

Durability of Autoclaved Aerated Concrete

Berit Straube¹
Peter Langer²
Andreas Stumm³

T 11

ABSTRACT

A main requirement of the “Construction Products Directive (CPD)” for buildings and building materials is their mechanical resistance and stability. A relevant part of the safety of components and buildings is their durability. The requirements for durability are affected by the economically useful life and the ambient conditions, such as physical- and chemical-environmental influences. The durability of cementitious building materials is based on Calcium-Silicate-Hydrate phases (C-S-H), and is crucially defined by the formation of their mineral phases. The crystalline C-S-H phase, tobermorite, directly affects the mechanical properties of autoclaved aerated concrete (AAC). The formation of tobermorite is influenced by raw materials and process parameters. Well crystallised C-S-H phases in AAC must not be compared to the poorly crystallised C-S-H phases in normal concrete. C-S-H phases in normal concrete have a low ordered structure, with highly variable amounts of calcium, silicon and water, which lead to structural changes with increasing lifetime. In this study, the durability of AAC was investigated in order to assess the quality of AAC after long term application. Correlations between phase formation, mechanical properties and durability were proved with examples. AAC with well crystallised tobermorite is not substantially influenced by CO₂ under normal atmospheric conditions. Due to these results, it was conducted that AAC is durable and does not lose its function of stability during long term application.

KEYWORDS

AAC, C-S-H phases, Tobermorite, Calcium sulphate, Durability

¹ Xella Technologie- und Forschungsgesellschaft mbH, Hohes Steinfeld 1, 14797 Kloster Lehnin, Germany, Phone +49 33844752111, Fax 33844752110, berit.straube@xella.com

² Xella Technologie- und Forschungsgesellschaft mbH, Hohes Steinfeld 1, 14797 Kloster Lehnin, Germany, Phone +49 33827060189, Fax 33827060120, peter.langer@xella.com

³ Xella Technologie- und Forschungsgesellschaft mbH, Hohes Steinfeld 1, 14797 Kloster Lehnin, Germany, Phone +49 33844752120, Fax 33844752110, andreas.stumm@xella.com

1 INTRODUCTION

Autoclaved aerated concrete (AAC) is produced of natural inorganic raw materials such as sand, lime, cement, water and the rising agent aluminium.

AAC has an unique structure, formed by millions of small air pores, which leads to an optimum correlation between compressive strength and low materials weight. Moreover, air has a low thermal conductivity which makes AAC one of the best insulating building materials.

A requirement of the “Construction Products Directive (CPD)” for buildings and building materials is their mechanical resistance and stability. A relevant part of the safety of components and buildings is their durability. The requirements for durability are affected by the economically useful life and the ambient conditions such as physical- and chemical-environmental influences. Well crystallised C-S-H phases, like tobermorite in AAC, are resistant to carbonation and cannot be compared to the poorly crystallised C-S-H gels in ordinary concrete.

Poorly crystallised AAC contains so called C-S-H(I), which is from the structural point of view, between C-S-H gel and tobermorite ($\text{CaO/SiO}_2 = 0.83$). C-S-H(I) has highly variable amounts of calcium, silicon ($0.75 < \text{CaO/SiO}_2 < 1.5$) [Taylor 1964] and water, which easily leads to structural changes with increasing lifetime.

C-S-H(I) encourages the carbonation process in autoclaved aerated concrete like in ordinary concrete. Internal investigations assume, that the amount of C-S-H(I) directly influences the shrinkage.

In the production of AAC the formation C-S-H(I) has to be avoided. The addition of calcium sulphate, such as anhydrite and gypsum, improves the material, i.e. higher compressive strength and a intensified formation of better crystallised tobermorite. The tobermorite formation is intensified with lower shrinkage, and probably better resistance upon carbonation.

Additional calcium sulphate has been used in AAC production since 1967 [Clementi 1967]. The mechanisms are not completely understood.

In this study, the durability of AAC was investigated to assess the material properties of AAC during long term application using X-ray powder diffraction, carbon/sulphur-analysis and compressive strength testing. Correlations between phase formation, mechanical properties and durability were proved with model substances, drilling cores taken from buildings and stored AAC units.

2 EXPERIMENTAL

2.1 Sample Preparation

2.1.1 Model samples synthesis

Four model samples of AAC with the raw density of 440 kg/m^3 were produced (6 h at 190°C) in lab sized moulds (10 litres) by using the usual method for the production of AAC [RILEM 1993]. The recipes are shown in Table 1. The content of calcium sulphate ($\text{CaSO}_4 = \text{anhydrite}$) was subsequently increased by substituting the non-reactive filler calcite (CaCO_3).

Eight AAC units (AU) with a bulk density 400 kg/m^3 from the identical production mixture were stored under a roof protected from rain. These materials were produced in 1980. Calcium sulphate was added to the mixture. The surface of the material was not protected by either mortar or paint.

These AAC units have been subsequently sampled and analysed for compressive strength after various time periods from the time of production (0 year) up to 26 years [Table 2].

Table 1. Recipes of the model mixes

<i>sample</i>	<i>quartz-sand</i> [% mass]	<i>CEM I</i> <i>52.5 N</i> [% mass]	<i>lime</i> [% mass]	<i>anhydrite</i> [% mass]	<i>calcite-filler</i> [% mass]	<i>aluminium-powder</i> [% mass]	<i>water/solid</i> <i>ratio</i>
M0	58	15	15	0	12	0.05	0.65
M1	58	15	15	1	11	0.05	0.65
M3	58	15	15	3	9	0.05	0.65
M4	58	15	15	4	8	0.05	0.65

2.1.2 Drilling cores and stored AAC units

Four drilling cores (DC) were taken from four different buildings distributed over Germany [Table 2].

Table 2. Location and ages of taken cores.

<i>sample</i>	<i>age</i> [years]	<i>geographic</i> <i>region</i>
DC1	42	south-western Germany
DC2	37	central Germany
DC3	34	south-eastern Germany
DC4	28	eastern Germany
AU	0,1,2,3,5,8,13,26	southern Germany

2.2 Sample Characterisation

2.2.1 Sulphur analysis and qualitative phase analysis

The material was characterised in the centre of the drilling core [Fig. 1]. A Philips PW 1800 diffractometer with autosampler employing CuK α radiation and graphite secondary monochromator was used. Measurements were performed over a 4-60° 2 θ range, with a 0.02 2 θ step size and a exposure time of 1s/step. Automatic divergent slits were used to maintain an illuminated sample length of 10 mm. Qualitative analysis was performed by using Panalytical's High Score.

The samples were treated before measurement with isopropanol in a McCrone micronising mill. The milled material was prepared into a back loaded sample holder. Carbon/sulphur analysis was performed by the use of an Eltra CS 800 device. The results are given as SO₃ total from sulphate in the final product.



Figure 1. Photograph of a taken core sample (on the left) with the analysed areas CS1 = compressive strength 1, CS2 = compressive strength 2, CA = chemical sulphur analysis and qualitative phase analysis; (on the right) compressive strength testing cubes

2.2.2 Compressive strength testing

An universal hydraulic compressive strength testing device from Toni Technik was used. The compressive strength of the drilling cores was determined from two cylinders with a length and diameter of 75 mm [Fig. 1].

The compressive strength of both the model substances and the stored AAC units was measured on three cubes of the size 100 mm x 100 mm x 100 mm. The cubes were cut out from the base, mid and top of the AAC unit. In the lab samples they were taken from the base.

In this paper, the samples are compared with their compressive strength as well as with their so called A-value. The A-value represents a relative level of the strength of AAC.

The bigger the A-value the better the level of stability. The A-value depends on the raw density and the compressive strength and can be described as followed: $A\text{-value} = CS / RD^2 \times 0.016$; with: CS = compressive strength [N/mm²], RD = raw density [kg/dm³], 0,016 = const. [Zörn 1997].

2.2.3 Determination of the shrinkage behaviour

According to RILEM [1993] water saturated specimens (40 mm x 40 mm x 160 mm) were dried at a temperature of 20 °C and a relative humidity of 43 % to the equilibrium moisture content, where the shortening of the specimens was recorded. The value of shrinkage in this paper is the complete change of the length from water saturated to equal moisture for this climate.

All tests were performed in a climate chamber (Feutron KPK 400.V).

3 RESULTS AND DISCUSSION

3.1 Model substances

The X-ray powder diffraction patterns of the model substances are shown in Fig. 2. The mineral phases are tobermorite, quartz, calcite and anhydrite. The peaks of tobermorite and anhydrite increase with increasing sulphate content [Fig. 2]. Calcite peaks gain intensity with decreasing calcite filler content. The AAC samples also show increasing compressive strength with increasing sulphate content. Finally, the measurement of the shortening shows decreasing shrinkage values with increasing amount of calcium sulphate.

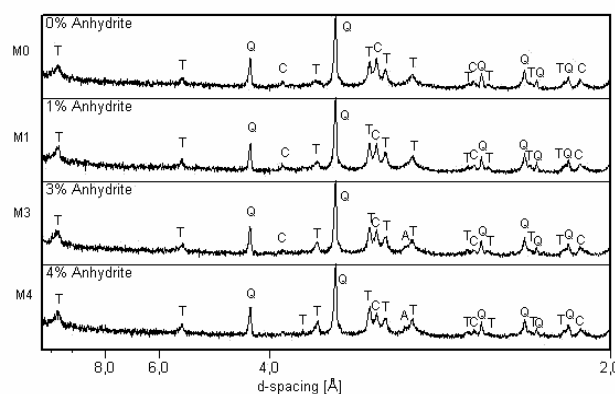


Figure 2. X-ray diffraction patterns of AAC with various amounts of sulphate. T = tobermorite, Q = quartz, C = calcite, A = anhydrite.

Table 3. Material properties of the model substances

Sample	Anhydrite [% mass*]	SO ₃ [% mass**]	Raw density [kg/m ³]	Compressive strength [N/mm ²]	A- value [a.u.]	Shrinkage value [mm/m]
M0	0	0.63	454	3.02	917	0.40
M1	1	0.91	440	3.45	1113	0.38
M3	3	1.99	441	3.80	1224	0.36
M4	4	2.29	433	3.90	1299	0.34

* of dry mix; ** of final product

3.2 Drilling Cores

The chemical analysis reveals, that sample DC1 has the highest amount of SO₃ (3.41 % mass), followed by DC2 (2.17 % mass), DC3 (1.98 % mass) and DC4 (0.89 % mass) [Table 4].

The compressive strength testing shows that sample C1 has the highest A-value (1104) followed by DC2 (1245), DC3 (972) and DC4 (686). The amount of sulphate determines the durability of the material, since the A-value increases with increasing amount SO₃ from sulphate. The compressive strength is less dependent from time than from the optimum mixture with its sulphate content. The samples (D1-D4) still fulfil the essential compressive strength values for building materials and buildings.

The X-ray diffraction analysis reveals in all samples tobermorite, quartz, anhydrite and calcite [Fig. 3]. Quartz is an residual product whereas anhydrite is a new formation. The amount of anhydrite increases parallel to the amount of SO₃. The intensity of calcite increases from sample DC1 to DC4. Low calcium sulphate content leads to an increasing formation of calcite, due to the higher CO₂ uptake [Fig. 3].

Table 4. Material's properties of the taken cores.

Sample	Age [years]	Raw- density [kg/m ³]	Compressive strength [N/mm ²]	A- value [a.u.]	SO ₃ [% mass*]
DC1	42	442	3,45	1104	3,41
DC2	37	496	4,90	1245	2,17
DC3	34	593	5,47	972	1,98
DC4	28	656	4,72	686	0,89

* of final product

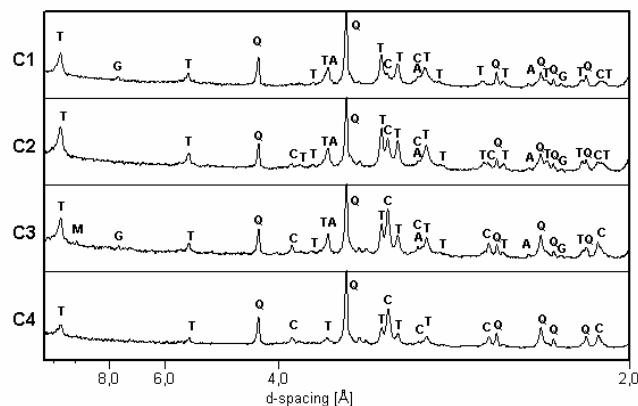


Figure 3. X-ray diffraction patterns of the 4 AAC drilling cores. T = tobermorite, Q = quartz, C = calcite, A = anhydrite, G = gypsum, M = muscovite.

3.2 Stored AAC units

Due to subsequent compressive strength testing, there is no detectable loss of compressive strength during the last 26 years of storage [Fig. 4]. The material did not lose its function of stability. AAC is durable, because it obviously has not changed its properties within 26 years.

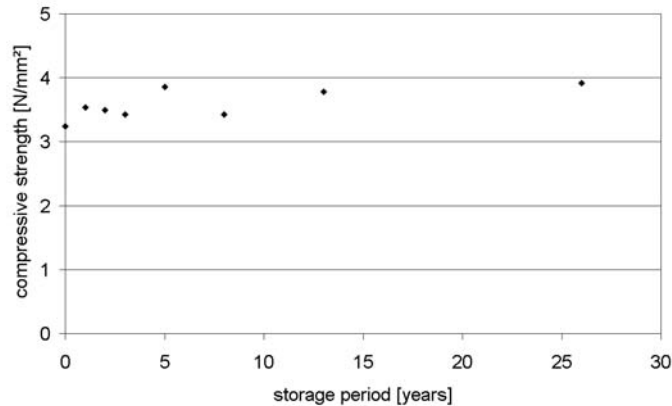


Figure 4. Compressive strength of sample AU after various storage periods.

4 CONCLUSIONS

Correlations between phase formation, mechanical properties and durability were proved with examples. The compressive strength testing reveals, that there is no loss of compressive strength over life time if calcium sulphate is used in the production of AAC. The addition of calcium sulphate leads to an intensified formation of the better crystallised C-S-H phase tobermorite.

AAC with well crystallised tobermorite is not substantially influenced by CO₂ under normal atmospheric conditions.

Due to these results, it was conducted that AAC is durable and does not lose its function of stability during long term application.

REFERENCES

- Taylor, H.F.W. 1964, 'The Calcium Silicate Hydrates', in *The Chemistry of Cements*, Academic Press, London, pp. 167-232
- Clementi, F. 1967, 'Verfahren zur Herstellung von dampfgehärtetem Gasbeton', *German patent, Aktenzeichen DE 16 46 580.8-45 (H 62442)*, Bundesrepublik Deutschland, Deutsches Patentamt
- Zürn, S.G. 1997, 'Einfluss der Sandminerale auf die Bildung von Calciumsilikathydraten (CSH-Phasen), das Gefüge und die mechanischen Eigenschaften von Porenbetonprodukten', Logos Verlag Berlin
- RILEM 1993, *Autoclaved Aerated Concrete – Properties, Testing and Design*, eds. S. Aroni, G.J. de Groot, M.J. Robinson, G. Svanholm & F.H. Wittman, E & FN SPON, London