated from quasi reactive criteria from Figure 1, represented as filled diamonds. The regression and correlation coefficients obtained for the respective lines are presented in Table 3