A TECHNICAL PAPERPRESENTATION ON

Autoclaved Aerated concrete (AAC, Aircrete)

Abstract:

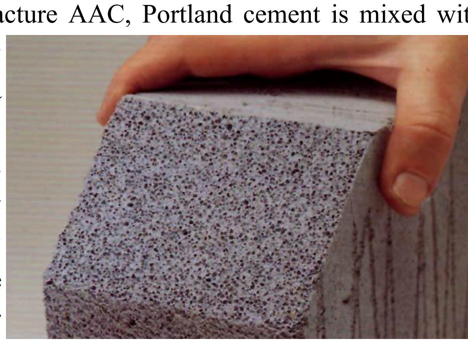
Autoclaved aerated concrete is a versatile lightweight construction material and usually used as blocks. Compared with normal (i.e.: "dense" concrete) aircrete has a low density and excellent insulation properties. Autoclaved Aerated Concrete (AAC) is a precast structural product made with all-natural raw materials. In 1914, the Swedes discovered a mixture of cement, lime, water and sand that expands by adding aluminum powder. The material was further developed to what we know today as autoclaved aerated concrete (also called autoclaved cellular concrete). It is an economical, sustainable, solid block that provides thermal and acoustic insulation as well as fire and termite resistance. In this paper we have made an attempt to give clear cut information about AAC and its production, composition, installation, environmental and other benefits.

Introduction:

The low density is achieved by the formation of air voids to produce a cellular structure. These voids are typically 1mm - 5mm across and give the material its characteristic appearance. Blocks typically have strengths ranging from 3-9 Nmm-2 (when tested in accordance with BS EN 771-1:2000). Densities range from about 460 to 750 kg m-3; for comparison, medium density concrete blocks have a typical density range of 1350-1500 kg m-3 and dense concrete blocks a range of 2300-2500 kg m-3.Autoclaved aerated concrete block with a sawn surface to show the cellular pore structure. Autoclaved aerated concrete blocks are excellent thermal insulators and are typically used to form the inner leaf of a cavity wall. They are also used in the outer leaf, when they are usually rendered, and in foundations. It is possible to construct virtually an entire house from autoclaved aerated concrete, including walls, floors - using reinforced aircrete beams, ceilings and the roof. Autoclaved aerated concrete is easily cut to any required shape. Aircrete also has good acoustic properties and it is durable, with good resistance to sulfate attack and to damage by fire and frost.

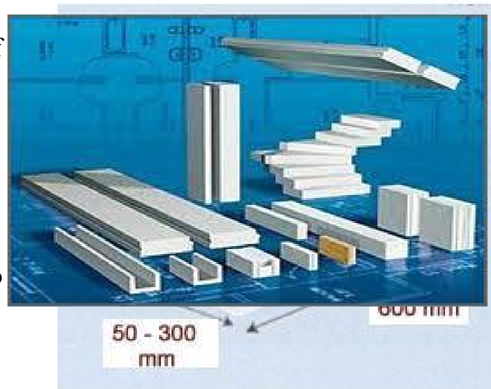
Production:

To manufacture AAC, Portland cement is mixed with lime, silica sand, or recycled fly ash (a byproduct from coal-burning power plants), water, and aluminum powder or paste and poured into a mold. The reaction between aluminum and concrete causes microscopic hydrogen bubbles to form, expanding the concrete to about five times its original volume. After evaporation of the hydrogen, the now highly closed-cell, aerated concrete is cut to size and formed by steam-curing in a pressurized chamber (an autoclave). The result is a non-organic, non-toxic, airtight material that can be used for wall, floor, and roof panels, blocks, and lintels which according to the manufacturers, generate no pollutants or



hazardous waste during the manufacturing process

Autoclaved aerated concrete is cured in an autoclave - a large pressure autoclave is normally a steel tube some 3 meters in diameter and 45 meters long. high pressure, typicallyreaching a pressure of 800 kPa and a temperature of 180 Â°

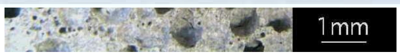


Autoclaved aerated concrete can be produced using a wide range of cementitous materials, commonly:

• Portland cement, lime and pulverized fuel ash (PFA)

Or

• Portland cement, lime and fine silica sand. The sand is usually milled to achieve adequate fineness.



A small amount of anhydrite or gypsum is also often added.Autoclaved aerated concrete is quite different from dense concrete (ie: “normal concrete”) in both the way it is produced and in the composition of the final product. Dense concrete is typically a mixture of cement and water, often with slag or PFA, and fine and coarse aggregate. It gains strength as the cement hydrates, reaching 50% of its final strength after perhaps about 2 days and most of its final strength after a month.

In contrast, autoclaved aerated concrete is of much lower density than dense concrete. The chemical reactions forming the hydration products go virtually to completion during autoclaving and so when removed from the autoclave and cooled, the blocks are ready for use.Autoclaved aerated concrete does not contain any aggregate; all the main mix components are reactive, even milled sand where it is used. The sand, inert when used in dense concrete, behaves as a pozzolan in the autoclave due to the high temperature and pressure.

The autoclaved aerated concrete production process differs slightly between individual production plants but the principles are similar. We will assume a mix that contains cement, lime and sand; these are mixed to form slurry. Also present in the slurry is fine aluminum powder - this is added to produce the cellular structure. The density of the final block can be varied by changing the amount of aluminum powder in the mix. The slurry is poured into moulds that resemble small railway wagons with drop-down sides. Over a period of several hours, two processes occur simultaneously: The cement hydrates normally to produce ettringite and calcium silicate hydrates and the mix gradually stiffens to form what is termed a "green cake".

The green cake rises in the mould due to the evolution of hydrogen gas formed from the reaction between the fine aluminum particles and the alkaline liquid. These gas bubbles give the material its cellular structure.There are some parallels between autoclaved aerated concrete production and bread-making. In bread, the dough contains yeast and is mixed, then left to rise as the yeast converts sugars to carbon dioxide.The dough must have the right consistency; too hard and the bubbles of carbon dioxide cannot 'stretch' the dough to make it rise, but if the dough is too sloppy, the carbon dioxide bubbles rise to the surface and are lost and the dough collapses. With the right consistency, the dough is sufficiently elastic to stretch and expand, but strong enough to retain the gas so that the dough does not collapse. When risen, the dough is placed in the oven.

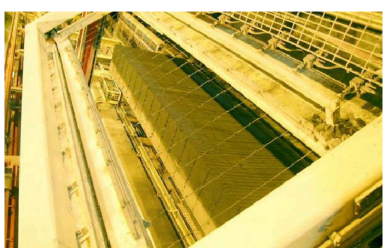
Although a much more complex process, Aircrete production conditions are precisely-controlled for, in part, somewhat similar reasons. The mix proportions and the initial mix temperature must be correct and the aluminium powder must be present in the required amount and with the appropriate reactivity an an alkaline environment. All of the materials bebe of suitable fineness. A complicating factor is that the temperature of the green cake increases due to the exothermic reactions as the lime and the cement hydrate, so the reactions proceed faster. When the cake has risen to the required height, the mould moves along a track to where the cake is cut to the required block size. Depending on the actual production process, the cake may be demoulded entirely onto a trolley before cutting, or it may be cut in the mould after the sides are removed.

The cake is cut by passing through a series of cutting wires. At the cutting stage, the blocks are still green - only a few hours has passed since the mix was poured into the mould and they are soft and easily damaged. However, if they are too soft, the cut blocks may either fall apart or stick together; if they are too hard, the wires will not cut them - here too, the process has to be carefully controlled to achieve the necessary consistency.

The cut blocks are then loaded into the autoclave. It takes a couple of hours for the autoclave to reach maximum temperature and pressure, which is held for perhaps 8-10 hours, or longer for high density/high strength aircrete. When removed from the autoclave and cooled, the blocks have achieved their full strength and are packed ready for transport.First steps to produce AAC on an international level were taken by Hebel in 1967, by creating a business relation with Asahi Chemical Material Co. Japan. Japans AAC industry is well developed and after the unexpected stability of AAC buildings during the 1995 Kobe earthquake a rising demand of AAC is to verify.
Since Hebel and Ytong merged under XELLA Holding in 2000 their AAC Plants can be find in Germany, Austria, Belgium, Bulgaria, Croatia, Czech Republic, France, Hungary, Holland, Poland, Slovakian Republic, Slovenia, Switzerland, USA, Mexico, Thailand, Chile, Malaysia, Indonesia, Peoples Republic of China, Japan, Australia, Turkey, Israel, Kuwait and Saudi Arabia.

The three leading AAC plant manufacturers:

1. HESS Maschinenbautechnik
2. WEHRHAN
3. MASA-HENKE



AAC Composition:

The essence of aircrete production is that lime from the cement and lime in the mix reacts with silica to form 1.1 nm tobermorite.NB: Cement chemistry notation is used below. If you are not familiar with this, see our cement chemistry notation explained page. During the green stage, the cement is hydrating at normal temperatures and the hydration products are initially similar to those in dense concrete - C-S-H, CH and ettringite and/or monosulfate. After autoclaving, tobermorite is normally the principal final reaction product due to the high temperature and pressure.

Small amounts of other hydrated phases will also be present in the final product. Additionally, hydrated phases form in the autoclave as intermediate products, principally C-S-H (I). This is a more crystalline form of calcium silicate hydrate than occurs in dense concrete; it can have a ratio of calcium to silicon of $(0.8<Ca/Si<1.5)$ but 0.8 to 1.0 is desirable as this ratio facilitates the formation of 1.1 nm tobermorite.

The compositions of the hydration products in aircrete are therefore quite different from those in dense concrete cured at normal temperatures (i.e.: calcium silicate hydrate (C-S-H), calcium hydroxide (CH), ettringite and monosulfate. See the “hydration” page for more information).

Looking at this in a little more detail from when the green blocks enter the autoclave, the main reactions that occur are broadly as follows:

•Over 2 hours or so, as the pressure and temperature increase, the normal cementhydration products that formed in the green state progressively disappear and the sand becomes reactive.

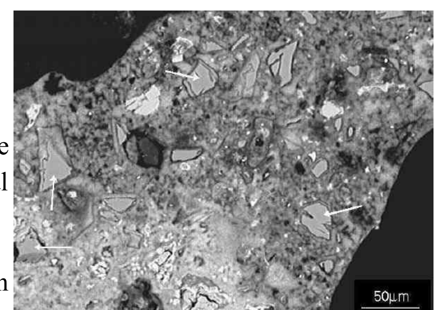
•C-S-H (I) forms, partly from silica derived from the sand.

•As more sand reacts, calcium hydroxide from the lime and from cement hydration is gradually used up by continued formation of C-S-H (I).

•With continued autoclaving, 1.1 nm tobermorite starts to crystallize from the C-S-H(I); the total proportion of C-S-H(I) declines and that of 1.1 nm tobermorite gradually increases. C-S-H (I) is therefore mainly an intermediate compound.

The final hydration products are then principally:

- 1.1nm tobermorite
- Possibly some residual C-S-H(I)
- Hydro garnet



Unreacted sand is likely to remain in the final product. There may also be some residual calcium hydroxide if insufficient silica has reacted and some residual anhydrite and/or hydroxyl-ellestadite if anhdrite was present in the mix.

SEM image of polished section showing a detail - a cell wall - of a block made with cement, lime and sand mix. Some residual unreacted sand particles remain (examples arrowed), often with rims of hydration product showing the size of the original particle. Most of the matrix is composed of tobermorite. Black areas at top left and bottom right are epoxy resin used in preparing the polished section filling air voids (air cells).

The objective is to react sufficient silica from the sand to form tobermorite from the available lime supplied by the lime and cement. This will depend on a range of factors, including the inherent reactivities of the materials, their fineness (especially the sand), and the temperature and pressure. If the autoclaving time is too short, the tobermorite content will not be maximized and some unreacted calcium hydroxide will remain and block strengths will be then less than optimum. If the autoclaving time is too long, other hydration products may form which may also be detrimental to strength and an unnecessary energy cost will be incurred.

There are different forms of tobermorite: 1.1 nm tobermorite and 1.4 nm tobermorite. Also, there are different types of 1.1 nm tobermorite and these behave differently when heated. Their crystal structure is that of layered sheets, with water molecules between the layers - on heating, the inter-layer water is lost; as a result, some 1.1 nm tobermorites shrink (a process known as lattice shrinkage) but some don’t.

1.4 nm tobermorite ($C_5S_6H_9$) - forms at room temperature and is found as a natural mineral. It decomposes at 55 Â°C to 1.1 nm tobermorite, and so is not found in AAC.

Calcium silicate hydrate compositions in AAC

- 1.1 nm tobermorite ($C_5S_6H_5$) is usually the main hydration product in AAC where cement, lime and sand are used
- C-S-H (I) - more crystalline than C-S-H in dense concrete, typically $0.8<Ca/Si<1.0$.
- Xonotlite (C_6S_6H) - forms with longer autoclaving times, or higher temperatures

'Normal ‘tobermorite shows lattice shrinkage, while non-shrinking tobermorite is called 'anomalous' tobermorite. Tobermorite in AAC made with cement, lime and sand is usually normal tobermorite. Tobermorite in autoclaved aerated concrete made with cement, lime and PFA is usually anomalous tobermorite. Aluminum and alkali together in solution (such as will be present in mixes of cement, lime and PFA) tend to produce anomalous tobermorite, with some aluminum and alkali taken up into the tobermorite crystal structure. The differences between the different forms of autoclaved calcium silicate hydrates are not well-defined; in an AAC block, intimately-mixed hydrates of different compositions and crystalline are likely to occur.

Other hydrothermally-formed minerals

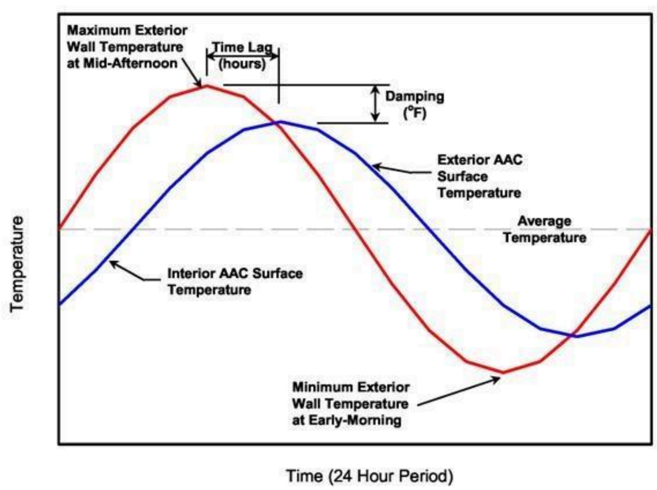


Figure 2 Thermal Damping and Lag

- Gyroplane ($C_2S_3H_2$) - not normally found in AAC
- Jennie ($C_9S_6H_{11}$) occurs as a natural mineral; not found in AAC
- C-S-H (II) - $Ca/Si \approx 2.0$. Does not occur in AAC
- C_2SH (α-C_2S hydrate) can occur in autoclaved products but is undesirable

Hydroxyl-ellestadite ($C_{10}S_3.3SO_3.H_2O$) - may be found in AAC; also occurs at the cooler end of cement kilns

Features:

AAC features include structural capacity, thermal, fire, and acoustical resistance properties. With an R-value of approximately 1.25 per inch, dependent on density, AAC significantly outperforms conventional concrete block or poured concrete. Consistency in quality and color may be difficult to obtain in AAC made with fly ash. Unfinished exterior walls should be covered with an exterior cladding or parged with mortar when exposed to physical damage, dirt, and water, because atmospheric debris can collect in the open cells. If installed in high humidity environments, interior finishes with low vapor permeability, and exterior finishes with a high permeability are recommended.

Because of the thermal mass of AAC and its ability to store and release energy over time, AAC may bebeneficial in climates where outdoor temperature fluctuates over a 24-hour period from above to below the indoor temperature conditioned air set point.

AAC units are available in numerous shapes and sizes. Panels are available in thicknesses of between 8 inches to 12 inches, 24-inches in width, and lengths up to 20 feet. Blocks come 24”, 32”, and 48” inches long, between four to 16 inches thick, and eight inches high

Attributes:

- The insulating properties of AAC, when compared with conventional concrete, make it an energy-efficient choice.
- AAC is recyclable.
- AAC is naturally resistant to fire, termites, and fungal decay.

Ease of Implementation:

AAC can be cut with conventional saws and tools. The lightweight, precast blocks are stacked like conventional concrete masonry units (CMU).Panels is usually installed by crane. Reinforcement bar is placed in panel joints for continuity and diaphragm performance.

Initial Cost :

ACC walls that are installed as block units cost approximately RS:120 in 8” x 8” x 24”, or $2.30 per square foot. This is comparable in price to the cost of concrete masonry units (CMU). Labor may be slightly less because the lighter weight of the units allow faster installation, however, this efficiency does not inure to the builder under piecework contracts which are common to masonry trades.

Operational Cost :

Compared with conventional CMU, AAC will have lower energy costs because it has a greater thermal resistance (approximately R-10 vs. less than R-1 in 8” thicknesses).

Installation:

The light weight of AAC makes shipping and handling more economical AAC block is installed with a thin-set mortar that limits leveling adjustments by masons. Block or panels are cored and filled with grout and reinforcement bar at stated intervals.

The material is easy to finish, too. Exterior walls can be painted, plastered, or finished with claddings like vinyl siding or fiber-cement siding. Interior surfaces can be plastered, sheet rocked, tiled, painted, or simply left exposed

Environmental benefits of Autoclaved Aerated Concrete:

The use of autoclaved aerated concrete has a range of environmental benefits:

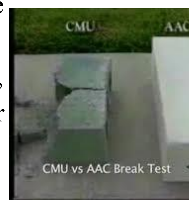
•**Insulation:** Most obviously, the insulation properties of aircrete will reduce the heating costs of buildings constructed with autoclaved aerated concrete, with consequent fuel savings over the lifetime of the building.

•**Materials:**Lime is one of the principal mix components and requires less energy to produce than Portland cement, which is fired at higher temperatures. Sand requires only milling before use, not heating, and PFA is a by-product from electricity generation. NB: lime may require less energy to manufacture compared with Portland cement but more CO2 is produced per tonne (cement approx. 800-900 kg CO2/tonne compared to lime at 1000 kg CO2 per tonne).

•**Carbonation:**Less obviously, the cellularstructure of aircrete gives it a very high surface area. Over time, much of the material is likely to carbonate, largely offsetting the carbon dioxide produced in the manufacture of the lime and cement due to the calcining of limestone.

DURABILITY

Durability and its environmental impact is an important factor when considering the use of a building material. Autoclaved Aerated Concrete is proven to be a very durable material - will not rot, warp, rust, corrode, or otherwise decompose.



Provides a very low maintenance, cost & time, saving solution for your building consideration.

HIGH THERMAL INSULATION

AAC has exceptional thermal insulating qualities. Buildings constructed with **AAC** tend to be cooler in summer and at the same time you can enjoy energy & cost savings on electricity.

FIRERESISTANCE

AAC is an inorganic material that does not burn. The melting point of Autoclaved Aerated Concrete is over 1593ºC, more than twice the typical temperature in a building fire of 649ºC.

AAC conform to **BS 476 (British Standards)** and**AS 1530.4 (Australian Standards)** to a 240 minutes fire rating test.

ACOUSTICINSULATION

A commonly overlooked environmental problem is noise pollution. The solid wall construction of a building made of **AAC** provides exceptional acoustic insulation. Its porous structure & high surface mass, coupled with its ability to dampen mechanical vibration energy, greatly reduces outside environmental noise pollution & the indoor echo effect in empty room thus providing a quieter and more comfortable interior for the occupants.

PEST&MOLDRESISTANCE

AAC is an inorganic, insect resistance, solid wall construction material. It is impossible for insects & rodents to inhabit in them. **AAC** is also Mold resistance. The typical nutrient source for mold is moisture damaged building materials. **AAC** is breathable, concrete product made with clean, inorganic materials, does not offer the nutrients for mold growth.

IMPROVED INDOOR AIR QUALITY

AAC is an inorganic material that contains no toxic substances & does not decompose or release gas. Since Autoclaved Aerated Concrete is a structural and insulation material, it allows the elimination of other materials that may contribute to poor indoor air quality.

WORKABILITY

AAC blocks are quickly & accurately cut with a band saw to the desired dimensions, and into accurate angles and other shapes. **AAC** can also be drilled, nailed, grooved, routed, shaped, sculpted, carved, coated, floated, screwed into and milled with common tools & finish with paint, tile, drywall or veneer. Window trim, chases for plumbing, wiring & outlets and decorative features like keystones, window sills and column can easily be created on the job site.

SIMPLIFIEDCONSTRUCTION

AAC simplifies construction by minimizing the number of different building products involved. Building owners may see a significant reduction of maintenance and energy costs as well as an increase in overall comfort and safety.

Conclusion:

AAC products and its manufacturing is to be considered as part of a sustainability policy imposed by more and more high developed industrial nations to answer on energy demand and environmental protection while keeping up their standard of living. The accessibility of raw material sources in almost any country worldwide and the low energy consumption in its production process makes AAC also to the material of choice for developing countries and nations with rather low national energy supply.

Surprisingly India which is in a present industrial boom is rather slow in building up a AAC industry. AAC is known there as CLC (Cellular Lightweight Concrete) and a New Deli based Government owned company, the Hindustan Prefab Limited (HPL) is know to be the only Plant in India to produce AAC. There where several attempts of European companies to enter the Indian mart but all attempts failed so fare, which is said to be caused by the high level of corruption taking almost any efforts to operate independently. There is a lose interest by several Indian investors to buy used plants, but significant effort to build up a net for AAC production and distribution could not be detected throughout the year 2005 -2006.

- *AAC is a green building material. It has little manufacturing impact, is recyclable, does not off gas and provides termite, water, fire, and sound resistance.*

References:

http://www.hebel.co.nz/about/hebel%20history.php

^ [ab]Swedish Association of Historical Buildings: Pioneering work in the early days of concrete - history 1890–1950 (from *Byggnadskultur* issue 4/2004)**(Swedish)**

^http://www.buildinggreen.com/auth/productsByCsiSection.cfm?SubBuilderCategoryID=6854

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