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Finland's Emerging Alkali-Aggregate Reaction Problem?

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ABSTRACT

Finland is known as a country having very durable granitic aggregate that is used in a wide range of construction applications. Yet recent field results from existing concrete structures have shown evidence of alkali aggregate reactions (AAR). In Finland there is a need to have a better understanding of what causes AAR and from what aggregate sources, how to identify it or separate it from other deterioration mechanisms and guidelines about how to avoid AAR in future construction. This paper shares information about a few of the Finnish structures where AAR has been detected.

Key words: deterioration, durability, alkalinity, aggregate, alkali aggregate reaction

1. BACKGROUND

Certain aggregate types have a high risk of dissolution when interacting with the alkalis released during the hydration of portland cement. In wet conditions, this reaction causes a gel around the aggregate particles that can crack the concrete and provide further paths for deleterious materials. The reaction is referred to as Alkali Silica Reaction (ASR) for concrete or aggregate containing silica, or more commonly Alkali Aggregate Reaction (AAR). It has often believed that the chemical reaction between Finnish aggregates and their surrounding environment is quite low. In this regard, the risk of AAR has been considered negligible in Finland. Yet recent in-situ structural concrete assessments have shown otherwise.

The three conditions required for AAR to occur include: 1) reactive silica (from aggregate), 2) sufficient alkalis (mainly from portland cement), and 3) sufficient moisture. Without a high moisture content (>80% RH), ASR will not occur. Higher temperature also accelerates AAR. Thus southern European climates often report a much higher incidence of AAR in concrete compared to Nordic environments. In Finland, the highest risk environment would be a very moist and warm environment, exemplified by modern indoor spa and pool facilities. Exterior concrete structures in Finland are also at risk of AAR, though the deterioration may take longer to appear. On the other hand, concrete exposed to a permanently dry or a heated indoor environment is considered not at risk of AAR, independent of aggregate type or binder composition.

The rate of AAR reaction is also very dependent on an aggregate's geological composition. The first sign of an AAR problem is usually random- or map-cracking on the concrete surface caused by excessive internal expansion. Internally, the gel causing the internal expansion can dry to form a white amorphous deposit, apparent as a reaction rim around individual aggregate particles. In addition to the aesthetic problem, such fractures and expansion due to AAR further accelerate other deterioration mechanisms, such as chloride ingress and/or frost damage. The structures most at risk for AAR damage are bridges, hydraulic structures, exposed frames (i.e. open multi-storey car parks) and foundations.

The reason why AAR has become a problem in recent years is because of changing materials, such as binders with higher alkalis and use of different aggregate sources, and also that we have better tools to identify when AAR is occurring. We have understood that in many cases in Finland it has been difficult to differentiate between damage initiated by frost action or AAR, especially because it is widely believed that AAR does not occur in Finland. In both cases the result that can be seen in the field is cracking on the surface of a structure. On the basis of crack patterns, a skilled person can make a quite good estimate on the cause of cracking. And sometimes it is possible to even see AAR gel that has moved out to the exposed concrete surface. This is the most distinguishing factor between frost damage and AAR: the appearance of gel within interior cracks. In frost damage, the cracking is normally heaviest near the surface and weakens deeper, whereas in AAR the reaction causes expansion inside the structure causing a homogeneous cracking network in the whole structure. In this way AAR can be more harmful than frost action. The only way to identify AAR from an existing structure is analyze the interior of the concrete, such as by petrographic analysis.

The suggested routes for testing the potential risk of AAR when selecting materials for new construction are: 1) petrographic analysis of aggregate alone, 2) accelerated expansion test of mortar bars (14 day test, i.e. by RILEM AAR-2 or ASTM C1260), or 3) one year expansion test of concrete prisms (i.e. by RILEM AAR-3 or ASTM C1293).

Figure 1. Areas in Finland where AAR has been found in structures.

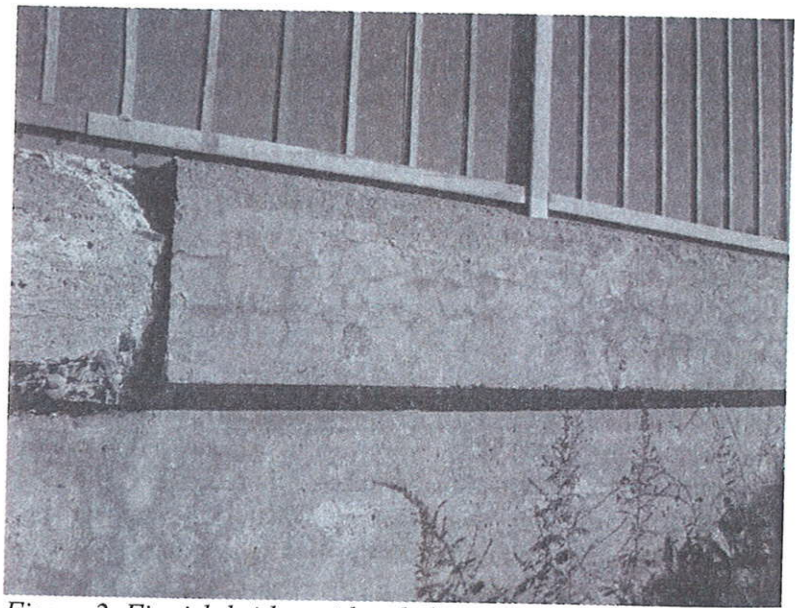

Figure 2. Finnish bridge with side beam having signs of AAR.

2. FINNISH EXPERIENCE

The geology of Finnish bedrock and soil is well studied and therefore there is a good general view of the composition of aggregates in different parts of Finland. This helps to estimate the potentiality of AAR. Though earlier not viewed as a deterioration concern, AAR has been found more recently in Finnish bridges when investigating other types of deterioration attack, such as chloride ingress and frost-salt exposure.

AAR in Finnish structures has been investigated at VTT by the use of petrographic thin section microscopy. Such studies have been integrated with studies of in-service structures for 25 years. It is during the past 10 years that AAR has been identified in about 10 bridges from various locations around Finland (Figures 1 and 2). This represents about 2 % of all concrete durability assessments by thin-section microscopy on bridges done at VTT in the past 10 years. In these cases the level of damage varies from low to high. Often the role of AAR has been smaller than the role of other damaging forces. In 2 – 3 of these cases, AAR has played a major role. In these cases initial thin section studies gave a warning about high levels of AAR and a heavier damage than was recognized on site. The studies were completed with additional thin section studies, where strong AAR was found on the bridge decks. Bridge decks are more favoured to AAR than other structures (like columns), because of the use of de-icing salts and occurrence of rain that pools on the decks.

The age of Finnish bridges where AAR has been found has varied from 31 years to over 50 years. In most cases the age of the bridge has been between 40-50 years when studied. AAR has not been found in bridges under the age of 30 years. In general frost action is the most important damaging force in Finnish exposed structures, yet when it hits together with AAR, severe damage is to be expected.

The appearance of AAR has been seen in thin section studies as a gel in the interfacial transition zone between the cement paste and aggregate, as well as in gel filling in cracks running from the reacted aggregates as a result of expansion and as cracked aggregates (Figure 3). The appearances are in-line with international guidelines [1]. During one petrographic study at VTT, it was even possible to see clear AAR gels coming out from the cored concrete surface a few days after the samples were taken.

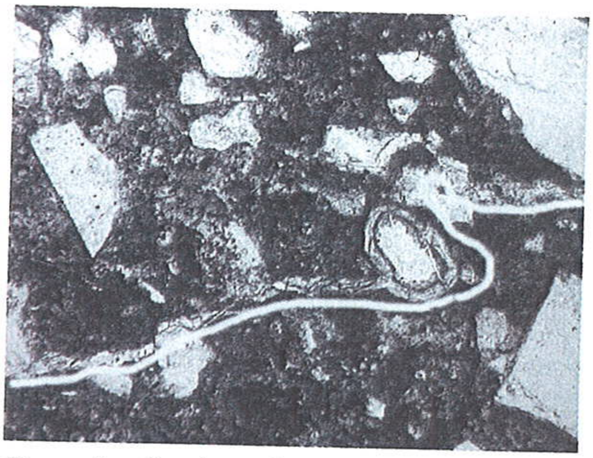

Figure 3a. Cracks and AAR gel in concrete (marked with yellow) from a Finnish bridge.

Figure 3b. Cracks and AAR gel in concrete from a Finnish paper mill.

In Finland AAR is more connected to certain rock types than to certain geographical areas. The Finnish rock types associated with AAR are in most cases fine grained stressed and strained mica bearing quartz rich shists and quartzites. The grain size is very often under 0.1 mm. Also some fine grained cataclastic and other rock types have shown AAR. In these cases the AAR is dependent on the structure of the quartz.

In addition to bridges, AAR has also been found in other Finnish structures. For instance, AAR has been seen in industrial indoor structures where the conditions are favoured, i.e. the temperature is high (even 30-40 °C) and the relative humidity is high. In the case of a Finnish swimming pool and in a paper mill (Figure 3b), the concrete structures have been wet during the use or manufacturing processes respectively.

3. FUTURE

Looking towards the future, there is a risk that AAR in Finnish concrete structures will continue to be found and could potentially accelerate. This could be a costly problem for real estate and structural owners if it is not addressed.

Our concrete industry knows that it is becoming necessary to use new aggregate sources of potentially lower quality. Recycling concrete and building materials may become more common as landfill costs rise. Use of new or alternative binders and cements with higher alkali contents will also have an affect on AAR risk. It is necessary for Finland to have knowledge [2] and guidelines about how AAR may contribute to structural durability as our construction practice adopts concrete materials with a wider range of properties.

The future needs for minimizing AAR in Finland include:

- geological mapping where potentially reactive aggregate are located in Finland.
- concrete structural mapping of locations where AAR has been found in Finland. This could also include identifying the concrete mix design and aggregate sources in these locations, if known.
- assessing test methods that can be used for AAR, with Finnish materials.
- clearly defining how to distinguish AAR from other deterioration mechanisms.
- establishing acceptance limits for AAR test results.
- educating concrete owners and testing companies on how to identify AAR.
- educating the concrete industry on how to avoid AAR.

It is hoped that by establishing guidelines about how to identify AAR and set limits on concrete material properties, it will be possible for Finnish concrete designers and owners to make well informed choices about mixture design and aggregate sources during the material specification and acceptance stages to minimize AAR risk. AAR in Finland is a deterioration risk that can be avoided but also should not be ignored.

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