

## ASSESSING THE EXTENT OF AAR IN FINLAND

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### Abstract

Finland has typically been considered a country with very durable granitic aggregate that is used in a wide range of construction applications. In general, the chemical reaction between Finnish aggregates and their surrounding environment is usually quite low. In this regard, the risk of Alkali Aggregate Reactions (AAR), where the alkalinity of concrete harmfully reacts with certain aggregates to cause expansion and cracking, has been considered negligible in Finland.

However, when investigating reinforced concrete infrastructure in Finland for other types of deterioration attack, such as chloride ingress and frost-salt exposure, AAR has been found. AAR deterioration is limited to certain rock types. 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. AAR has been investigated at VTT - Technical Research Centre of Finland by use of petrographic thin section microscopy. This paper shares the findings of 25 years of review from in-service structures, with respect to ASR findings.

In addition, as new alternative hydraulic binders and aggregate sources (including recycled materials) are used in future concrete production, the mechanisms and risks of AAR need to be addressed in Finnish practice. The hope is that by initiating open discussions within Finland and abroad, the potential risk of future AAR deterioration can be evaluated and a process to handle AAR can be created to ensure concrete durability and service life of our structures.

**Keywords:** deterioration, durability, alkalinity, aggregate, alkali aggregate reaction

### 1 INTRODUCTION

In Finland, the construction industry widely believes that there is no AAR. The reasons for this are that: i) the aggregate commonly used originates from very high quality granitic rock; ii) the very extreme meteorological conditions favour the delay in visual detection due to the effect that the very cold climate has on the chemical reaction rates; iii) AAR has traditionally been left out of academic curriculum so engineers are not knowledgeable concerning it; iv) the visual manifestations of the AAR degradation mechanism are very similar to those of frost attack, and therefore it is possible that the problem has in many cases been erroneously diagnosed.

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While historically there have been no well-publicised cases to contradict the general belief that AAR does not occur in Finland, recent findings when investigating reinforced concrete infrastructure for other types of deterioration attack, such as chloride ingress and frost-salt exposure, have also identified the occurrence of AAR. There is the possibility that AAR will become a problem in the near future because of changing materials, such as binders with higher alkalis and use of alternative aggregate sources, but also because better and more sophisticated tools to identify the occurrence of AAR are available. Also much of the infrastructure in Finland has been built during and after 1970's, and these structures are now coming to the age where AAR has been found. The authors suspect that a mixture of extreme climate and favourable geology have helped keep AAR undetected for so long. However, the ever aging infrastructure is beginning to show more and more signs.

This paper is written with the intent of informing the scientific community that AAR also occurs in Finland. The several cases that have been identified provide evidence of its occurrence. There is no understanding yet as to reason of its manifestation, nor of the extent of potentially damaged infrastructure at a national level. Therefore, it is imperative that both the causes and the level of widespread damage of reinforced concrete infrastructure due to AAR in Finland be addressed.

## **2 BACKGROUND**

### **2.1 Geology, climate and exposure conditions**

#### *Geology*

In Finland the bedrock is mainly made of Precambrian plutonic and metamorphic rocks. The occurrence of sedimentary rocks is marginal and also these rocks are of Precambrian age. The metamorphic rocks are different metavulcanites, gneisses, schists and quartzites and they are often highly metamorphosed folded. The very old bedrock is covered by soil from the latest ice age, about 10000 years ago, so there is a wide time gap between these two. The soil represents well the composition of the underlying bedrock. Granites and granodiorites are the most common rock types in the bedrock and soil in our country and for this reason Finland is known as a country having very durable granitic aggregate that is used in a wide range of construction applications.

From a geological point of view, there is very much in common with Finland and its neighbour Sweden. In both countries the bedrock is mainly made of Precambrian rocks (Figure 1). This is, in itself, quite an important aspect because Sweden has acknowledged the existence of AAR already for 20 years ago [1] and has addressed this problem accordingly.

As mentioned 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. 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 (Figure 2). Also some fine grained mylonitic, cataclastic and other rock types have shown AAR. In these cases the AAR is dependent on the structure and size of the quartz.

#### *Climate and exposure conditions*

Finland has a humid and cool semi continental climate, characterized by warm summers and freezing winters. The climate type in southern Finland is a northerly temperate climate, with an average January temperature of -4°C in the Helsinki region and -14°C in Lapland. Winters of southern Finland (average day time temperature < 0°C/32°F) are usually 4 months long. The main factor influencing Finland's climate is the country's geographical position between the 60th and 70th northern parallels in the Eurasian continent's

coastal zone, which shows characteristics of both a maritime and a continental climate, depending on the direction of air flow. Finland is near enough to the Atlantic Ocean to be continuously warmed by the Gulf Stream, which explains the unusually warm climate considering the absolute latitude cracks [2]. As a consequence of this climate, concrete infrastructures are subjected on average to approximately 70 freeze-thaw cycles yearly (data for 2007-2010) [3]. Northern Finland has a harsher climate, though the number of freeze-thaw cycles is about the same. The cycles are concentrated in the spring and fall, while in the capital region of the south they occur through-out the winter period.

Many economically significant industrial facilities (i.e. pulp and paper factories) and public services (pools, spas, etc.) are obliged to create artificial environments to guarantee the continuation of their activity throughout the year, resulting in high risk environments where concrete structures are often very moist and warm. Exterior concrete structures in Finland are also at a risk of AAR, though the deterioration may take longer to appear. The cold climate slows the chemical reaction rate involved in AAR.

## 2.2 Typical infrastructure and concrete materials

The structures most at risk for AAR damage in Finland are bridges, highway passes, dam structures, exposed frames (i.e. open multi-storey car parks), foundations, and many types of industries (pulp and paper factories, nuclear energy, power generation, water management, etc.) with concrete infrastructure.

The Finnish concrete industry is estimated to have turnover of about 700 million euros per year, with cement production about 1,5 million tons/year. Even with a cold climate, construction proceeds year-round. This is accommodated by an industry highly dependent on pre-fabrication factories, as 47% of concrete is delivered as precast elements and 31% is ready-made concrete [4].

The common bridge concrete mixes in Finland are characterized by a water/binder ratio of 0.40 to 0.55, typically with 5% air and a design compressive strength class of 35-45MPa. The most common cement type is classified as CEM II/A\_M(S-LL) 42,5 N, which contains up to 10% interground limestone or slag and a Blaine fineness of 370-440 m<sup>2</sup>/kg. Finnish practice allows for relatively high amounts of mineral by-product additions to concrete, with blast furnace slag and fly ash readily available. Sulphate resistant cements are also produced and used in some cases. The Na<sub>2</sub>O<sub>EQ</sub> of Finnish cements is typically around 1.0%.

## 2.3 Assessment of AAR in Finland

It is the authors' understanding that in many cases 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. The result that can be seen *in situ* is cracking on the surface of a structure, either as a map-pattern or aligned due to constraints. In Finnish practice the near surface is the area from which cores are typically taken. Historically, field deterioration studies have often neglected to take deeper cores to consider if AAR was the cracking cause. In addition, the AAR-induced cracking can also be affected by restraint, leading to aligned cracking. 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 [5]. However, the gel can also be leached from the cracks. In frost damage, the cracking is normally heaviest near the surface and weakens deeper, whereas in AAR an internal reaction causes expansion from within the structure causing a homogeneous cracking network in the whole structure. In this way AAR can be more harmful than frost action.

Typically, the assessment of a potential AAR problem begins with core extraction from an existing structure and the corresponding Petrographic Examination, according to a modified ASTM C856-11 [6], to identify the rock and mineral types that comprise the coarse and fine aggregates. Petrographic Examination

may require in-depth analyses including thin-section/polarized microscopy, SEM, XRA and XRF among others. AAR in Finnish structures has been investigated at VTT by the use of petrographic thin-section/polarized microscopy. Such analyses have been integrated with studies of in-service structures for 25 years.

### **3 CASES OF AAR IN CONCRETE – THE PROOF**

It is during the recent years that AAR has been identified in about 10 bridges from various locations around Finland (Figure 4). This represents about 2 % of all concrete durability assessments by thin-section microscopy on bridges done at VTT in the past 10 years. Other structures, like facades, piers, factory buildings and some swimming pools have also been studied. In the following, some thin section examples from different types of concrete structures are presented.

#### *Bridges*

Bridges from all over the country have been studied. The greatest number of those are however located in southern Finland and near bigger cities. The findings of AAR are distributed around the country as shown in Figure 3. 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 (Figure 4a).

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 4b). The appearances are in-line with international guidelines. During one petrographic study at VTT, it was even possible to see clear AAR gel coming out from the cored concrete surface a few days after the samples were taken.

#### *Industrial structures*

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. One example is a paper mill from early 1970's, where conditions are favoured to AAR; temperature is around 40°C and the concrete structures wet during the use or manufacturing processes. In here AAR was found in a cataclastic medium to fine grained schist (Figure 4).

#### *Other structures*

In addition to bridges and industrial structures hundreds of facades and balconies have been studied, but only in some cases AAR has been found. In these cases the aggregate used proved to be from abroad.

Finnish indoor swimming pools and spas have moist and warm conditions and are potential risk structures of AAR. The number of these structures studied so far is low, and no significant damage caused by AAR has been found yet.

### **4 PROSPECTS FOR THE NEAR 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 in a timely manner.

The Finnish 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 the AAR risk. It is necessary for Finland to have knowledge and guidelines about how AAR may contribute to structural durability as our construction practice adopts concrete materials with a wider range of properties. Some steps have been initiated to educate the Finnish construction industry about the risks of AAR and need for research [5,7].

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.

## 5 CONCLUSIONS

This paper is written with the intent of informing the scientific community that AAR also occurs in Finland. While AAR is thought not to be an extensive problem in Finland, no specific inspection program has been undertaken to confirm this. It is not yet possible to define the extent or severity of the reaction in Finland. Several cases that have been identified where AAR is presented, of which, some have been presented and discussed.

It is therefore imperative that both the causes and the level of widespread damage of reinforced concrete infrastructure due to AAR in Finland be addressed.

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