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Durability assessment of external renderings on AAC based on 10-year long-term monitoring data

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ABSTRACT

Long-term performance and durability of external walls made of rendered autoclaved aerated concrete was investigated within a research project, based on continuous monitoring of temperature and moisture in the materials employed in the weathering test conducted in Gavle, Sweden. The details of natural exposure test set-up and preliminary measurement and experiment results were published elsewhere. Among the external rendering systems applied on AAC wall panels, a variety of coatings including inorganic and organic coatings with and without hydrophobic agents were tested. Together with the surface and bulk temperatures and moisture contents of the tested materials, microclimate parameters were also continuously measured. In this paper, monitoring data collected during 10 years of natural exposure are examined, and some results, particularly on moisture performance of external rendering systems, are presented and briefly discussed.

Keywords. Durability, external renderings, hydrophobic agents, moisture, monitoring.

INTRODUCTION

Due to its low thermal conductivity, autoclaved aerated concrete (AAC) has been widely used as wall blocks or wall panels for different types of buildings in different climates and geographical locations. The long-term performance and durability of external walls made of AAC against exposure conditions is generally maintained with external renderings and surface treatments. Thus, the weathering resistance of AAC walls is generally improved by protection of its highly porous structure by minimizing and delaying deteriorating effects of the atmosphere, particularly rainwater. Various rendering systems, either inorganic or organic, have been utilized on external walls, appropriate number of layers, composition, and application depending on the substrate properties and the actual microclimate characteristics. High moisture content in materials maintained for a longer duration is usually associated with performance loss and degradation of external renderings. Frequent wetting and drying cycles of driving rain and temperature causing over stresses and fatigue may result in leaching, brittleness and cracking of the exposed surfaces (Kus, H. and Carlsson, T 2003). Intensity, duration, and frequency ofdriving rain together with the capillary water absorption and desorption properties of surface material are the primary factors in determining long-term performance and durability of particularly porous inorganic materials (Trechsel 1994). Besides, severity of performance loss and degradation is also affected by the surface characteristics of finish material like texture, colour, micro cracks, ageing, etc. In general, traditional lime-cement inorganic renderings, owing to their evaporative behaviour, flexibility, and compatibility which can further be enhanced by utilizing various modifications such as fibres, hydrophobic agents, etc. are expected to lead to extended service life with minimum maintenance costs.

In accordance with the EU's Construction Products Directive (CPD), ISO 15686-2 (ISO), and the sustainable building approach, a research project was conducted to study in-use performance and durability of external walls made of rendered AAC. Tested rendering systems mounted on a test cabin have been naturally exposed for over ten years in the climate of Gavle, Sweden. Micro climate parameters were continuously monitored. In this paper, measurement data obtained during ten-year exposure period has been thoroughly examined. Some results on moisture performance are presented and briefly discussed.

BACKGROUND

Long-term performance and durability of external walls made of rendered AAC has been investigated through monitoring of wall panels mounted at the field exposure station built in Gavle, Sweden (Figure 1). Twelve AAC test panels, having a thickness of 150 mm and rendered with different external coating systems, were employed on the north-east and south-west facades. Continuous temperature and moisture measurements were conducted at 5-minute intervals over a 10-year exposure period. Visual observations were performed periodically on panel surfaces to examine the ageing effects (Figure 2).

Brief details of test systems and measurements are given below. All other details, relevant information, and other assessments made earlier can be found in previous publications (Kus et.al. 2001, 2002, 2004, and 2005).

Figure 1. Test panels

Figure 2. Aged panel surface

Test Systems and Materials. A variety of traditional and new recipes of external renderings were tested within the exposure program. The internal surfaces of AAC panels were left uncoated for the installation of measuring devices. The rendering systems were mainly selected from inorganic systems and their modifications with hydrophobic agents. All rendering types and hydrophobic products tested are to some extent vapour permeable.

Test panels can be classified according to the nature of external coating systems as: (i) inorganic renderings together with the uncoated and untreated AAC control panel, (ii) organic renderings, and (iii) hydrophobic systems with silicon-based water repellent surface applications. In Table 1, compositions of test systems are presented.

Table 1. Rendering systems applied on AAC test panels

Group	Panel number		Primer	Undercoat	Final coat	Thickness (mm)
Inorganic Systems	1	-	-	-	-	-
	5	-	Lime/white cement/dolomite 10/90/350	-	Lime/white cement/white dolomite 50/50/450	3-4
	7	-	Lime/white cement/dolomite 10/90/350	Lime/cement/dolomite –sand 50/50/650	Hydraulic lime/lime/dolomite	12-15
Organic Systems	3	-	Acrylic–styrene	-	Acrylic–styrene	< 1
	6	-	Lime/white cement/dolomite 10/90/350 with silicon powder additive (active content 50% by weight)	-	Lime/white cement/white dolomite 50/50/450 with silicon powder additive (active content 50% by weight)	3-4
	8	-	Lime/white cement/dolomite 10/90/350 with silicon powder additive (active content 50% by weight)	Lime/cement/dolomite –sand 50/50/650 with silicon powder additive (active content 50% by weight)	Silicate paint	12-15
	10	-	-	Lime/cement/fibres with ethylene/vinyl acetate redispersible powder	Silicate paint	7-9
	12	-	-	Cement/polymer/limestone–plastic fibres	Cement/polymer/limestone–plastic fibres	5-7
Water Repellent Surface Applications	2	Silicone micro-emulsion concentrate (active content 100% by weight)	-	-	-	-
	4	Silane–siloxane emulsion (active content 50% by weight)	Acrylic–styrene	-	Acrylic–styrene	< 1
	9	Silane–siloxane emulsion (active content 50% by weight)	Acrylic/dolomite–calcite with silicon additive	-	Pure acrylic copolymer/dolomite – calcite	< 1
	11	Silane–siloxane emulsion (active content 50% by weight)	-	-	Silicon resin paint	< 1

Testing Equipment and Measurement Positions. Bulk temperatures and moisture contents were measured continuously using thermocouples and resistance type nail electrodes, respectively, at different depths in the AAC substrate material including 5 mm, 25 mm, and 50 mm depths from the outer surface of AAC. Monitored data were collected by means of multiplexers and dataloggers. Calibrations were made in the laboratory for necessary conversions and on-site for error controls.

Climate Conditions. Microclimate parameters like surface wetness and temperature, air temperature, relative humidity, driving rain, and UV were continuously measured at each facade. Indoor air conditions in the test cabin were also monitored. An indoor temperature of about 15 °C was maintained throughout the whole exposure period.

TEST RESULTS AND DISCUSSION

All data were examined on yearly basis and the results obtained during most intense exposure conditions (i.e. driving rain) throughout each year were analysed. A comparative assessment was made between the systems classified according to their nature and within the exposure years. Not only the composition and the thickness of the rendering but also the prevailing microenvironment characteristics play role in the moisture performance and durability of the tested systems. Accordingly, monitoring data obtained from north-east facade exhibited greater variations in driving rain conditions than south-west façade. Therefore, interpretations were made based on both the material properties and the microenvironment conditions of north-east facade.

Inorganic Renderings. During the initial driving rains at the start of the exposure period, thick lime-cement rendering system (Panel 7) absorbed higher moisture amounts compared to that of thin lime-cement rendering (Panel 5). In Figure 3, the measurement results obtained during the first rainy weeks are shown. These weeks are the only times in the whole ten years exposure period when the moisture content levels in Panel 7 reached almost 130% (by weight). In the first year of exposure, when the whole year is examined, Panel 7 absorbed the highest amounts and even mostly higher than the control Panel 1. However, in later years, an improvement is observed in moisture absorption performance of Panel 7. During rainy days of the second and third years, even under more intense weather conditions, the highest moisture content levels decreased to 100%, and the next years decreased to about 80% at highest. In general, a gradual decrease in moisture uptake is observed for Panel 7 within ten years (Figure 4). The improvement in performance can be explained by the long cure process, carbonation, and durable characteristics of hydraulic lime top coating. There is almost no change in ten years in moisture absorption amounts of thin lime-cement rendering (Panel 5). The highest moisture content levels varied between 100% and 110% yearly basis. First two years, AAC control panel (Panel 1) absorbed slightly higher moisture compared to subsequent years. Panel 1 and Panel 5 exhibited quite similar moisture content levels except for intense driving rain conditions, where Panel 1 occasionally rose above Panel 5.

The drying rates of inorganic systems range as Panel 1, Panel 5, and Panel 7, from higher to lower, respectively. Hardly any changes were observed in this ranking during the whole exposure period. Depending on its thickness, Panel 7 demonstrated retarded and significantly long drying cycles compared to Panel 5. Therefore, when compared to Panel 5, Panel 7 generally exhibited more wet conditions under longer periods at 25 mm depth of the AAC substrate, particularly after the first year. In Figure 5, an example is given for data measured at 25 mm depth in AAC showing the wetting and drying cycles of inorganic renderings in 2003. It is clearly seen that Panel 7 absorbed relatively higher amounts and thus retained the moisture longer due to its lower drying rate. When the moisture contents at 50 mm depth in AAC were examined for the whole exposure period, both panels with inorganic renderings exhibited usually similar maximum levels particularly after the first couple of years, the highest being 65-70% (by weight). An example from 2007 is presented in Figure 6, showing the moisture conditions at 50 mm depth during rain cycles. Even though Panel 7 dries more slowly, the maximum moisture content remains almost the same as that of Panel 5, but it often retained its wetness while Panel 5 completely dried out before the next rain.

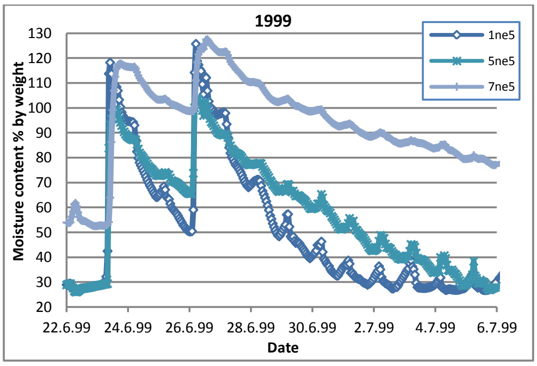

Figure 3. Inorganic systems at the start of exposure (at 5 mm depth).

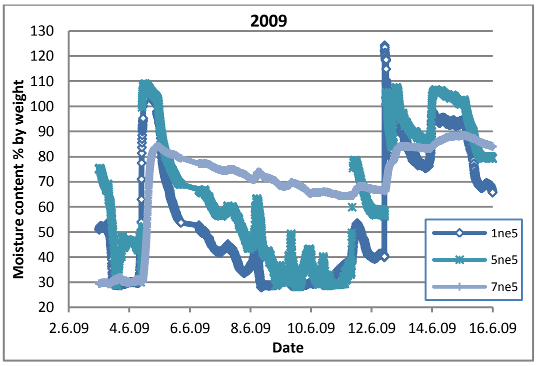

Figure 4. Inorganic systems after ten years of exposure (at 5 mm depth).

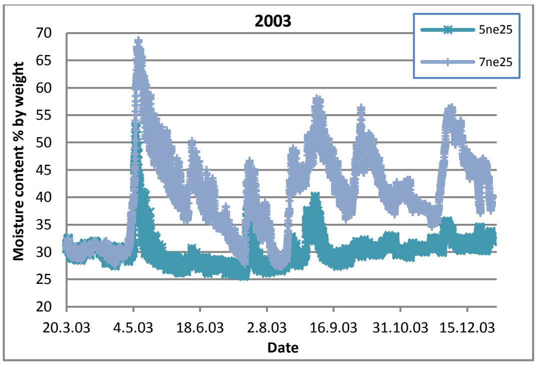

Figure 5. Inorganic systems in 2003 (at 25 mm depth).

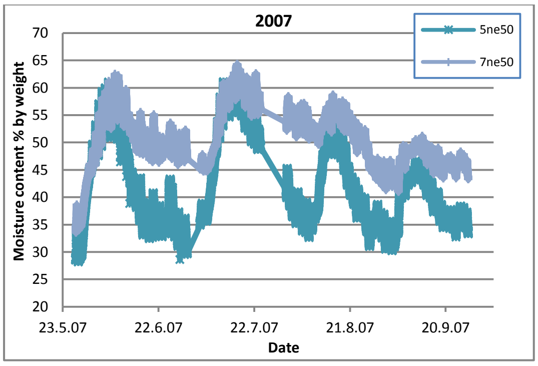

Figure 6. Inorganic systems in 2007 (at 50 mm depth).

Organic Renderings. In the first year of natural weathering, Panel 12 demonstrated relatively highest moisture content among other organic systems (Figure 7). During the first intense rainy period within the second month of exposure after the installation of test cabin, the moisture content of Panel 12 was measured about 90% and up to about 54% (by weight) during the next intense rainy period. However, in the subsequent years, Panel 6 and Panel 3 exhibited significantly higher moisture absorbance compared to that of Panel 12 (Figure 8). This can be explained by the composition of the cement rendering system applied to Panel 12, which modified with polymer, limestone and plastic fibres. The first year, the rendering system of Panel 12 probably exhibited long hydration process possibly as a result of the carbonation process through calcifying of (unreacted) limestone in the mortar which fills the micro pores and micro cracks at the surface zone. It is most likely that fibres, functioning as reinforcement, prevent the stresses emerging from wet-dry cycles thus the performance loss was much lower during ten years of exposure. On the other hand, plastic fibres and the polymer modification might have likely provided a less permeable, and in turn, a durable protection layer. Moreover, the possible long hydration process during the first year seems to have improved the performance since the moisture content has never increased up to the same initial levels afterwards, even during more intense driving rain conditions. Among organic rendering systems, Panel 6, having a rendering mix including silicon additive, demonstrated the highest moisture content levels during the whole exposure period, except for the first year (Figure 8). The last couple years of ten-year exposure period, its performance loss seems to have increased significantly. The moisture content of Panel 6 was measured as high as 86% during the last year of exposure period. The performance loss in acrylic-styrene painted system, Panel 3, has gradually increased in the last four years of exposure. The cumulative fatigue effects from wear impacts and runoff of driving rains and possible air pollutants might have caused degradation of this system as a result of possible surface soiling of protection film. After the first two years of exposure, Panel 8 and Panel 12 demonstrated a similar performance in moisture absorption particularly during cold and humid weather conditions, which was a quite low level when compared to those of Panel 6 and Panel 3 (Figure 8). Panel 10 seems to have had the best long-term performance and durability among the organic systems since very few and very small pulses have been received from moisture sensors in ten years of monitoring (Figure 8). It is most likely that the modification of lime-cement rendering with fibres and redispersible powder has greatly improved its characteristics like adhesion, flexibility, impermeability, and in turn, durability.

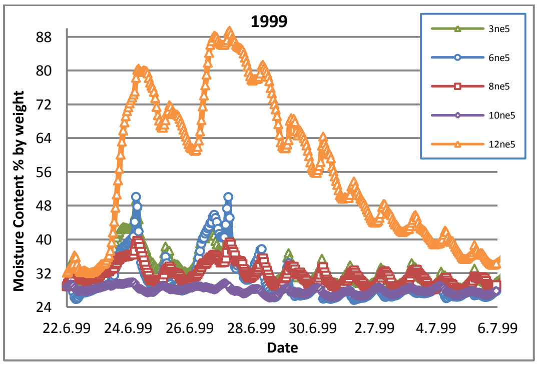

Figure 7. Organic systems at the start of the exposure.

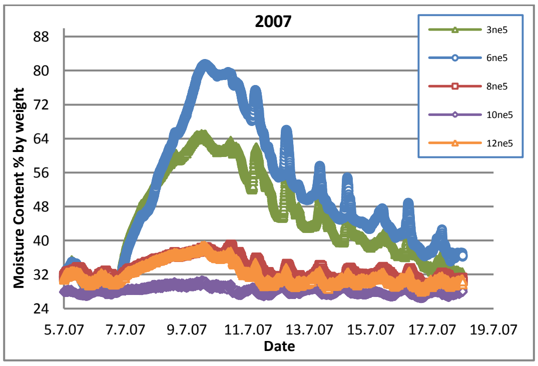

Figure 8. Organic systems after eight years of exposure.

Water Repellent Surface Applications. In general, water repellent surface treated systems demonstrated the lowest moisture content levels among all systems tested. The average levels oscillated around 26% to 32% depending on the daily and seasonal temperature and relative humidity cycles. Only little changes in moisture absorption behaviour have been observed within ten years. Relatively higher peaks and distinguishable differences were observed during the first and the last two years. At the start of the exposure period with the first couple of summer rains, Panel 9, surface treated system coated with acrylic based rendering, demonstrated significantly higher moisture absorption (42%) compared to other systems in this group (Figure 9). Mineral fillers in this rendering type might have probably influenced the early performance despite the presence of hydrophobic additives. Otherwise, the highest moisture content at 5 mm depth for Panel 9 was about 39%, measured only at two different times in the last two years of exposure. When the moisture conditions of Panel 9 deeper at 25 mm were examined, relatively higher levels were observed compared to the surface zone at 5 mm depth (Figure 10). All other three systems demonstrated either similar or lower moisture levels deeper at 25 mm depth. During the whole monitoring period, the highest level for Panel 4 was measured about 42% in winter time, whereas the moisture content of Panel 2 was only about 35% at the same time. In general, almost no significant change was observed in performances over time except for Panel 2 which has started to demonstrate relatively higher peaks during the last intense driving rains of the last year, i.e. at the very end of the ten-year exposure period and monitoring. Nevertheless, as this was still very low compared to all other inorganic and organic systems, and also the drying rate was very high, it was negligible. Depending on all these results, all hydrophobic systems can be said to have been sufficiently durable in ten-year exposure period under Nordic climatic conditions.

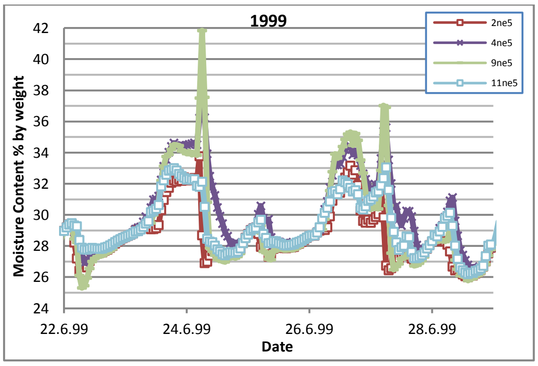

Figure 9. Water repellent treated systems at the start of the exposure.

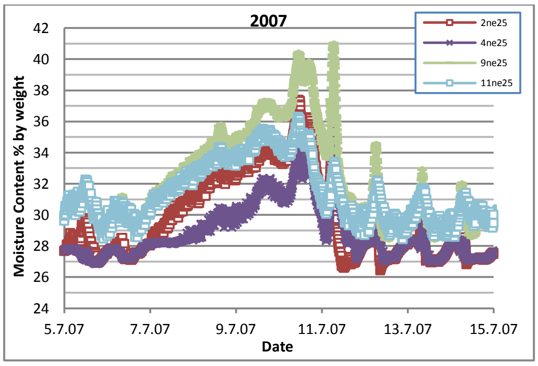

Figure 10. Water repellent treated systems in 2007.

CONCLUSIONS

When assessing the long-term performance and durability of external renderings applied on AAC walls under specific climate conditions of Sweden, the following conclusions can be drawn based on ten-year monitoring data measured at the north-east facade;

- All inorganic mineral rendering systems with relatively thicker layers have maintained their hydration process with the rains during the first year of exposure; therefore the moisture content levels were highest at the start. Their actual in-use performance could only be observed afterwards.
- In general, in winter seasons, depending on the lower air temperatures and higher relative humidity levels in the air, some of the rendering systems exhibited significantly higher moisture contents independent of what they exhibited under driving rain conditions in summer.
- Although some fading, micro cracking, briefly ageing and aesthetic impairments were observed on some panel surfaces after ten years of exposure, the loss in their moisture performances was still negligible.
- All systems demonstrated good moisture balance between wetting and drying cycles despite longer drying periods of inorganic systems. But, even these systems exhibited a sufficiently dry state deeper inside the AAC material.
- The thickest organic rendering system containing silicon additive and coated with silicate paint, and the relatively thicker two other organic systems modified with

fibres, including either redispersible powder or polymer, one of them which coated with silicate paint, exhibited significantly better long-term performances compared to those of relatively thinner systems containing silicon additive and the thinnest organic system with acrylic-styrene paint.

- When the two thickest rendering systems are compared (panels 7 and 8) a significant improvement in moisture uptake was obtained through silicon additive inclusion together with silicate paint coating. The sole effect of silicon additive (as demonstrated by Panel 6), on the other hand, was found to be quite low. The moisture uptake of Panel 6 increased to similar levels with Panel 7 (i.e. renderings with and without hydrophobic additives) particularly after eight years of exposure.
- Under intense driving rain conditions, a slight impairment appeared for the hydrophobic system with silicon-based water repellent surface application towards the end of the ten-year exposure period. However, it was still negligible when compared to the performances of all inorganic and most organic systems.

REFERENCES

ISO 15686-2 (2012) Building and Constructed Assets – Service Life Planning. Part 2: Service life prediction procedures, ISO.

Kus, H. and Carlsson, T (2003) "Microstructural investigations of naturally and artificially weathered autoclaved aerated concrete", *Cement and Concrete Research*, 33 (9), 1423-1432.

Kus, H., Marteinsson, B, and Norberg, P. (2005) "Temperature and Moisture Conditions in Materials- Effects on Risk for Degradation of Rendered Autoclaved Aerated Concrete" *10th Int. Conf. on Durability of Building Materials and Components (10DBMC)*, Lyon, France.

Kus, H., Nygren, K. and Norberg, P. (2004) "In-use performance assessment of rendered autoclaved aerated concrete walls by long-term moisture monitoring", *Building and Environment*, 39 (6), 677-687.

Kus, H. and Nygren, K. (2002) "Microenvironmental characterization of rendered autoclaved aerated concrete", *Building Research and Information*, 30 (1), 25-34.

Kus, H. and Norberg, P. (2001) "Monitoring of Moisture in Rendered Autoclaved Aerated Concrete Wall by Nail Electrodes", *6th Int. Conf. on Building Envelope Systems and Technologies (ICBEST 2001)*, Ottawa, Canada.

MLN 18, Moisture Control in Buildings. Editor: Heinz R. Trechsel. ASTM, 1994.

The CPD Guidance Paper F. (2004) Durability and the construction products directive. available at: http://eurocodes.jrc.ec.europa.eu/doc/gpf.pdf (accessed January 31, 2013).