THE CONTROVERSY OF ALKALI CARBONATE REACTION: STATE OF ART ON THE REACTION MECHANISMS AND BEHAVIOUR IN CONCRETE

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Abstract

Carbonate aggregates can react in concrete under certain conditions by alkali silica reaction (ASR) or alkali carbonate reaction (ACR). Recent petrographic examinations performed on the basis of modern techniques suggest a need for redefinition of ACR and for a clear distinction between a chemical reaction involved and an expansion mechanism of the carbonate aggregates. The paper gives a "state of art" on former and recent research on reaction caused by "classical" carbonate aggregates and the discussion whether reaction and expansion is caused by alkali carbonate reaction or alkali silica reaction. Unfortunately potentially reactive carbonate aggregates are difficult to identify by petrographic methods (thin section) only. The paper describes methods for identification of potentially reactive carbonate rocks according to the procedures given in RILEM AAR-0 annex A (2011).

Keywords: Concrete, carbonate aggregate, alkali carbonate reaction (ACR), alkali silica reaction (ASR),

1 FOREWORD

Rilem committee TC 219 ACS publish guidelines for use of RILEM methods including "Assessment of Carbonate Rock Aggregates for Reactivity Potential" in RILEM recommended Test Method AAR-0 annex A 2011 [1] and RILEM Recommended Specification: AAR-7.2 "International Specification to Minimize Damage from Alkali Reactions in Concrete Part 2: Alkali-Carbonate Reaction" 2011 [2]. The reaction mechanism of Alkali Carbonate Reaction is today questioned and RILEM Committee TC 219 ACS has requested the author to give a "state of art" on ACR which is presented in this paper.

2 INTRODUCTION

Carbonate aggregates (limestone and dolostone) are important worldwide aggregate types for concrete purposes. In certain regions carbonate aggregates are the only rock types available for concreting. Carbonate aggregates can cause deleterious chemical reactions in concrete. Silica in impure carbonate aggregates might cause Alkali-Silica Reaction (ASR). Much rarer and today not satisfactory explained is Alkali-Carbonate Reaction (ACR) caused by certain types of argillaceous dolomite-bearing aggregates. On a world wide basis ACR is rare and potentially reactive ACR aggregates occur often in some limited beds in quarries. ACR, according to the original definition in Canada half a century ago, is very deleterious and fast reactive, and concrete structures suffering from ACR can be largely disrupted within few years. Preventive measures, which work well and reduce the risk for typical ASR, have reportedly little effect on ACR. During the 13th Int. AAR Conference in Trondheim, Norway June 2008 there was a workshop on ACR chaired by the author. From the presentations and discussions during the workshop it was clear that there occur different views on ACR. Some researchers claimed that alkali carbonate reaction does not exist but is alkali silica reaction. Other researchers accept ACR as formerly explained by Gillott [6, 17] or the dedolomitization process to be the expansive and destructive mechanism by Tang [18, 19] and alkali silica reaction to be secondary regarding to expansion. The paper gives a "state of art" on the ACR controversy problem.

General procedures or guidelines to sort out the reactive types have been published by RILEM TC ACS AAR-0 annex A [1], but more experiences with this procedure should be obtained. X-ray Fluorescense Analysis (XRF), Rogers 1986a [4] has during decades been used in North America but experiences with this method outside North America is limited.

3 HISTORY

ACR was first found in Canada and since the late 1980's also in China. Alkali Carbonate Reaction has now been observed in several states in USA and in several countries e.g. Iraq, Bahrain, Argentina, Spain and Brazil (and laboratory samples from Austria).

3.1 ACR in North America

ACR was first observed in the Kingston area Ontario, Canada by Swenson 1957 [5] and a few years later also in Virginia, USA. The reaction mechanism of ACR was explained by Gillott 1964 [6] to be a combination of dedolimitization and swelling of clay minerals. In Canada no cases of ACR have been found caused by gravel aggregates probably because of the low resistance to freezing and thawing of these rocks Rogers 1986b [7]. In Canada an accelerated concrete prism test method was developed for assessment of potentially reactive carbonate aggregates CSA A23.2-14A [32] which also are suitable for other rock types. A similar method are published as ASTM C 1293 (Alkali Silica Reaction) [39]) and a non accelerated concrete prism method as ASTM C 1105 (carbonate rock) [3]. A rock cylinder test method ASTM C 586 [33] is also shown to be suitable for testing carbonate rocks.

3.2 ACR in China

In China severe cracking in concrete structures, road bridges, air port pavements (runways) and railway ties were observed in late 1980's. In all these structures dolomitic limestones or dolomitic rocks were used as coarse concrete aggregate Tong 1994 [8]. In China comprehensive research have been carried out on ACR and an "overview" has been given by Tang and Deng 2004 [9]. Important research in China is study on the reaction mechanism, development of the Chinese autoclave method and study of the micro texture of reactive carbonate aggregates. It has also been shown that lithium which prevents ASR does not prevent ACR. This has been used to distinguish potentially ASR aggregates from potentially ACR aggregates, Tang and Deng 2000 [10].

3.3 Research in Japan

Katayama 1992, 2004, 2010 [11, 12, 13] claimed that deleterious expansion of dolomitic aggregates is likely due to ASR of cryptocrystalline quartz invisible in thin section microscopy. Dedolomitization which always is distinctly associated does not cause expansion. Moreover he examined thin sections from Kingstone dolomite and observed small cracks filled with alkali gel.

4 CHARACTERISTICS OF ACR

The sign of reaction and behaviour in concrete differ in many ways from traditional ASR:

- The ACR is very fast and deleterious. In Canada (Kingston area) and China (Beijing) damaged concrete structures had to be demolished within few years of service life. Normally ASR is "slower" depending on type of reactive aggregate (fast reacting e.g. opal or slow reacting e.g. granite)
- In reacted ACR concrete very little alkali gel can be observed (generally only visible by use of scanning electron microscopy) and therefore difficult to accept to be the major expansive force of expansion and deterioration of the concrete. Moreover, due to the reaction with brucite, gels are

generally enriched by Magnesium (Mg-Al-Ca-silica gel) which are possible less expansive than "normal" Na-K silica gel.

- The ACR is caused by reaction of coarser particles in the concrete (same for slow reactive ASR). Fast reactive ASR react both in the fine and coarse particle sizes but is generally more expansive in the finer grain sizes and has often a pessimum relation on particle size and content.
- The ACR expansion curve of concrete prism test is generally very steep and obtains maximum expansion faster than ASR aggregates.
- The ACR can occur deleterious in concrete with use of low alkali cement. Normally low alkali cement prevents ASR.
- The ACR can occur deleterious in concrete with use of fly ash cement. Normally fly ash cement prevents ASR.
- The ACR can occur deleterious in concrete with use of high content of slag cement. Normally slag cement prevents ASR (high slag replacement has shown to be efficient in laboratory samples [2]).
- Lithium prevent ASR (fast reactive aggregates) but has no effect on ACR

5 REACTION AND EXPANSION MECHANISM OF ASR AND ACR

5.1 Reaction and expansion mechanism of ASR

The reaction mechanism of ASR was first explained in the early 1950's by Steinour & Powers 1955 [14] and expansion of the concrete to be caused by swelling and expansion of alkali silica gel. This work and several later works are based on experiments and experiences with fast reactive aggregates as e.g. opal, chert and cryptocrystalline quartz. ASR caused by microcrystalline and coarser crystalline rocks (sandstone, quartzite, granite etc.), so called slow reactive rocks, can not solely be explained by swelling and expansion by water of alkali silica gel alone and differs in many ways from reaction caused by fast reactive aggregates Jensen 1993, 2012 [15, 16]. Reaction mechanism of ASR (fast or slow) is not further discussed in the paper but it has to be noted that alkali silica gel observed in reacted dolomite aggregates most likely is caused by fast reactive ASR.

5.2 Reaction and expansion mechanism of ACR

According to Gillott, 1964 [6], the reaction mechanism of ACR is a combination of dedolimitization, which does not cause expansion, and expansion by clay minerals. Gillott explained the dedolimitization process simplified by the following chemical equation:

Eq. (1) $$CaCO_3MgCO_3 + 2NaOH = CaCO_3 + Mg(OH)_2 + Na_2CO_3 .$$

The reaction produces calcite ($CaCO_3$), brucite ($Mg(OH)_2$) and sodium carbonate (Na_2CO_3). Both NaOH and Na_2CO_3 occur in liquid phases. The experiments by Gillott was based on reactions with $2M$ NaOH but in real concrete potassium ion will also react, therefore NaOH and Na_2CO_3 should be written as MOH and M_2CO_3 where M is an alkali metal ion. The dedolomitization process produce a negative volume change Therefore, because expansion probably not is caused by dedolomitization, it is suggested that clay minerals distributed in the aggregate matrix absorb Na^+ ions, (K^+ ions), Ca^{++} ions, Mg^{++} ions on surfaces and a double layer develops. Water then enters into the clay minerals with consequence of swelling and disruption of the concrete. The expansion is due to wetting of previously unwetted clay minerals made possible by the dedolomitization reaction which produce access channels for moisture, Gillott & Swenson 1969 [17].

Tong 1994 [8] suggest a micro structural model where dedolomitization makes two interfaces of solid reaction products, 1) a reaction rim surrounding the carbonate aggregate called interface I which not is expansive and 2) interface surrounding individual dolomite crystals internal in the carbonate aggregate called interface II which might be expansive depending on the porosity of the aggregate. Tang 1986 [18] by TEM analysis observed both calcite and brucite surrounding individual dolomite crystals and a decreased Ca/Mg-ratio in the dolomite crystals in the Kingston dolomite. Experiments with pure dolostone, magnesite and limestone (without silica) all expanded deleteriously even the volume of solid compounds were negative [18]. These results confirm that even the solid volumes is reduced the expansion can occur by the chemical reaction and pressure by recrystallization. Based on kinetic experiments and mathematical analyses Tang 1989 [19] suggest that the dedolimitization process has a negative free energy on -12.19KJ at 298K. The negative free energy means that the reaction (topochemical) is a spontaneous process and the driving force is Na^+ ions, K^+ ions and OH^- ions into the dolomite crystals. The negative free energy can also explain why the reaction occur with a relative low pH value in the concrete and why low alkali cement, slag cement and fly ash cement not are efficient preventing the reaction.

Lopez-Buendia 2008 [20] suggests that that during the transformation of dolomite to calcite and brucite the calcite unit cell has wider structure than dolomite and consequently higher volume than the equivalent dolomite and hereby causes the expansion in concrete.

6 IS ACR JUST ASR?

Katayama 2004, 2010 [12, 13] studied mortar bar Rilem AAR-5 samples from Austria and Pittsburg quarry in Kingston and a sample from a Canadian concrete structure damaged by “so called ACR” where carbonate aggregates from the Pittsburg quarry where used as concrete aggregate. He analysed the samples with different techniques such as thin section petrography, EPMA/EDS and element mapping. In all samples ASR were found and it was concluded that expansion was caused by ASR and not dedolomitization which also was observed in all the samples. It is suggested that the degree of dedolomitization is proportional to the content of dolomite crystals and not texture of the aggregate. He point out that ASR is very difficult to observe by use of classical petrography (e.g. thin sections) which can explain why ASR not has been recognised before. Internal in carbonate aggregates he observed a porous mottled (myrmekitic) texture with precipitations of calcite and brucite and pseudomorph of dolomite crystals. Mg-silicate gel was formed around reacted dolomite crystals either in the matrix or around the ASR gel. Carbonate aggregates was surrounded by a rim (halo) with calcite. In some samples cracks expelling from preexisting cracks of the dolomite aggregates were lined with calcite. These rims was explained to be caused by the newly formed M_2CO_3 from the dedolomite reaction and reaction with calcium hydroxide in the cement paste and not directly from the dedolomite reaction. By use of phosphoric acid extraction of silica by Rilem AAR-1 method in annex 7.2 [21] it was shown that micro-cryptocrystalline quartz varied from 0.5 % to 14.3 % in the samples which suggest the source of ASR expansion to be caused by pure silica.

Grattan-Bellew 2010 [22] study insoluble residues from 3 well documented limestones, from Kingston, Spratt and Chinese limestone. He finds a “correlation” between the insoluble residues of fine-grained soluble quartz and expansion by concrete prism test but not in the Chinese autoclave test. He concludes that the reaction of fine-grained, highly soluble, quartz in alkali carbonate reactive aggregates plays a major role in the expansion and cracking of concrete, and thus ACR is most likely just a variant of alkali silica reaction. However, several unsolved questions related to ACR are unsolved e.g why does Kingston dolomite cause less expansion in mortar bar test than in concrete prism test, the very little gel observed in reacted concrete and why does slag cement and lithium not prevent expansion.

7 THE CONTROVERSY ABOUT ACR

7.1 General

Gillott & Swenson 1969 [17] suggested that dedolomitization produce access channels for moisture with consequence of rewetting and expansion of clay minerals in the aggregate. Here the clay minerals are the expansive force for alkali-expansivity and should be possible in case aggregates contains clay minerals. However, later research has not confirmed this hypothesis.

The dedolomitization process which by volume calculations gives a negative volume increase probably not can be responsible of the expansion in concrete. On the other hand it is difficult to understand that the insignificant amount of ASR gel observed by Katayama in reacted carbonate aggregates can be solely responsible for the very expansive and damaging process in concrete alone. It has to be noted that in carbonate aggregates ASR and ASR cracking only can be observed by use of scanning electron microscopy (SEM) except in some few samples by carefully examination with thin section microscopy. In other types of alkali reactive aggregates ASR is visible by use of thin section microscopy and alkali silica gel and cracking are often "abundant". However, dedolomitization is by some researcher claimed to cause expansion in concretes.

7.2 Expansion by dedolomitization

Tong 1996[8] claims that the expansion of carbonate aggregates is the result of the reaction that occurs at the interface II. Expansive pressure around dolomite crystals in the rock can be generated from the formation and growth of crystalline calcite and brucite. He also observes micro cracks around "reacted" dolomite crystals. Only carbonate rocks with a suitable porosity, fine grained "dense" dolomite rock bearing rocks are able to concentrate enough expansive force. In more "porous" rocks the surrounding matrix will take up the crystallization pressure of calcite and brucite. The dedolimitization process will "open" up the rock for ingress of alkali ions and hydroxide ions which in addition will react with silica particles in the rock with consequence of ASR. Experiments also have shown that pure magnesite concrete microbars will expand. Tang [18] suggest a topochemical reaction where brucite produces the expansion.

Radonjic 1999, 2000 [23, 24] studied surface changes at room temperature of single dolomite crystals, before and after exposures in NaOH solutions, with different microscopic techniques (SEM/ESEM/AFM). She found that the first stage of the reaction involves the dissolution of dolomite followed by precipitation of brucite and second calcite growth on the surface of the dolomite crystals. Brucite would be susceptible for further chemical changes with the alkaline environment. Expansive forces would not only be generated by brucite but also through the oxidation of Fe phases.

Lopez-Buendia 2008 [20] study and compare the d-spacing obtained by XRD with theoretical "ideal" d-spacing and claims that during the transformation of dolomite to calcite and brucite the calcite unit cell has wider structure than dolomite and consequently higher volume than the equivalent dolomite. Cell dimension in the 104 reflection for calcite is 3.03Å and 2.89 Å for Ca-Mg-dolomite. During transformation of dolomite calcite is expansive as well as brucite. When there is an in situ crystal growing the expansion will take place due to limitation of the space. Moreover, in ferroan dolomite the Fe^{2+} ion will oxidize and be followed by iron compounds with consequence of expansion. When d-spacing in dolomite differ from "ideal" stoichiometry and ferroan dolomite occurs in the rock the dedolomitization process show a faster reaction. Dedolomitization can produce expansion due to ACR when it occurs after hardening of the cement paste and shrinkage when dedolomitization occur during the first days of setting.

7.3 Is alkali silica reaction the only expansive mechanism in argillaceous dolomitic limestone ?

Katayama 2011 [25] comment the topochemical reaction by Tang and claims that the experimental autoclave method (150 ^{o}C) is to vigorous for carbonate aggregates which produce irreversible thermal expansion of well crystalline rocks as shown by Mu 1996 [26] . Hereby should the measured expansions not be caused by ACR but by the method itself due to the irreversible expansion of the aggregate. The dedolomitization process and volume–increase by larger calcite D-spacing in Spanish dolomitic limestone as suggested by Lopez-Buendia does according to Katayama 2011 [25] not apply in concrete but only in natural geological environments. The hypothesis that rewetting causes swelling of clay minerals suggested by Swenson & Gillott 1969 [17] does not exists because the dominant clay mineral is illite and illite has not been documented to be expansive in concrete [25]. If expansion of illite or other clay minerals has occurred the following drying in field concretes will show concentric drying cracks around the aggregates which not has been observed [25].

8 IDENTIFICATION OF POTENTIALLY REACTIVE CARBONATE ROCKS

8.1 General

Carbonate rock is by definition composed by more than 50% by weight of carbonate minerals such as calcite and dolomite. Carbonate rocks can be sedimentary or metamorphic or rarely igneous. The composition and micro structure of carbonate rocks is often complex depending on origin and succeeding geological events. Rilem AAR-0 annex A gives procedures for "Assessment of carbonate rock aggregates for reactivity potential" by use of petrographic analysis and expansion tests [1]. The procedures also allows use of 3 optional methods when carbonate rocks have been identified in thin section, namely X-ray fluorescence analysis (XRF), X-ray diffraction analysis (XRD) and Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray analysis (EDX).

8.2 Petrographic analysis

It is recommended to perform petrographic analysis of aggregates intended to be used in concrete. Thin section analysis by use of the petrologic microscope is a common technique worldwide e. g Rilem AAR 1 "petrographic method" [21]. For carbonate aggregate it is recommended to stain samples for identification of type of carbonate minerals because these often can be difficult to be distinguishes under microscope. At present time thin section analyses of micro texture and mineral composition is not sufficient alone for certain identification of potentially reactive carbonate aggregates. However, the following general descriptions can be suggested:

1) Carbonate aggregate composed by pure crystalline calcite without impurities should be assessed as innocuous according to ASR and ACR. Some marbles might contain smectite (swelling clay) which can give problems in concrete.
2) Impure carbonate aggregates with quartz, clay minerals etc. should be considered to be potentially reactive for ASR and more uncertain for ACR. The reactivity increases with increased content of impurities, decreased particle size of quartz and increased dissolubility of quartz or other silica particles.
3) Impure carbonate aggregates with porphyrotopic texture of scattered up to 0.05 mm or larger? dolomite rhombs in a matrix of calcite, clay minerals and impurities should be considered as potentially reactive for ACR and possibly for ASR, see also Figure 1.

Use of phosphoric acid extraction on carbonate aggregate surfaces and SEM/EDX examination is recommended for identification of silica particles in carbonate aggregates, Rilem AAR-1 method A. 7.2 [21].

In concrete with ACR reaction products often is invisible in thin section and SEM/EDX analysis is recommended to be performed. Fluorescents impregnated thin section examined in UV light is very useful and able to visualise micro cracks in reacted aggregates and in the cement paste. In case micro crack from reacted aggregates runs out into the cement paste it is a strong indication for a deleterious reaction, see also Figure 2.

8.3 X-Ray Fluorescense Analysis

X-Ray Fluorescence Analysis (XRF) for assessment of ACR is optional [1] and based primarily on Canadian experience. When carbonate minerals are identified preferably by thin section XRF analysis on bulk sample might be carried out. Minimum elements analysed are Calcium, Magnesium and Aluminium. For the assessment of reactivity the calcium-oxide/magnesium-oxide ratio shall be calculated and the ratio plotted in a chart against the aluminium-oxide content enclosed as Figure A.2 in RILEM AAR-0 annex A (slightly modified from Rogers 1986a [4]). Two possibilities will result, namely to be "considered potentially expansive" or "considered non-expansive". In a case where the aggregate sample is assessed as "considered potentially expansive" ACR is likely and further testing is recommended e.g by RILEM AAR-5 [17] or concrete prism test e.g. [28, 32]. In a case where the aggregate sample is assessed as "considered non-expansive" ACR is unlikely, but ASR is possible and testing according to ASR should be performed e.g. according to RILEM AAR-2 [30] or other expansion tests.

Figure 3 shows XRF analyses from 288 Norwegian carbonate aggregate samples [31] calculated and plotted according to figure A.2 [1]. Note that 18 of the samples are "considered potentially expansive" and therefore potentially ACR. Most of the samples are considered non-expansive and possible ASR. ACR has at present time not been diagnosed in Norway but the chart suggests that ACR might be possible to occur in Norway too. It has to be noted that the procedures and limit values of the XRF method has to be validated or revised on carbonate rocks other than the Canadian materials.

8.4 Expansion tests

The concrete prism method CSA A23.2-14A [32] as originally was developed for alkali carbonate reactive aggregates is together with similar concrete prism methods [28, 39] today the most reliable test methods for assessing alkali carbonate reactive aggregates as well as alkali silica reactive aggregates. The disadvantage with the method is that results first can be obtained after one year testing. At present time it is uncertain if the more accelerated concrete prism method at 60 degree °C [29] can be used for alkali carbonate reactive aggregates. Accelerated mortar bar methods as e. g Rilem AAR-2 [30] and ASTM C1260 [33] is not recommended for assessing ACR. This because particles are crushed down to sand fractions and that carbonate expansion generally occur in the coarser fractions. Results have also shown decreased expansion of carbonate aggregates in mortar bar compared with concrete prism test results. The procedure in Rilem AAR-0, annex A use a combination of Rilem AAR-2 prisms for assessing ASR and Rilem AAR-5 concrete micro bar with particles 4-8 mm for assessing ACR. Other expansion methods in use are the rock cylinder test method ASTM C586 [34] and the Chinese autoclave method (150 °C) [35].

9 DISCUSSION AND CONCLUSION

The paper has presented a "state of art" on the research dealing with ACR. Today the situation is that some researcher claims that ACR not exist but is ASR. However, it is difficult to understand that the insignificant amount of alkali silica gel which generally can only be observed by use of scanning electron microscopy can be responsible for the very expansive and damaging effect in concrete alone. Other researcher believes that dedolomitization or expansion by clay minerals is the expansive force of ACR and that ASR is secondary.

Some additional mechanisms not mentioned in published papers dealing with ACR are dissolution of quartz by carbonate [36, 37]. This is a well-known phenomenon in sandstone diagenesis and is most likely also occurring in carbonate rocks containing clastic quartz grains which often are observed in carbonate rocks e.g. the Pittsburg and Kingston dolomite. Dissolution of quartz by carbonate is partially or total and dissolved silica will occur as disseminated sub-microscopic particles in the carbonate. This phenomenon is an "inherent attribute" of the aggregate causing disseminated silica, but it is uncertain that dissolution of quartz can be "accelerated" in the more basic environment in concrete. In earth-science there are indications for expansions by illite clay minerals [38] in natural earths, but it is uncertain this also will occur in a more basic environment as in carbonate aggregates in concrete.

At present time it can be concluded about the reaction of carbonate aggregates:

1) dedolomitization and derived reactions products can possibly cause expansion in concrete.
2) dedolomitization "opens" up the aggregate for ingress of constituents for ASR, rewetting of clay minerals and dedolomitization process
3) ASR in reacted carbonate aggregates have been found in the "traditional" alkali carbonate aggregates e.g. Kingston but the amount of gel is insignificant and doubtfully responsible for the expansion of concrete.
4) ASR in reacted carbonate aggregates is most likely caused by fast reactive ASR.
5) Fast reactive ASR can "maybe" explain why alkali cement, high content of slag cement and fly ash cement not can be used as preventive measure but, not why Lithium does not work.

Until the reaction mechanism is better understood the reaction of carbonate aggregates should be considered as a combined reaction of dedolomitization and alkali silica reaction. Rewetting and expansion of clay minerals in certain clay bearing carbonate aggregates and expansion by dedolomitization and derived products should be considered until more knowledge has been obtained on these issues. The reaction should be named Alkali Carbonate Reaction (ACR). A more neutral name "Carbonate Aggregate Reaction" (CAR) suggested by the RILEM Carbonate aggregate working group was not accepted by a ballot in 2009.

The suggested Rilem AAR-0, Annex A test procedures should be confirmed by more experience and testing. X-ray Fluorescent Analysis (XRF) and plots according to Rogers 1986a [4] should be documented and confirmed outside North America. Alternative chemical methods such as AAS and ICP-AES should be considered as alternative methods to XRF analysis. The mechanism of ACR is still not fully understood today and more research is needed on this issue.

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11 FIGURES

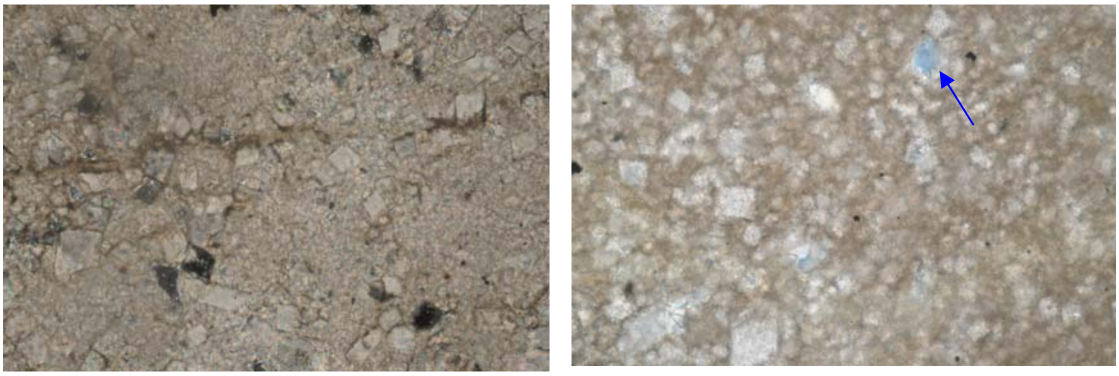

FIGURE 1: Dolomite rhombs in Pittsburg dolomite (Canada) photographed in polarized light. Photos shows dolomite rhombs and right photo also “corroded” quartz particle (arrow). Width of photos are 0.55 mm

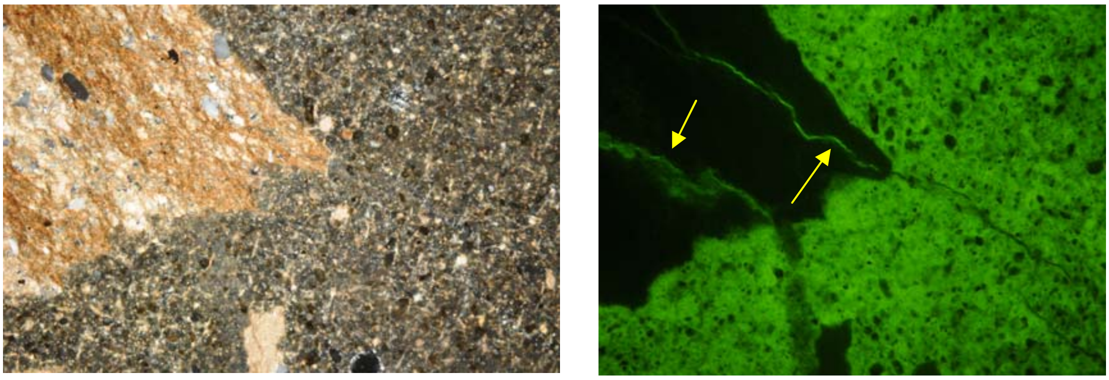

FIGURE 2: Reacted Kingston dolomite (Canada) in RILEM AAR-2 accelerated mortar bar test. Left photo photographed in plain polarized light. Note that the aggregate contains detrital quartz particles and sign of reaction is invisible. Right photo photographed in fluorescence light, same as left area. Note inter granular micro cracks (arrows) and that cracks runs into the cement paste. Width of photos are 2.2 mm

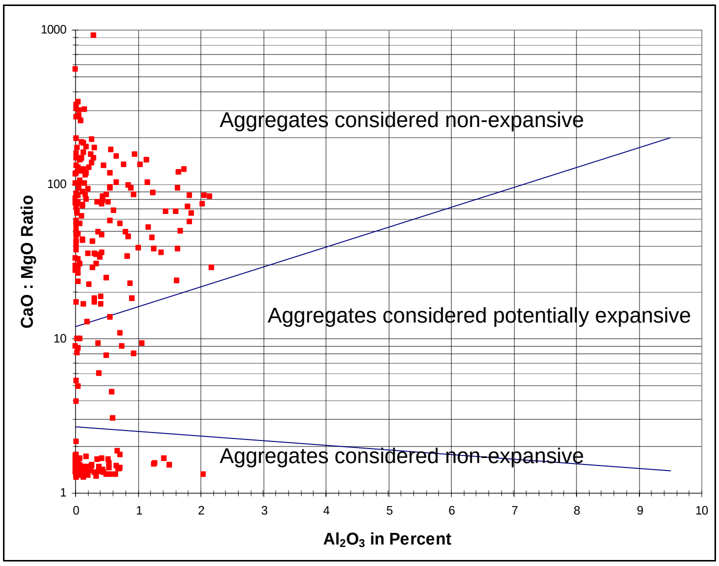

FIGURE 3. Chart for assessing potentially reactivity of carbonate aggregates with 288 Norwegian carbonate aggregate samples analysed by Korneliussen, NGU 2008 [in 31].