ABSTRACT: A summary of worldwide Autoclaved Aerated Concrete (AAC) products will highlight the different global production developments, market cultures and applications of AAC building materials. The recent developments in modern AAC production technology are also reviewed, including a discussion of Tilting, Flat Cake and Combination systems. This review will highlight production capability and capacity, manufacturing cost and product versatility. A brief analysis of key trends in the AAC market as well as tips on production technology concludes the paper.

1 A WORLD REVIEW OF AAC DEVELOPMENTS

1.1 Western Europe

Western Europe has several different building cultures all of which rigorously compete for their own market share of the building materials industry. The AAC market struggled in the last years as the construction industry in general experienced an economic downturn that enhanced the competition between manufacturers of different building materials. Currently in Western Europe, the AAC market is showing signs of growth and is generally considered a block market. For several reasons, the AAC industry has been unsuccessful increasing the reinforced element market and production levels. In the 1960’s and 70’s, the reinforced element market was seriously impeded due to problems with production and quality. In addition to quality issues, price levels compelled architects and contractors to use other materials, such as hollow-core concrete panels, precast concrete elements, steel constructions and wood. Therefore, blocks have become the dominating product and have the largest AAC market share in Western Europe.

The UK for instance is a typical block market where both sand based as well as Pulverised Fly ash are used in the block production. Typical block dimensions differ from the continent with a height of 215 mm, and 440 mm - 620 mm length . The UK market offers a versatile range of products for inner leafs, floor blocks and foundation blocks below DPC etc. Block product tolerances vary considerably within the production standards; however, these variations have little to no impact as long as mortar is properly used in the installation. Thin mortar layer installation for quicker and improved building remains underutilized in the UK market, as blocks used for thin joint require a higher accuracy (see EN 771-4). The need to produce higher accuracy product will demand significant investments for most of the UK factories. Additionally, tongue and grooves as well as handholds are not yet a regular practice in this market. It is likely that manufacturers and resellers will bring AAC products to the market as well as building material system suppliers offering full system concepts. In the long term, we are convinced that application versus best quality and best price, integral calculated, will be the determining factor in realizing a greater AAC market share.
In the Netherlands, there is an entirely different AAC market. Competition with other building materials, such as precast elements, hollow core concrete slabs, Sand lime bricks, Self-compacting concrete (SCC), and metal stud construction, is very stiff. This competition forced AAC manufacturers to another approach in the 1980’s and 90’s. The AAC industry has gained and will continue to increase market share by better utilizing the specific and unique properties of AAC as well as developing systems to build quicker and better at a lower cost compared to other building materials. Currently, the Netherlands AAC market for inner leaf panels, partition, firewalls and Casco systems is considered a significant success. The AAC market is shifting from m$^3$ to m$^2$ production, which means it is moving away from pallets of standard blocks to prefabricated wall systems ready for installation at the work site. Another innovative product that has increased AAC’s competitiveness and has great worldwide potential is super smooth panels that are immediately ready for finishing without any need for stucco. The other remarkable building process that has enhanced the use of AAC is the dry stapling method without mortar or thin joint, in which the AAC blocks have a groove and strip to secure position. Builders in the Netherlands view the dismountable and reusable nature of AAC blocks as a significant advantage.

In the German AAC market, which is primarily a block market, significant market increase has already been achieved due to the use of innovative jumbo-sized blocks. These large blocks were primarily developed to increase building speed. Thin joint construction is generally accepted in Germany and recognized as a considerable advantage. It is used in most building sites for quicker and higher quality building. Another innovation is the gluing of U-blocks with hot melt that allows for more efficient and less expensive production.

1.2 Eastern and Southern Europe

The Eastern European AAC market is primarily a block market that is showing signs of significant growth with millions of m$^3$ consumed annually. The Russian and Polish markets are demonstrating the strongest growth; however, these markets remain dominated by blocks produced to their own standards and quality levels. The recent construction of several new manufacturing plants in the region demonstrates the market growth. Italy, Spain, and Greece are showing much slower market growth though AAC is a good material for these warm climates due to its insulation properties.

1.3 The Middle East

The Middle East is currently a typical block market used for gap filling and walls that has potential for a significant capacity increase for utilization of AAC. Recently, block profiling and handholds were introduced in the AAC market. The unique properties of AAC are well known and accepted as a first class building material and market research to harmonize the products with the cultural and geographical conditions of the Middle East is nearing completion. The Middle East market for reinforced material is slowly developing. Middle Eastern AAC market growth is substantiated by the construction of several production plants.

1.4 Asia

The use of AAC in Asia is remarkably innovative and the Asian markets are growing rapidly within the AAC industry. Specifically, Japan is one of the Asian countries where AAC developed as a high quality, flexible building material. The applications and building systems for AAC in Japan differ greatly from those in Western Europe, especially the use of AAC systems for seismic building technology. Thin reinforced panels used as cladding for high-rise construction are earthquake resistant due to both vertical and horizontal panel’s ability to shift when under seismic stress. Another Japanese innovation is the use of thin panels with a perfect smooth surface, custom pattern or even coating that provides AAC products with considerably more added value and greater options for building facade finishing.
1.5 North America

North America remains a developing market as AAC products have a very limited market share in the building industry. For several reasons, the marketing of AAC as an alternative building material and the achievement of technological improvements is slow to succeed. In the United States block market, the standard hollow concrete CMU is the primary competitor. However, the installation of CMU in the United States continues as a labor-intensive process. In our opinion, the utilization of large size AAC blocks produced to US standards and installed with thin joint techniques would considerably increase building speed and allow for an increase in market share for AAC. With greater technology transfer and improved expertise in the US, the large sized AAC block may become a very successful building material within a short time. We envision promising market opportunities for companies offering full system concepts with top quality reinforced products and high building installation speed.

An innovative application developing in the US is the use of AAC for decorative elements. Freely formed products are creatively used for balustrades, sills, columns and wall finishings. These decorative elements are produced with special sawing and milling tools, which are reliable and quickly implemented.
1.6 AAC Prefabrication Trend

At the end of the 1990’s significant effort was made by the Sand Lime Brick industry to develop and deliver prefabricated walls direct to the building site. The AAC industry, primarily in Western Europe, reacted to this advancement and is currently researching and testing different prefabricated options. However, developing the market is taking a longer period than is desirable. The hope is that the development of prefabricated AAC products will succeed in gaining a greater market share. At this point though, AAC as a ready-made façade has not developed enough for use in industrial buildings.

In order to gain maximum results with prefabricated AAC elements, it is necessary to have building systems that include other periphery concepts such as window glass energy. In several countries, we see a trend towards: IFD.

I = Industrial method of building (i.e. from building site to factory)
F = Flexible and individualized production
D = Dismountable and reusable product

The increase of prefabricated elements has allowed work previously completed at the building site is now possible at the factory. Additionally, prefabrication allows for better-organized and more efficient building practices due to less stakeholder involvement in the construction process and weather not affecting building material production at a factory.

Figure 5. Prefabricated AAC wall elements

1.7 AAC Market Competition

In the Benelux countries, developments in professional high-speed building practices are occurring quickly. Building a house in a week is no longer an exceptional accomplishment. Manufacturers can deliver complete facades with other complementary building materials and components with efficient logistics directly to the building site. An example of this building system is a manufacturer in the Netherlands that is potentially able to prefabricate 95% of a building in their factory. There is considerable potential for AAC manufacturers to add complementary elements to complete façade systems. However, these prefabricated elements should not use conflicting materials, as the focus should be on AAC as much as possible.

Figure 6 and 7. Competition prefabricated wall elements
2 AAC MODERN PRODUCTION TECHNOLOGY

2.1 Raw Materials Preparation

The technology used for raw materials preparation is essentially the same as that used 30 years ago. However, modern laboratory technology equipment has made it possible to monitor the supplied raw materials quicker and with greater accuracy. This enhanced monitoring has resulted in a more consistent and precise recipes with a corresponding improvement of the entire AAC production process. Raw material preparation has also been enhanced by the increase in automation for feeding, grinding and slurry handling in many factories, so that much of the operation is now unmanned.

Good plant engineering and component selection are key factors for reliable plant operation at the lowest possible cost. New liner materials in ball mills in many plants have resulted in reduced maintenance and considerable increase in operating lifetime. The development of orbital tube-type storage slurry mixers demonstrate high performance with a significant decrease in energy consumption and enhanced reliability.

2.2 Weighing and Dosing

New weighing and dosing technological developments have improved accuracy and flexibility in the production process. The introduction of the soft Industrial-based PC technology has simplified the mixer-control hardware systems. These systems offer nearly endless flexibility with more possibilities of raw material components, decrease installation cost and make manufacturers less dependent on ridged Programmable Logic Controller (PLC) platform systems. The improved accuracy has allowed for better consistency and leaner recipes for AAC production. Additionally, weighing and dosing improvements has resulted in increased safety of aluminum systems.

2.3 Mixer Technology

Mixers used in the AAC production process are classified in three categories: the high, medium and low speed. Respectively, these mixers use double screw, propeller and multi-paddle types of mixing mechanism. It is important for each manufacturing plant to select the proper type of mixer depending on the raw materials and specific process used for production. Special PU coatings now allow for easier cleaning and less maintenance of the mixers, which results in reduced long-term operating costs.

![Figure 8. High speed mixer](image)

![Figure 9. Low speed multi paddle mixer](image)
2.4 Cutting Technology

‘Green’ cutting technology is often perceived as the heart of an AAC production plant. The cutting technology is the essential process of production as it determines the accuracy, geometry and finish of the AAC product. Many production process names created in the past, but still used to this day, are related to different cutting technology methods. In the last ten years, the performance of ‘green’ cutting technology has increased considerably. The highlights of the new cutting technology include, profiles, handholds, all-side cutting and hollow block cutting. Currently, the cutting systems are generally classified as:

- Flat Cake Systems (cake cakes are processed horizontally)
- Tilt Cake Systems (cakes are tilted 90° vertical for further processing)
- Combination Systems (cakes are tilted and subsequently tilted back)

Each system has now developed into a robust and reliable production process due to considerable improvement of ‘green’ cutting technology. However, not all products can be produced in the same quality with each of the different techniques. The resulting differences may be significant in terms of surface quality, profiling options, format size and dimensional accuracy.

2.4.1 Tilt Cake System Development

The tilt cake system was originally designed and operated as a system without the use of a bottom layer. After pre-curing the cake is turned 90° and brought to the cutting line. Tilt cake systems have had a turbulent development in Western Europe over the last eight years, but is now starting to gain greater stability. Approximately 14 factories have implemented the Durox double shaft cross cut system in their Tilt cake systems. This introduction has considerably improved block accuracy height at a critical dimension of 200 and 250 mm. Tilt cake products are now easily within the EN tolerances.

Currently, automated tilt cake systems are operating unmanned and have a high degree of flexibility in production. Cutting wire and profile knives cleaning and changing is now conducted with cell robotics within the cutting line. The cell robotics operate similarly to tool changers in the metal working industry. The use of an unmanned cutting line has resulted in less readjustment needs and maintenance. Additionally, automated cutting has significantly increased the safety level as no workers have to be in the hazard zone during production.

A disadvantage of the tilt cake system is that sticking of cured autoclaved products remains a problem. The sticking problems create a certain amount of inevitable breakage in every factory. The most common method for separating blocks is with hydraulic gripping and clamping. To resolve these sticking and fusing issues a few plants tilt the ‘green’ cake back after cutting and separate each layer of the ‘green’ shape on a grid frame. In this process, blocks are autoclaved horizontally as in the flat cake system. Most tilt cake systems currently operating are successfully used in the block production sector.

2.4.2 “Green” Waste Bottom Layer Removal

In order to improve AAC product quality, including accuracy, appearance and removal of concentrated oil, the bottom layer was introduced years ago. The bottom layer was used as a waste layer of approximately 40-70mm on the bottom of curing plates. In the mid-1990’s, dedicated efforts were made in the UK (Celcon) and Germany (Ytong) to remove the bottom layer in the ‘green’ state to save cost by avoiding unnecessary hard waste. Cakes were tilted, the bottom layer was removed and then the cakes were tilted back on a curing plate. Major manufacturers did not continue with this method because of remaining oil residues from the curing plates on the lower block layers. Appearance differences in the surface texture and color of the white sand based AAC blocks were also considered a potential marketing problem.

2.4.3 Flat Cake Systems

Flat cake production systems are available in several types. These systems are well known for their high accuracy and large sized products. One of the advantages of the flat cake systems is that the vertical cut side of the block or panel is the part of the product visible when installed. The smoothly cut surface is directly exposed whether the block or panel is used for a wall, roof or floor. Without sticking problems, long products up to 8 m with reinforcement can be pro-
duced in high quality using a flat cake system. Another remarkable advantage of the system is the possibility for the production of thin façade elements, partition panels and blocks. Products with a thickness of 28 mm are becoming more standard rather than an exception.

The Durox machines are operating in the purported One and Two section machine type. In the 2-section type, the ‘green’ cake moves through the wires and in the 1-section type wires move through the positioned cake. The 1-section machine was developed by Polish manufactur- ing in the mid-1980’s due to a lack of Western European spare parts. The buckle bridges below the strip bed as well as the screw type top crust remover are innovative solutions; however, the 1-section machine still has its limitations. Other than the discussed machines, there are several other flat cake systems in production, including the Siporex-Hebel and Stema systems.

2.4.4 Super Smooth Surface Cutting
Cutting technology research and development over the last twenty years has led to the ability to produce super smooth surface AAC. The research first started in the mid 1980’s in the Netherlands at a Durox plant under the direction of Wim Schreuders assisted by Jan Sleeuwenhoek. The research focused on the characteristics and possibilities from cutting AAC with high frequency moving wires. Prototypes were built and tested for several years and by the end of the 1980’s the first systems were in production at selected Durox plants. Combined with the high-speed cutting technology it was possible to create a closed, smooth surface with narrow product tolerances and the potential for new product applications. Special steel wires typically move with a high frequency wave of 20-50 Hz that cuts the ‘green’ cake with reduced mechanical forces, which produces highly accurate, thin smooth surface slices. This smooth surface cutting process can be referred to as SILCRETE finishing. The product surface is closed and compacted similar to the properties of sand lime bricks, while the internal material maintains the typical AAC cell structure.

With smooth surface cutting, the use of stucco for finishing is generally not necessary in most cases. Only a thin film to close the panel seal is sufficient for further treatment, such as direct coating, wallpaper or sometimes absolutely no further finishing. To connect the smooth surface products the thin joint is necessary or highly recommended for satisfactory installation. In the Netherlands, Scandinavia and Japan these smooth surface products are mass produced and have taken significant market share away from other building materials. Higher quality, faster installation and lower building cost was achieved with the product, so that the AAC market in these areas is increasing slightly in a relatively flat or even decreasing building market.

In the past year, research was completed with piezo actuators on wires as well as knives. Cutting wires and knives are now actuated with several kHz, which further improved the surface result considerably so that it is possible to be smoother than paper. This advancement is a promising development, but is not yet economically feasible for mass production.
2.5 Curing (Autoclaving)

In the last five years, the industrial PC was introduced to autoclaved silicate products market. Steam quantity, temperature, pressure and vacuum are now precisely controlled by intelligent software working on standard industrial PCs. The software allows the curing process to follow the pre-selected curves accurately for the selected products. The energy management is monitored and controlled by the system itself concerning boiler usage and steam transfer. Recent examples are available where 19% of energy was saved by controlling and managing the steam in a more efficient manner. This method of controlling autoclaves demonstrates a shift away from the usual expensive PLC platform systems with cabinets full of hardware. The capital investment for industrial PC systems is only a fraction of what it was in the past, allowing for significant improvements in this production area.

Another advancement in the curing process is the development of automatic opening and closing of the autoclave doors. The function of the autoclave operator can now shift to more of an observing operator role.
2.6 Unloading and Packaging

Highly standardized gantry robotics up to two tons payload are the most prominent development in the unloading process. These robotics offer flexibility with smooth and fast handling and continue to gain greater acceptance in the AAC industry. It is now possible to achieve a production of 160 Euro packs per hour with the efficient handling of gantry robotics. Cell robotics are presently making a successful entrance in auxiliary functions for pallet and product handling activities. However, the payload in relation to stiffness is limited, with payloads varying from 150 to 400 kg and in exceptional cases attaining 600 kg.

2.7 Sawing and Milling

It is generally impossible to avoid sawing and milling on finished AAC products. In the reinforced production market, it is common to mill and saw products according to customer specifications. Circle saw blades generally cut AAC products, including steel reinforced panels, to the requested dimensions. Diamond cable saws can cut special cavities and openings in reinforced produce as well as creating opportunities for free-form building walls.

An important milling development is the modern Computer Numerically Controlled (CNC) milling lines. This technology performs with the highest accuracy and flexibility against acceptable cost. In many cases where special and deep profiles are requested (flooring and roofing) a CNC milling machine performs the operation quickly and at low cost.

2.8 Steel Reinforcement

The AAC industry has been struggling already for many years with the flexibility and availability of reinforced production. There has been little economy of scale and a low degree of automation as every AAC manufacturer has attempted to develop their own solutions. This tends to result in inadequate availability and high cost. Other products, such as hollow core slabs and T beams, were often considerably less expensive to produce and purchase than reinforced AAC products.

New developments for steel reinforcement where steel from a 4-12 mm coil is straightened, cut and welded automatically for accurate cages are now possible. Currently, quantities of 2000 cages per day are achievable with this automated production process. The AAC industry should learn from the concrete industry in order to increase automation and economy of scale for reinforced products.

There is also a need for the European standardization committees to harmonize standards as soon as possible in order to make a simple cost effective and high volume production method available. Fragmented standards with regional, national or competition interests will limit the AAC reinforced market and drive demand further to other building material markets. Presently, the competitive difficulties of AAC reinforced product are due to high cost and a lack of economy of scale and specialization.

![Figure 14. Advanced steel reinforcement production system](attachment:image)
2.9 Steel Reinforcement Treatment

For technological reasons it is necessary to coat the steel reinforcement with a special treatment to protect against rust. Coating requirements caused serious issues for manufacturers as the use of bituminous coatings resulted in new specializations and the need for many health, safety and environmental precautions. New user and environmentally friendly coatings were developed in the 1990’s that addressed many of these serious concerns. Currently, automatic coating lines with dipping baths and wax for needle cleaning and lubrication are in operation. The development of automated coating lines significantly enhanced capacity and made the production of steel reinforcement more cost effective. The next step to improve coating is to hang the cages automatically in the needle frames. This advancement is still in the development stage and is currently operating as a prototype.

3 CONCLUSIONS

The developments in the technology of the design, production and application of AAC offer architects, contractors and builders new possibilities for uniquely and creatively designed buildings. Using AAC blocks and, prefabricated panels and elements is very effective in reducing the overall building time. The developments that reduce manufacturing cost enhance AAC’s position in the building materials market. The precision and smooth finish on AAC is an advantage over other similar building materials and is greatly valued in the Benelux, Japan and Scandinavian countries. There is a strong and growing interest for AAC in rapidly developing countries worldwide. However, the highly automated SCC precast industry creates stiff competition for AAC. Therefore, the AAC industry must continue to strive for technological developments that will result in lower cost for both the producer and consumer. It is strongly recommended that the AAC industry continue towards harmonization and standardization and to cooperate as an industry to increase the AAC market as a whole.

4 REFERENCES