CAN LIGHT WEIGHT AGGREGATE (LWA) LEAD TO HARMFUL ASR IN THE FIELD?

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Abstract

Due to their silica content, most light weight aggregates (LWAs) are potentially reactive. Despite this, knowledge regarding pre-testing ASR properties of LWA and LWA concrete (LWAC) is lacking internationally. The accelerated mortar prism test shows that several LWAs can develop ASR, but it is uncertain if this will ever occur in the field.

As a part of a Norwegian research project managed by SINTEF running from 2014 to 2018, one objective is to examine the ASR potential of LWA used in Norwegian concrete structures as basis for recommendation with respect to documentation and utilization of LWA and LWAC. Based on a literature study and results from accelerated tests, the consequence of potential ASR in LWAC is discussed.

Keywords: Alkali-silica reaction (ASR), light weight aggregates (LWA), performance testing, field experience

1 INTRODUCTION

Light weight aggregate concrete (LWAC) find application where low density structural concrete is beneficial; ranging from floating structures to bridges with solid foundations either in the whole structure or in segments. LWAC is for example used in some cantilever bridges in the mid span where the two parts of the bridge deck will meet during construction. The durability of such structures is of importance to achieve long service life, and in this context the alkali-reactivity of LWA has been questioned.

LWAs based on foamed glass are classified as alkali-reactive in laboratory tests [1-3], among other in the chemical test ASTM C 289 [3] and in the accelerated mortar bar test ASTM C 1260 [1]. It is also known that a housing complex with walls of LWAC based on foamed glass suffered from damages after few years in service (not published). The damage occurred in areas on the facade with access to surplus water. Yu et al. [4] studied ultra-light concrete based on a similar LWA and tested among other properties potential ASR. After 14 days of exposure to 1N NaOH and 80°C they found no expansion, but discuss the possibility of forming ASR products within the LWA that would not lead to expansion, since the porous aggregate particles provide sufficient space for any ASR products. However, in an earlier study [5] the same authors studied LWAC with the same LWA by SEM after 20 months storage at 100 % RH and 20°C and found no ASR products between the foamed glass in the ASTM C 227 mortar bar test, but the chemical method ASTM C 289 showed that the aggregate is highly reactive and additionally indicated that the foamed glass might release significant amounts of alkalis into the concrete pore water. The different results [1-5] can be due to different glass composition and different test conditions (e.g. temperature and internal alkali content in the test prisms).

Mladenovic et al. [6] evaluated 4 different LWAs with respect to ASR based on expanded vermiculite and clay that was deemed non-reactive, as well as expanded glass and perlite that was found to be reactive. The test procedures used was ASTM C 289 and ASTM C 1260. ASR products were found by SEM within the two latter LWAs, but this did not result in expansion.

Justnes et al [7] performed a comparative study of the two expanded clay based LWAs Liapor and Leca and evaluated their potential alkali reactivity with the ASTM C 289 method. There was no significant difference between them in terms of ASR and both barely passed the test and deemed non-reactive.

De Ceukelaire [8] reported on a 13 year old LWAC bridge in Belgium that was demolished in 1989 due to ASR caused by the normal density sand containing chert. The coarse LWA based on expanded shale did not show any sign of reactivity, but had most likely released a very high amount of alkalis to the concrete pore water. He also referred to 2 LWAC bridges in Denmark and 1 in USA where ASR was detected.

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The Norwegian Public Roads Administration (NPRA) has recently prepared an overview of Norwegian LWAC bridges built in the period 1987-2002 [9]. Three types of LWA have been used, i.e. Liapor, Leca and Stalite, and the estimated alkali content in the concretes ranges from 2.2-4.5 kg/m³ Na₂O_{eq}. In 2013, three of the LWACs used in the bridges were examined by microstructural analyses (plane polished and thin sections), after several years of field exposure. In these bridges with CEM I cement (OPC), the type of LWA, alkali content (Na₂O_{eq}) and age were as follows: Liapor/4.4 kg/m³/26 years, Stalite/2.3 kg/m³/16 years and Leca/2.3 kg/m³/16 years. None of the examined LWACs show any signs of ASR.

In 2005, the NPRA initiated a laboratory test program performed at SINTEF. The reports from this testing [10,11] are published as Appendices in [9]. The test program and results are presented in this paper.

2 MATERIALS AND METHODS

2.1 General

During the period 2005-2013, SINTEF performed two laboratory test programs designed to answer the following questions: 1) Are the LWAs pozzolanic? 2) Can LWA be a source of extra alkalis by alkali release? 3) Does the LWAC expand? 4) Does the LWAC mass increase? 5) Does the LWAC crack? 6) Is alkali-silica gel (ASR gel) produced during accelerated tests? 7) How is any ASR gel distributed (in cracks, voids or inside LWA particles)?

2.2 Materials

In the first test program, initiated and financed by the NPRA [10,11], the selected LWAs were Stalite, Leca 800 and Liapor 8 with dry densities 1440, 1450 and 1500 kg/m³, respectively, after 1 h water absorption resulting in 6, 7 and 3% mass increase (uncrushed LWA), respectively. The corresponding numbers for crushed LWA is 25, 26 and 24 % (Table 1). The cement used in the accelerated mortar bar test [12] was a CEM I called "Industry cement" produced by Norcem, Brevik, Norway, containing 1.11% Na_2O_{eq} alkalis. Deionized water of 20°C was used. The plasticizing agent (SP) was Scanflux AD-18 with 18% dry matter and 0.67% Na_2O_{eq} alkalis from Scancem Chemicals, Norway. The slaked lime (i.e. calcium hydroxide) used was of analytical grade.

In the second test program Liaver expanded glass was tested (only according to the accelerated mortar bar test [12], see section 2.4). The dry particle density varied from about 300 kg/m³ (fraction 2-4 mm) to about 550 kg/m³ (fraction 0.25-0.5 mm).

2.2 Pozzolanic test

The test is based on how much calcium hydroxide that can be consumed by ground LWA and is a measure of LWA reactivity or pozzolanicity. The LWAs were ground down to $<125 \,\mu$ m and mixed with 50% slaked lime leading to LWA:lime ratio 2:1. The powders were then mixed with alkaline pore water of pH = 13.5 and a K/Na=2 in order to simulate the pore water of concrete. The alkali hydroxides will also accelerate the pozzolanic reaction. The water to powder ratio was 0.60. One part of the suspension was stopped with excess ethanol and dried at 105°C to serve as internal reference before reaction started, and the rest of the suspension was divided in two parts to be cured at 20 and 80°C, respectively, for 27 days. Thereafter the reaction was again stopped by replacing water with excessive ethanol and dried at 105°C. The content of calcium hydroxide was determined by thermogravimetric analysis as the mass loss between 300 and 500°C.

2.3 Alkali release

If the LWA can release (leach out) alkalis when they are exposed to the alkaline pore water of concrete, they can contribute so the alkali content exceeds the critical limit of the concrete. Since concrete also contain calcium hydroxide from cement hydration, and that calcium can ion exchange with alkalis at the surface of LWA, it is important that the exposure solution contains some calcium hydroxide in excess with respect to its solubility (1.7 and 1.0 g/l at 20 and 80°C, respectively).

Ground LWA (20 g) was added 1 g calcium hydroxide and suspended in 0.7 N potassium hydroxide (KOH) and 0.7 N sodium hydroxide (NaOH), respectively, corresponding to pH 13.85. The suspensions were shaken vigorously and placed at both 20°C and 80°C where they were shaken weekly. A small amount of liquid sample was drawn from the suspensions after 28 days and half a year and analyzed by ICP-MS. The KOH suspension was analyzed for Na and NaOH suspension for K, respectively, that should be extracted from LWA.

2.4 The accelerated mortar bar test

The three LWAs; Liapor 8, Leca 800 and Stalite, was at first crushed, fractionated, washed and dried. The fractions were then composed to fulfill a particle size distribution according to the accelerated mortar bar test [12] for particles with equal densities as shown in Table 1, but in the case of LWA the smaller grains have

higher densities than the bigger ones. In the end the crushed LWAs were submerged in water for 1 h and dried to a surface dry condition prior to use in the mortar mix.

The mortar mixes were composed of 1 part cement, 1.55 parts LWA by mass (volumetrically corresponding to 2.25 parts normal density aggregate of 2.67 kg/m³), varying amount of absorbed water, 0.45 parts free water and varying amount of plasticizer for satisfactory consistency (see Table 1). The consistency was measured by a jolting flow table (EN 1015-3) before 3 prisms of dimension 40.40.160 mm were cast.

The reference length and mass of the prisms were measured after 24 ± 2 h stored at $20\pm1^{\circ}$ C, 100% RH and 24 ± 2 h additional storage in water heated from $20\pm1^{\circ}$ C to $80\pm2^{\circ}$ C. The change in length and mass relative to the ref. values were measured as a function of time of submerged storage in a 1N NaOH solution at $80\pm2^{\circ}$ C. All length measurements were taken within 20 sec after the prisms were taken out of the liquid.

The Liaver LWA was treated and tested similarly as the other three LWAs. For all the four LWAs the length and mass change of the prisms as function of time are plotted in Figure 1, where their behavior is compared with a mortar with the normal density alkali-reactive cataclasite aggregate.

2.5 Microstructural analysis

After 56 days and 13.5 months of exposure in the accelerated mortar bar test [12], one of the three mortar bars for each of the three LWAs Stalite, Liapor 8 and Leca 800 were investigated by thin section (TS) analysis (polarization microscope) and scanning electron microscopy (SEM). The objective was to look for cracks and gel formation from ASR and for details of particular interest. For example was the chemical composition estimated by EDS (energy dispersive spectra) in the SEM. Correspondingly, one mortar bar with Liaver LWA was removed after about 15 months of exposure before a TS analysis was performed.

For each of the four LWA mortar bars a piece was cut from the middle part, and 3 mortar bar surfaces were included in the thin sections (size 28x48 mm²). The thin sections were made without cover glass so the same samples could be inspected by polarization microscopy and SEM. The thin sections were sputtered with a thin layer of carbon to become electrical conductive before they were inspected by SEM.

3 RESULTS

3.1 Pozzolanicity

The results from the pozzolanicity test are listed in Table 2, and reveal that the order of lime consumption was Liapor 8 >> Leca $800 \ge$ Stalite.

3.2 Alkali release

The results from the alkali release are given in Table 3 as Na, K, Si (only measured at 28 days) in % released of dry LWA mass, which can be done taking the densities of 0.7 N NaOH and 0.7 N KOH as 1.310 and 1.390 kg/l, respectively. The amount of alkali equivalent, Na₂O_{eq}, was calculated as well.

At 20°C, it seems like a bit more potassium (K) is released from the LWAs than sodium (Na). Release of K is not so much affected by temperature, but release of Na increases at 80°C (in particular for Stalite).

The release of silicon (Si) is stronger in a sodium hydroxide than in a potassium hydroxide solution and the amount of Si is drastically increased (by a factor of 6-23) when the temperature is increased from 20 to 80°C. This can be of importance when evaluating very accelerated methods like the mortar bar test [12].

3.3 The accelerated mortar bar test

The accelerated mortar bar test [12] criterion according to the national Norwegian ASR regulations [13] is that normal density coarse aggregates leading to expansions of >0.08% after 14 days of exposure is classified as alkali-reactive. The results in Figure 1 indicate that coarse fractions of Stalite (0.083%) would be regarded alkali-reactive, while coarse Liapor 8 (0.04%) and Leca 800 (0.04%) would be rated non-reactive. Also the fine Liaver aggregate (0.05%) would be classified as non-reactive (critical limit 0.14%). However, according to the Norwegian ASR regulations [13], we do not for the moment have any approved test method for classifying the alkali-reactivity of LWAs. This is mainly due to two reasons: 1) we lack experience from the laboratory/field correlation with LWAs, and 2) the acceptance criterion only based on prism expansion cannot be used for LWAs, since the main "damage" observed in laboratory tests is increased weight.

The huge weight increase of the mortar bars with the various LWAs is clearly shown in Figure 1, ranging from 150-300 kg/m³. In particular the mortar bars with the Liaver aggregate has an extreme weight increase. If one assumes that the solid part of the LWAs (without pores) has a density of about 2.6 kg/l, the LWAs (except Liaver) after crushing and fractionation contained 44-48 volume% porosity. Prior to mixing into mortar, about half of this porosity was filled with water. The remaining non-filled LWA porosity can then be estimated to 0.18 l per liter mortar, leading to a mass increase of 180 kg/m³ mortar if filled with water or another medium of similar density. As can be seen from Figure 1, only Stalite reached such a mass increase within the test period of 800 days.

(Comment: When testing Stalite, Liapor and Leca the original plan was to end the tests after about 7 months. Of this reason, the level of liquid was not controlled sufficiently after this period. As a consequence, the mortar bars have periodically in the period 210 to 760 days of exposure not been totally submerged in the NaOH liquid. Thus, the measured expansion and weight gain should most likely have been somewhat higher at the two last measuring points in time than shown in Figure 1).

3.4 Microstructural analysis

The thin section (TS) analysis of the mortar with Liaver after 15 months of exposure to 1N NaOH at 80°C (Figure 2) showed disintegration of coarser LWA particles. Some cracking was observed in the cement paste, and the air voids contained reaction products. Reaction products were also observed inside the Liaver particles. No SEM analysis has been performed for this sample.

The TS analysis of the other LWA mortars after 56 days of exposure showed that mortar with Stalite and Leca 800 LWA had few microcracks, some fine cracks going mainly inwards from the mortar bar surface, but only few coarse cracks. The mortar with Liapor 8 had few microcracks, some fine cracks going mainly from the surface inwards and no coarse cracks. The mortar with Stalite had significant amounts of alkali-silica gel from ASR observed as white and brown largely within the pores of the LWA, but some as a rim in air voids in the paste as well. The mortar with Liapor 8 seemed a bit washed out with some ASR gel appearing white and brown observed largely as rims in air bubbles and voids in the paste, but a few cases of gel in voids inside LWA was observed as well. For the mortar with Leca 800 only small amounts of ASR gel were observed as rim in air voids, and a few cases of gel in voids of LWA was also seen. The porosity of the paste looked uneven under the polarization microscopy.

After 13.5 months of exposure, the TS analyses (Figures 3-5) showed that the porosity of the cement paste in the mortar bars with Stalite and Leca 800 appeared to be very low. This is valid also for the mortar with Liapor 8, but smaller areas of this thin section had very high porosity. For the three LWA mortars the cracking was now significantly more pronounced compared with the TS analysis after 56 days of exposure. The extent of cracking was ranged as follows: Stalite > Leca 800 > Liapor 8. The amount of ASR-gel in air voids in the cement paste has also increased significantly for all the three LWAs. For the mortars with Stalite and Liapor 8, a corresponding increase of ASR gel was also observed in air voids inside the LWAs.

SEM analyses performed after 56 days of exposure revealed that all three LWA types developed ASR and detailed images are shown in Figures 3, 4 and 5 for Stalite, Liapor 8 and Leca 800, respectively, with explanatory text. Crystals and gel grow in the voids inside the LWAs as well as in air voids in the paste as rims. When the crystals grow inside the voids of the LWAs there can be mass increase without too much expansion for a while. However, when more ASR products are produced inside the LWAs and in air voids in the paste, as documented after 13.5 months of exposure (see Figures 3-5), the expansion of the mortar bars increases as shown in Figure 1.

4 DISCUSSION

The pozzolanic behavior of ground LWA was expected as it has been shown [14] that Leca LWA ground to $5 \,\mu$ m is highly reactive as a pozzolan.

If one assumes that the LWAs release as much alkalis to the concrete pore water as KOH releases Na and NaOH releases K, respectively, then one can sum up the Na₂O_{eq} for the two solutions in Table 3 to get the total potential alkali release from the ground (<125 μ m) LWAs. After 28 days, the alkali release from Stalite, Liapor 8 and Leca 800 will then be 0.30, 0.34 and 0.34% of dry aggregate mass Na₂O_{eq} at 20°C, respectively, with analogous values of 0.96, 0.32 and 0.60% at 80°C. After half a year, the values are 0.52, 0.51 and 0.56% at 20°C and 1.31, 0.40 and 0.88% at 80°C for Stalite, Liapor 8 and Leca 800, respectively. The released Na₂O_{eq} increased from 28 days to half a year for all the LWAs. Knowing how much LWA and which type there is in any concrete recipe, one can multiply with the respective Na₂O_{eq} and thereby estimate the "worst case" alkali contribution from the LWAs. However, for coarser LWA particles the alkali release is assumed to be less than measured for ground LWA, as shown by Lindgård for normal density aggregates [15].

The way the four LWAs were tested (crushed) in the accelerated mortar bar test, they had significantly less porosity than the way LWA will be used in practice (non-crushed) for production of LWAC. Thus, the testing resulted in less than theoretical capacity for mass increase and larger capacity for expansion caused by absorption of liquid and reaction products from possible ASR than they would have in field LWA. It seems like the 80°C mortar bar method [12] is not suitable for clay-based LWA (like Leca and Liapor) and glass based ASR (like Liaver) due to their pozzolanic nature. The smallest particles might thus act as a pozzolan at this high temperature and reduce the development of ASR. Stalite, which is based on expanded slate, seems to behave more like normal density aggregates in this accelerated test.

For all the LWAs, it is urgent to perform more realistic laboratory tests with real LWAC, preferably by use of the 38°C Norwegian concrete prism test (CPT) [12] that has shown to have a relatively low extent of alkali leaching (that will lead to reduced prism expansion) compared with comparable CPTs using smaller

prism size [15]. SINTEF have previously tested expanded glass according to this CPT [12], where rather low ASR expansion (0.015-0.025 %) but a high weight gain (50-125 kg/m³) were revealed (not published). For the moment similar tests are on-going with a mix of Liaver and Liapor. Monitored field exposure cubes [15] have also been prepared. It is of course also important to survey real structures were LWAs have been used.

The commented SEM images with EDS analyses in Figures 3-5 show that ASR products within the LWA are dominated by the elements Si, Al and K with some Na, but poor in calcium (Ca). ASR products near the interface with binder are richer in Ca. The solid material of the LWA is composed of a glassy aluminosilicate (sometimes with inclusions of quartz) and the glassy phase may react with potassium hydroxide as indicated in Eq. 1 (a similar reaction may occur in the sodium hydroxide solution):

"AlSiO₅" (glass) + KOH + $xH_2O \rightarrow$ "KAlSiO₆· xH_2O " (ASR gel) (1)

Eq. 1 is meant principally and the composition is not necessarily correct. This type of "K-Al-Si" hydrated gel may have a certain solubility and a realtive low viscosity depending on water content. However, one can not exclude formation of crystalline products like zeolites of comparable composition. Closer to the inteface with the paste, or if it oozes into the paste, it will meet calcium hydroxide and react to more stable products:

 $\text{``KAlSiO}_{6} \cdot \text{xH}_{2}\text{O''} + 5 \text{ Ca}(\text{OH})_{2} + 2 \text{ H}_{2}\text{O} \rightarrow 2 \text{ CaSiO}_{3} \cdot \text{xH}_{2}\text{O} \text{ (ASR gel)} + \text{Ca}_{3}\text{Al}_{2}\text{O}_{6} \cdot 6\text{H}_{2}\text{O} + 2 \text{ KOH}$ (2)

The "CaSi" hydrate ASR gel in Eq. 2 will probably have lower solubility than the "K-Al-Si" hydrated ASR gel in Eq. 1. The product $Ca_3Al_2O_6.6H_2O$ is probably crystalline, but there is also gel-like variants. Mixed "Ca-Al-Si" gels cannot be ruled out as well. The alkali hydroxides (exemplified by KOH) will be released when the ASR gels react with calcium and can then again react with glass. Thus, alkalis can then act as catalyst for ASR as long as there is calcium hydroxide available for interaction. The LWA can also contribute with alkalis as shown in Table 3.

5 CONCLUSION

Based on the accelerated mortar bar test [12] applied on the four LWAs Stalite, Liapor 8, Leca 800 and Liaver, there is a possibility that the LWAs may develop ASR over time in real structures, even though there is very few cases documented in the field world-wide. Stalite led to higher expansion, larger mass increase and developed more ASR products than Liapor and Leca LWA. Liaver (expanded glass) led to the lowest expansion, but the most extreme weight gain during the testing. The accelerated mortar bar method might be suitable for testing Stalite, but most likely not Liapor, Leca and Liaver due to their pozzolanic nature when smaller particles are included. Performance of concrete prism tests linked to field exposed monitored cubes [15], in addition to field survey of structures and corresponding laboratory documentation are recommended.

LWAs may release alkalis to the concrete pore water and contribute to the total Na_2O_{eq} of the LWAC.

Since any ASR in LWA probably would lead to larger mass increase relative to expansion due to ASR products remaining in the pores of LWA, the practical consequence would have been more severe for floating structures due to reduced buoyancy than for instance LWA bridges with solid fundaments.

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TABLE 1: Water absorption and density of crushed LWA, the particle size distribution, the mortar composition and mortar consistency.

LWA		Liapor 8	Leca 800	Stalite		
1 h water absorption (crushed LWA), %		25	24			
Density, incl. absorbed water, kg/m ³		1700 1700		1800		
Particle size distribution, Mass% retained	0.125-0.25 mm	12.0				
	0.25-0.5 mm	27.3				
	0.5-1 mm	25.2				
	1-2 mm	23.2				
	2-5 mm	12.3				
Mortar composition	Free water, g	270				
	LWA, g	1169	1170	1156		
	SP, g	20	0	0		
Consistency on flow table, mm		189	143	227		

TABLE 2: Content of calcium hydroxide in mixes of ground LWA and slaked lime								
LWA	Stalite	Leca 800	Liapor 8					
Reference	100 %	100 %	100 %					
(0 days)	(0.293 g/g burnt1)	(0.306 g/g burnt ¹)	(0.307 g/g burnt1)					
27 days at 20°C	79.7 %	77.2 %	64.3 %					
27 days at 80°C	61.9 %	60.5 %	40.3 %					

¹Burnt refers to mass of sample heated to 1000°C

LWA		Stalite		Liapor 8		Leca 800	
Temperature		20°C	80°C	20°C	80°C	20°C	80°C
28 dg KOH release	Na	0.136	0.637	0.076	0.150	0.124	0.293
	Na ₂ O _{eq}	0.183	0.859	0.102	0.202	0.167	0.395
	Si	0.071	1.637	0.109	1.272	0.040	0.691
28 dg NaOH release	K	0.147	0.144	0.294	0.146	0.213	0.260
	Na ₂ O _{eq}	0.117	0.114	0.233	0.116	0.169	0.206
	Si	0.189	2.740	0.230	1.486	0.189	3.079
182 dg KOH release	Na	0.212	0.857	0.093	0.200	0.167	0.491
	Na ₂ O _{eq}	0.285	1.153	0.125	0.269	0.225	0.661
	Si	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
182 dg NaOH release	K	0.298	0.194	0.480	0.159	0.419	0.279
	Na ₂ O _{eq}	0.237	0.154	0.382	0.127	0.333	0.222
	Si	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.



FIGURE 1: Linear expansion (upper) and mass increase (lower) of mortar bars submerged in 1N NaOH at 80°C. The four LWAs are compared with the normal density alkali-reactive cataclasite aggregate.





FIGURE 2: Mortar prism with Liaver LWA exposed for 1N NaOH at 80°C for 15 months. The left picture shows disintegration of coarser Liaver LWA particles during the exposure. Some cracking is observed in the cement paste, and the air voids contain reaction products. Reaction products are observed inside the Liaver particles, as well (right picture).



FIGURE 3: The two upper SEM pictures show mortar with Stalite LWA exposed for 56 days. The upper left picture shows the borderline between LWA (left) and paste (right) running from top to bottom of the image. Reaction products (marked A and B) are observed in air voids inside the Stalite particles. The relative atomic composition of the gel marked A was 42 Si, 15 Al, 4 K, 1 Na and 1 Ca, while the composition of the fibre like point B was 38 S, 13 Al, 10 K, 1 Ca and 1 Na. The upper right picture shows a circular air void in the paste that is filled to the rim with reaction product. In the upper part of the image a LWA particle is visible and some denser grey lines seem to connect the LWA particle to the air void. Microcracks are radiating out of the filled air void.

The two lower pictures show mortar with Stalite LWA exposed for 13.5 months. The left picture is taken in a polarization microscope (TS analysis), and shows alkali-silica gel in voids inside a Stalite particle. The SEM picture to the right shows a reacted Stalite particle with crystalline gel with minor alkalis (marked A) and amorphous gel with a high content of alkalis (marked B).



FIGURE 4: The two upper SEM pictures show mortar with Liapor 8 LWA exposed for 56 days. The upper left image serve as an overview. The apparent topography is likely to be density differences between cement paste depleted in calcium hydroxide used to react through some of the smaller LWA particles. A Liapor particle with a reaction rim in visible in the middle. The particle is less affected inside. The upper right picture shows the reacted interface zone (marked A) between a Liapor particle (right) and the cement paste. When analyzing point A by EDS in a defocused circular area of 10 μm diameter, the following relative atomic composition was found: 31 Si, 18 Ca, 10 Al, 5 K and 2 Na, while a similar analysis in point B inside the LWA gives 32 Si, 6 Ca, 15 Al, 7 K and 2 Na.

The two lower pictures show mortar with Liapor 8 LWA exposed for 13.5 months. The left picture is taken in a polarization microscope (TS analysis), and shows alkali-silica gel in air voids in the cement paste. The SEM picture to the right shows different reaction products inside a LWA particle, in which the chemical composition is dominated by Si and Al, with some Ca, K and Na. The white areas are iron compositions, a possibly consequence of alkali-silica reactions.



FIGURE 5: The two upper SEM pictures show mortar with Leca 800 LWA exposed for 56 days. The upper left picture shows reaction rims around coarser LWA particles, while the smaller LWA particles seem dense and have reacted through. The right picture (upper part) shows a Leca particle with a reaction rim. EDS of a circular are of 10 µm diameter in the area marked A indicates a relative atomic content of 34 Si, 13 Ca, 8 Al, 2 Na and 3 K. The composition of the area marked B inside the reaction rim indicates a composition of 36 Si, 3 Ca, 14 Al, 4 Na and 9 K. The analysis of the fringed products marked C in the void corresponds to 36 Si, 23 Ca, 1 Na, 1 K.

The two lower pictures show mortar with Leca 800 LWA exposed for 13.5 months. The left picture is taken in a polarization microscope (TS analysis), and shows possibly white alkali-silica gel in voids inside the LWA particle. The SEM picture to the right shows reaction products consisting of Si, Al and some K in air voids inside a Leca particle (small air voids are completely filled). The Leca 800 particle is cracked.