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**Thomsen, Hans Christian Brolin; Grelk, Bent; Barbosa, Ricardo Antonio; Hansen, Kurt Kielsgaard**

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# Alkali Release from Typical Danish Aggregates to Potential ASR Reactive Concrete



Hans Chr. Brolin  
Thomsen  
M.Sc  
DTU Civil Engineering  
Brovej, Building 118  
DK - 2800 Kgs. Lyngby  
hatho@byg.dtu.dk



Bent Grelk  
M.Sc, Chief Consultant  
Grelk Consult  
bng@ramboll.com



Ricardo Antonio  
Barbosa  
Ph.D.  
DTU Civil Engineering  
Brovej, Building 118  
DK - 2800 Kgs. Lyngby  
ranba@byg.dtu.dk



Kurt Kielsgaard Hansen  
Associated professor,  
Ph.D.  
DTU Civil Engineering  
Brovej, Building 118  
DK - 2800 Kgs. Lyngby  
kkh@byg.dtu.dk

## ABSTRACT

Alkali-silica reaction (ASR) in concrete is a well-known deterioration mechanism affecting the long term durability of Danish concrete structures. Deleterious ASR cracking can be significantly reduced or prevented by limiting the total alkali content of concrete under a certain threshold limit, which in Denmark is recommended to  $3 \text{ kg/m}^3 \text{ Na}_2\text{O}_{\text{eq.}}$ . However, this threshold limit does not account for the possible internal contribution of alkali to the concrete pore solution by release from aggregates or external contributions from various sources. This study indicates that certain Danish aggregates are capable of releasing more than  $0.46 \text{ kg/m}^3 \text{ Na}_2\text{O}_{\text{eq.}}$  at 13 weeks of exposure in laboratory test which may increase the risk for deleterious cracking due to an increase in alkali content in the concrete.

**Keywords:** Alkali-silica reaction, aggregate, alkali content, durability.

## INTRODUCTION

ASR is a complex physical and chemical reaction between water, alkali in the concrete pore solution and reactive silica minerals in aggregates [1]. The reaction demands an alkaline environment which is found inside the concrete where a natural presence of free calcium hydroxide is found. The product of ASR is a hygroscopic gel which expands in volume resulting in internal pressure which can lead to extensive cracking in concrete structures. ASR cracking affects significantly the durability and the mechanical properties of the concrete. Furthermore, the formation of ASR cracking may enhance the effect of other concrete degradation mechanisms such as carbonation, frost action and reinforcement corrosion.

Preventing deleterious ASR in future concrete structures is an important aspect and can be achieved by controlling the three main components which are necessary to initiate and sustain ASR in concrete. Controlling the total alkali,  $\text{Na}_2\text{O}_{\text{eq}}$ , content is one way of doing so. To prevent ASR in concrete Danish regulations recommend that the total  $\text{Na}_2\text{O}_{\text{eq}}$  content, for a given concrete mix, is kept below  $3 \text{ kg/m}^3$  of concrete [2]. However, this threshold limit does not consider an alkali contribution from external sources or internally from the aggregates. The results from previous Danish studies, connected to the construction of the Great Belt Bridge, indicated that some Danish aggregates potentially may release alkali when subjected to an alkaline environment, as in concrete [3]. This present study investigates the release of alkali from typical Danish aggregates according to the RILEM AAR-8 method [4].

## 1. MATERIALS

Three different Danish aggregate types were tested in accordance to the RILEM AAR-8 method: sand from marine deposits, sand from inland deposits and crushed granite from Rønne, Denmark. The fourth aggregate type, pure quartz sand, is applied as a reference material due to its simple composition and also to validate the test method. According to RILEM AAR-8 method fine material is tested in their natural grain size distribution where particles larger than 4 mm are discarded. Natural coarse aggregates are crushed, graded and combined in a specific grain size distribution described further in RILEM AAR-8 [4].

## 2. RILEM AAR-8 METHOD

RILEM AAR-8 is a draft method used for estimating the releasable alkali content of aggregates used in concrete. The aggregates of interest are prepared according to [4] and two test solutions are made to study the release of sodium and potassium separately. One solution has an initial high content of sodium and is used to observe the release of potassium. The other solution has an initial high content of potassium and is likewise used to test the release of sodium. Both solutions are saturated with calcium hydroxide which is similar to the concrete pore solution. The release tests are initiated by submerging the aggregates into the two different extraction solutions. The change in alkali content is measured at given predefined time steps by use of Inductively Coupled Plasma (ICP). RILEM AAR-8 suggests that the release of alkali is studied for both an exposure temperature of  $38^\circ\text{C}$  and  $60^\circ\text{C}$ .

## 3. RESULTS AND DISCUSSION

Fig. 1 shows the release of alkali  $\text{Na}_2\text{O}_{\text{eq}}$  as a function of temperature and exposure time. The individual contribution from  $\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}$  to the summarized  $\text{Na}_2\text{O}_{\text{eq}}$  content for Rønne granite after 13 weeks of exposure and a temperature of  $60^\circ\text{C}$  is 61.5 % and 38.5 % respectively. The RILEM AAR-8 method suggest a total exposure time of at least 56 weeks or until reaching equilibrium of released alkali. This is not achieved for the present results thus the final releases for some aggregate types are expected to increase with increasing exposure time. Quartz sand and sand from inland deposits are absorbing alkali or having a very low rate of release. However, there seems to be an increase in alkali release from aggregates after 6 weeks and forward. The main composition of quartz is silicium and oxygen hence a release of alkali in the region of zero is expected. The large difference in alkali release for marine and inland sand is unknown, however the results might suggest that marine sand contains larger portions of alkali rich particles than inland sand thus releasing more alkali when tested. All aggregates are firmly washed in distilled water before testing which means that the difference in alkali release is not due to a surplus of marine salts from the surface of the aggregates. The inland sand is known to

contain porous opaline or calcareous opaline flint which is highly ASR reactive. The formation of ASR in the test solution with inland sand is therefore plausible. An alkali consumption might take place which lowers the free alkali content in the extraction solution. This hypothesis is however not further studied. Rønne granite is releasing large portions of alkali which is expected due to the presence of alkali rich minerals such as mica and alkali feldspar.

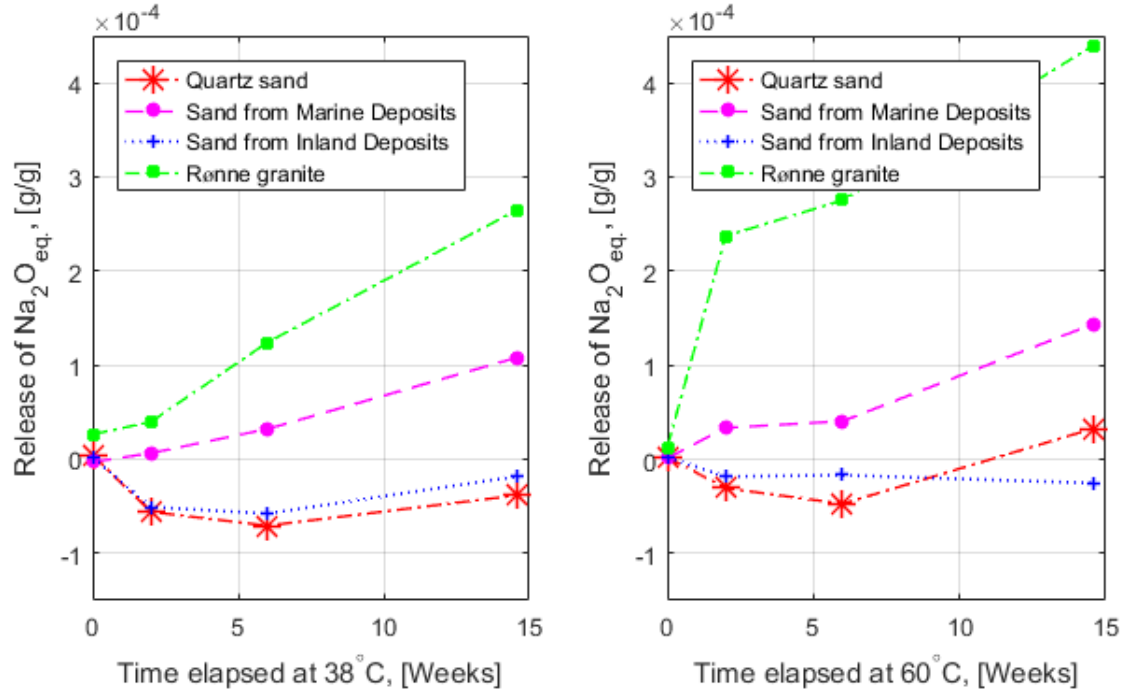


Figure 1 Release of  $\text{Na}_2\text{O}_{eq.}$  for three typical Danish aggregates and quartz sand according to RILEM AAR-8 method where two different exposure temperatures are used, The result is presented as grams of released alkali pr. gram of aggregate at 38°C (left) and at 60°C (right).

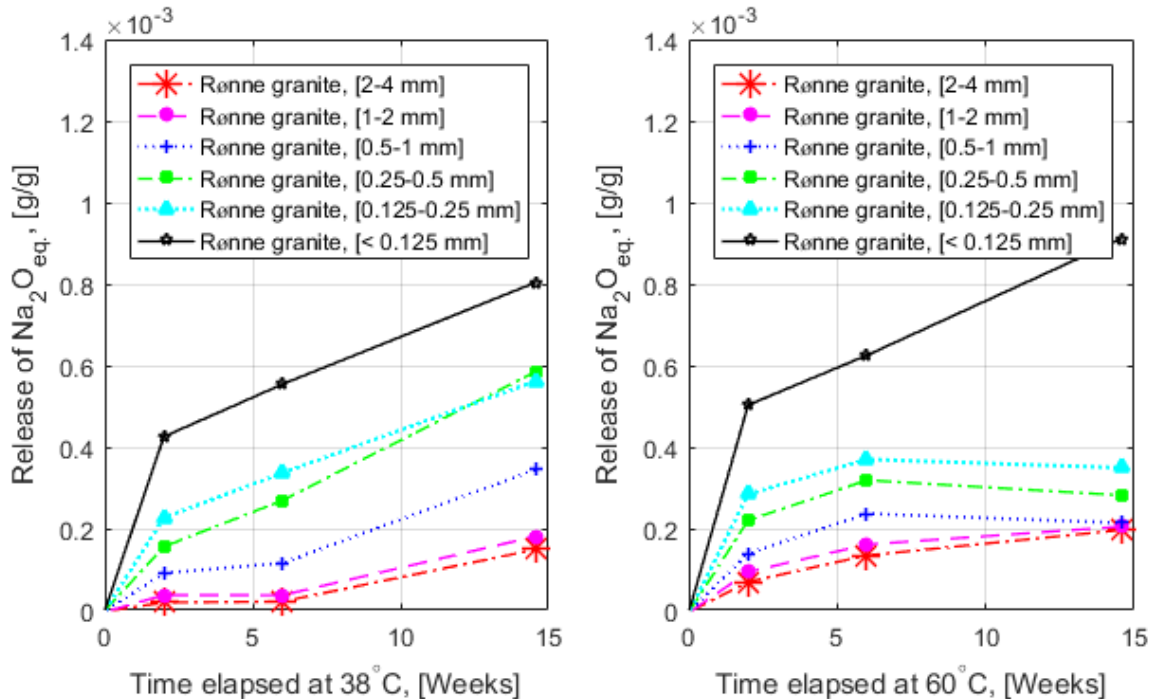


Figure 2 Release of  $\text{Na}_2\text{O}_{eq.}$  for 6 fractions of Rønne granite according to RILEM AAR-8 method where two different exposure temperatures are used, The result is presented as grams of released alkali pr. gram of aggregate at 38°C (left) and at 60°C (right).

Rønne granite, fraction 4-8 mm, is grinded and divided into six sieve grain sizes to investigate the rate of release and grain size. Fig. 2 shows the release of alkali for the six graduations of Rønne granite as a function of temperature and exposure time. Smaller grain size are equal to a larger specific surface area. Fig. 2 show that smaller grain sizes result in considerable more release of alkali than larger grain sizes. The contact area between solution and grain is increased with larger specific surface area hence larger amount of released alkali was expected for smaller grain sizes.

Fig. 1 indicate that higher temperature results in higher release of alkali for 13 weeks of exposure time. However, Fig. 2 show contradictory results. Fig. 2 shows that a faster convergence is found for higher temperatures but the total amount of released alkali is larger for lower temperatures and is still increasing after 13 weeks measurement. This implies that exposure temperature is affecting the release of alkali and also that testing aggregates outside their natural temperature range might give a false image of the releasable alkali content. Apparently, increasing the temperature is not always a conservative approach and one should also consider dynamic temperature exposure for more realistic extraction conditions.

The release curves presented in Fig. 1 is used to estimate the expected contribution of alkali to one cubic meter concrete. RILEM AAR-8 method suggests that a standard concrete consist of  $700 \text{ kg/m}^3$  fine and  $1050 \text{ kg/m}^3$  coarse aggregates. This yields an expected contribution of  $0.46 \text{ kg/m}^3 \text{ Na}_2\text{O}_{\text{eq}}$  for Rønne granite at an exposure temperature of  $60^\circ\text{C}$ . This representation of the alkali release is directly comparable to the alkali threshold limit of  $3 \text{ kg/m}^3$ . It should be noted that this estimation is based on 13 weeks measurement where the experiments have not reached equilibrium and are still in the process of releasing alkali. However, it may be questioned if the same rate of alkali release could be expected inside the concrete which is a stationary condition surrounded by cement paste. The aggregates tested by the RILEM AAR-8 method are surrounded by liquid implying that the release of alkali may be accelerated for the test method yielding an overestimation of the potential release rates in the concrete.

#### 4 . CONCLUSION

The scope of this study was to test whether one can expect a release of alkali from typical Danish aggregates or not. RILEM AAR-8 was applied and the results indicate that Rønne granite is capable of releasing more than  $0.46 \text{ kg/m}^3$  alkali in only 13 weeks of extraction. The release of alkali from aggregates is dependent on the specific surface area where a larger specific surface area is enhancing both the rate of release and the total release of alkali. The effect of having different exposure temperatures is indicating that it is not always conservative to test aggregates at higher temperatures. This draws the conclusion that aggregates should be tested in a realistic temperature domain for which suits the location of where the aggregates are supposed to be used.

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