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Aar in Precast Concrete Wall Elements

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Abstract

This paper investigates defects (pop-outs) in precast concrete facade, caused by Alkali-aggregate reaction (AAR) on insulated wall elements, which were produced in Lithuania and shipped to Sweden. Links between climate data and AAR were found, samples from the site taken and studied with optical microscope. Information about concrete composition, aggregate granulometry and AAR risk discussed. Finally, possible AAR preventive measures for such production technique discussed and repair of the facade described.

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1. Introduction

1.1. AAR in Lithuania

Lithuania has a long history with alkali-aggregate corrosion of concrete. First cases were reported during 1969-1975 in precast concrete elements for residential construction (walls and floor slabs). Scales sizing from 1 to 5 centimeters started to pop out from the surface of concrete and whitish thick liquid was leaching to the surface, forming dripstone on the ceiling [1]. This process damaged facing of interior walls and stopped only after concrete was fully dry. On 1997 in depth investigation of AAR was finished in Kaunas Technological University by

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Gumuliauskas A. and Navickas A. and all aggregate quarries of Lithuania were checked for reactive aggregates [2,3]. Same year, Lithuanian standard for evaluating quantities of reactive SiO_2 in aggregates was released [4]. Researches showed, that average quantities of reactive SiO_2 (mostly Opoka and some Flint) in Lithuanian aggregate quarries do not exceed 2% for coarse and 4% for fine aggregates. Important to note, that there are national requirements in Lithuanian concrete standard LST 1974:2012, stating that equivalent content of Na and K oxides $((\text{Na}_2\text{O})_{\text{ekv}} = \text{Na}_2\text{O} + 0.658\text{K}_2\text{O})$ in CEM I should be less than 0.8% (by mass) and in the concrete mix should not exceed 3 kg/m^3 .

If above mentioned requirements for alkaline content are met, there is no risk for major map cracking or decrease of compressive strength due to AAR in concrete with aggregates from quarries of Lithuania. But pop- out defects are quite common in concrete floors [5] and in some cases occur in external layer of precast concrete wall elements. Such case was reported on 2013 in Sweden, city Hellsinborg on precast concrete wall elements which were manufactured in Lithuania and delivered to Sweden (Fig. 1). Defects were investigated and are described further in this paper.

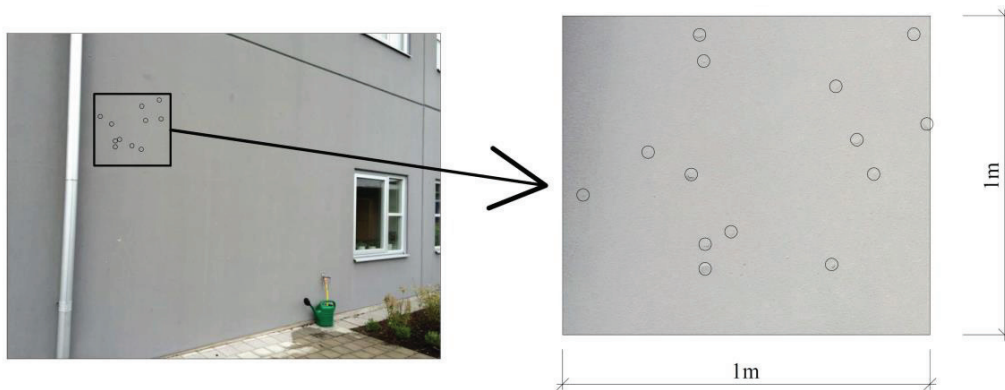


Fig.1. Defects in external layer of precast concrete insulated wall elements

1.2. Principles of AAR

Alkali- Aggregate Reaction (AAR) is one of the main concrete corrosion mechanisms, leading to structural and aesthetical damage throughout the history of Portland cement [6]. The reaction forms a hygroscopic gel which imbibes water and swells. The swelling forces generated may be sufficient to disrupt aggregate particles and the surrounding concrete, causing expansion and cracking [7-9].

For AAR reaction to start in concrete, three conditions must be satisfied: presence of potentially reactive aggregates; high alkali concentration in the concrete pore solution, and high humidity of the environment [10].

Minerals, present in the aggregate react with ions (OH^- , Na^+ and K^+) from hydrated cement paste, forming a hygroscopic gel that expands by uptake of moisture. Water is released and the cations (Na^+ and K^+) attracted to counterbalance the negative charges, forming Siliceous gel. Calcium ions are also involved in reaction [11]. The product of reaction is alkali- silica gel, composed of Na, K, Ca and Si, which forms around and within the aggregate (figure 2). Alkali silicate reaction is accumulated in the aggregate to give an expansive pressure enough for cracking the aggregate and the surrounding concrete.

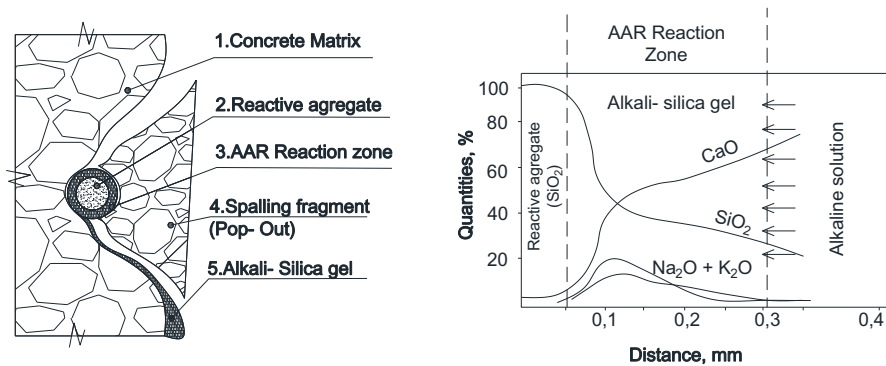


Fig.2. Alkali- aggregate reaction.

Left: Pressure build-up around reactive aggregate; Right: AAR reaction zone [1]

2. Composition and methods for investigation

Tests have been conducted in order to determine causes of defects in wall elements (figures 3, 4) Wall elements for Helsingborg project were produced and assembled in mid- summer of 2011. AAR defects reported in the spring of 2013. Sizes of walls are around 7m by 3m and up to 100 pop- outs found on some of the elements. Defects are on all facades of the building, they do not show any connection with cardinal points. Cross section of elements is shown in figure 5.



Fig.3. Maximum size of scales- about 30mm



Fig.4. Maximum size of reacted aggregate- 4-5mm

Concrete mix, used for external layer of concrete was C30/37-XC4-XF3-CI0.1-Dmax16-S2 with water/ cement ratio 0,45. Size of coarse aggregate was 4/16 and 0/4 for fine aggregate. All aggregates were produced in local quarries of Kaunas city. Granulometric composition of aggregates is shown in figure 10. As a binder, CEM I 52,5R with equivalent alkali content less than 0.8% ($(\text{Na}_2\text{O})_{\text{ekv}} = \text{Na}_2\text{O} + 0.658\text{K}_2\text{O}$ by mass) was used, and total amount of alkali was 2.9 kg/m³ for whole concrete mix.

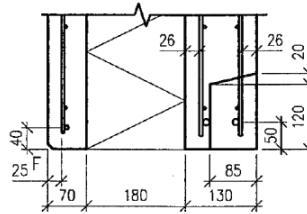


Fig.5. Cross section of insulated precast concrete wall elements

According to sieving tests, about 60% of particles in fine aggregate are between 0,25 and 1 mm and about 25% of them are between 1 and 4 mm. For coarse aggregate, 50% of particles are between 5 and 10 mm, and 45% are over 10mm (Figure 6.). Field tests showed that pop- outs happened due to reactive particles, that are mostly about 5mm, which brings us to a conclusion, that the main source of AAR was the coarse aggregate.

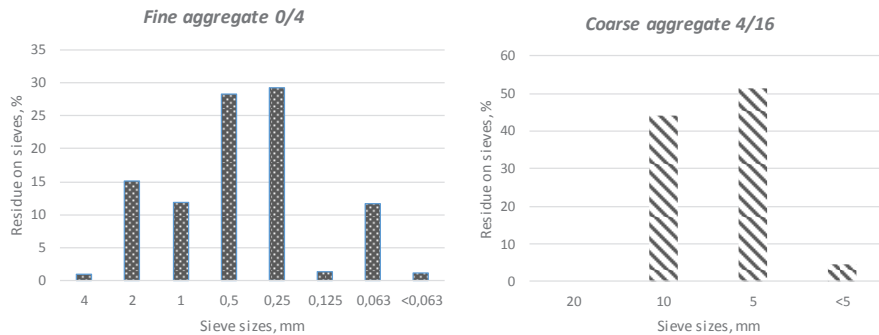


Fig.6. Granulometric composition of aggregates

Scales were collected from the building site and at first examined visually (figure 6), indicating reacted particles. The enhanced top layer of the surface of specimens was checked for signs of Silica gel with HIROX RH-2000 optical microscope and using electron microscopy (SEM), with microscope JEOL 7600F, resolution of which is 1nm.

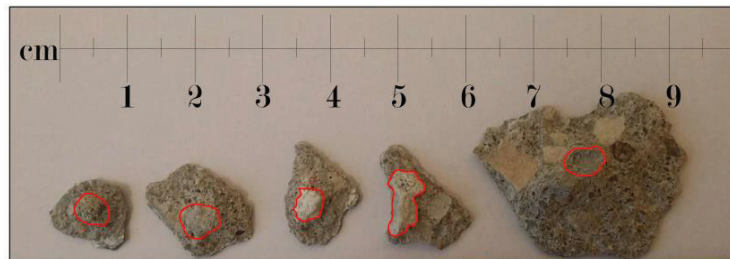


Fig.7. Scales with SiO₂ reactive aggregates

3. Results and discussion

3.1. Climate data compared

In Lithuania, about 20-30 % of total precast concrete elements are exported to Scandinavia, mostly Sweden. For evaluation of AAR, it is important to know the climate differences between two countries. Helsingborg is in South-West part of Sweden, on the shore of North Sea, facing to the Danish kingdom. The climate here is mild, and generally warm and temperate. There is a great deal of rainfall in Helsingborg, even in the driest month. The Köppen-Geiger climate classification is Cfb (Temperate/mesothermal- Without dry season- Warm summer). In Helsingborg, the average annual temperature is 7.8 °C. About 668 mm of precipitation falls annually [12].

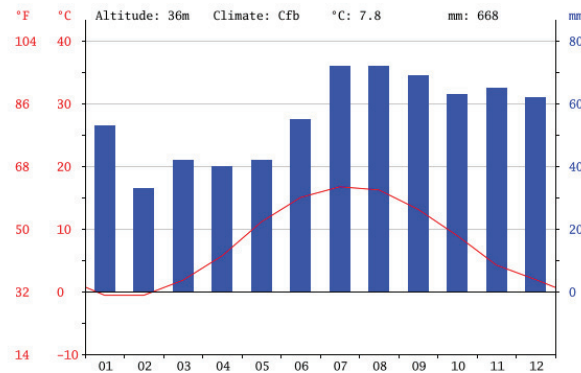


Fig.8. Average monthly rainfall (in columns) and temperature (curve) data of Helsingborg city, Sweden.

In Kaunas, the climate is cold and temperate. There is significant rainfall throughout the year. Even the driest month still has a lot of rainfall. The climate here is classified as Dfb (Cold (Continental)- Without dry season- Warm summer) by the Köppen-Geiger system. In Kaunas, the average annual temperature is 6.6 °C. About 614 mm of precipitation falls annually [12].

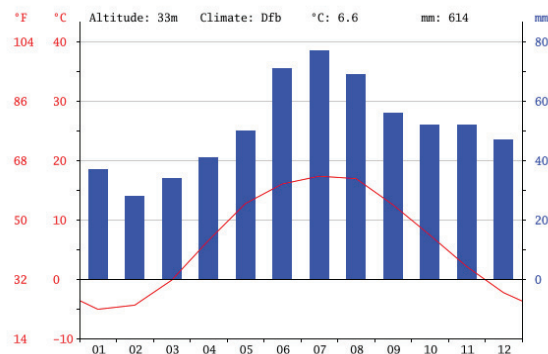


Fig.9. Average monthly rainfall (in columns) and temperature (curve) data of Kaunas city, Lithuania.

From temperature and precipitation graphs we can see, that in Helsingborg there is much more precipitation during 9-12 months and temperature is around 0°C during first 3 month of year (figure 8), when in Kaunas

temperature is around -5°C during January-March (figure 9). This shows, that environment for AAR to happen is more suitable in Helsingborg than in Kaunas, because moisture and warm temperature are the key features for AAR.

3.2. Examination of scales

During examination, it has been determined that local defects appear in the external layer of insulated precast concrete walls due to reactive SiO_2 particles in fine aggregate, that are located near the surface. Optical microscopy allowed to identify traces of reaction products- silica gel, which is around the aggregate (Figures 10 and 11).



Fig.10. Traces of silica gel found with optical microscope

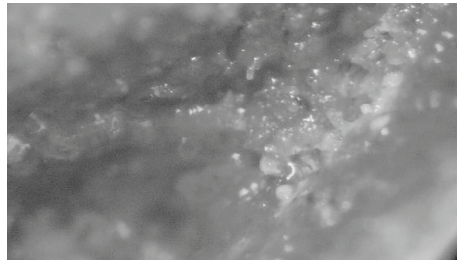


Fig.11. Porous glassy structure of silica gel (SEM test)

Reaction zone is very porous and consists of big amounts of glassy silica gel, which is a result of chemical reaction between alkaline compounds, found in cement and reactive siliceous aggregates. Semipermeable siliceous membrane forms around the aggregate which allows water molecules and sodium and potassium alkaline solution to travel only one direction- towards the reactive aggregate. In such a way, big internal forces are created around the aggregate, pushing out the scales of concrete. After the forces are released and channels to the surface opened, water washed out the reaction products from the reaction zone (Figure 12).



Fig.12. Reaction products leaching from the scales

3.3. Repair of the façade and prevention

AAR in precast concrete walls causes esthetical damage of facades, which is hard to repair due to the fact, that AAR is ongoing process and new defects can appear in the future. To slow down the speed of AAR-reaction and the phenomena of AAR, Hydrophobic agent can be applied in order to stop the moisture or water infiltration into the concrete pores/capillaries. In case of Helsingborg, cylinders in the places of defects were drilled and covered with non-shrinking Portland cement based concrete repair mix (Figure 13). After that, whole facade was repainted.

During this research, 10 projects in Kaunas, manufactured during 2010-2012 at the same factory were visited with a goal to find signs of AAR. Even though concrete composition and aggregates were same as for Helsingborg project and most of visited buildings were super markets with ground elements near parking areas with higher risk of moisture, no signs of AAR were found (Figure 14).

In precast production, the key factor is time. Wall elements are lifted from the molds after 20 hours, so all preventive measures, for example pozzolanic additives should not reduce early strength of concrete.



Fig.13. Facade in Helsingborg during repair



Fig.14. No AAR found on socle elements in Kaunas

4. Conclusions

Gravel quarries of Lithuania are infected with small amounts of alkali reactive SiO₂ aggregates. If total alkali content in the concrete mix does not exceed 3 kg/m³, there is no risk of structural damage. On the other hand, pop-outs (scales) still appear on the concrete surface for various constructions (precast concrete wall elements, floors, etc...).

There is increased risk of AAR in Sweden for precast concrete elements, that are produced with aggregates from quarries of Lithuania. Construction areas, that are close to the sea are more favorable for AAR due to larger amounts of moisture collecting in the concrete throughout autumn and winter before spring- summer, when warm temperature acts as a trigger for AAR to start.

For precast concrete wall elements, most common reactive aggregate sizes are around 5 mm, which is mostly found in coarse aggregate. Changing coarse aggregate to AAR neutral can significantly reduce the risk of AAR.

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