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AUTOCLAVED AERATED CONCRETE: A LIME-BASED TECHNOLOGY[*]

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Abstract

Autoclaved Aerated Concrete (AAC) is a non-combustible, lime-based, cementitious building material that is expanding into new worldwide markets. As a single-component building material, AAC has achieved acceptance in new markets throughout the world. AAC provides a structural building system with inherent properties that include thermal insulation, acoustical insulation, and excellent fire protection ratings. This paper will describe the production, material properties, construction applications, and building code developments for AAC throughout the United States.

Keywords

AAC, lime, fire, noncombustible, acoustical, thermal, structural.

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1 Introduction

Autoclaved Aerated Concrete (AAC) has been utilized as a building material throughout the world for many years. It was developed during the early 1920s at the Technical College in Stockholm, Sweden. Since then, it has been used in the construction of commercial, industrial, institutional and residential structures throughout the world.

2 Production

A mixture of finely-ground silica sand (approximately 70% by weight), cement (15% by weight), quicklime (15% by weight), and a small amount of aluminium powder are mixed with water into a slurry. The slurry is then poured into a steel mould, 20 feet long by 4 feet wide by 2 feet deep. The form is filled only to about two-thirds of its depth. When producing reinforced panels, such as floor, wall, and roof panels, corrosion-coated reinforcement is placed into the steel mould immediately after the slurry is poured into the mould.

The aluminium powder reacts with the water in the alkaline environment to produce hydrogen gas (H_2). Macroscopic air bubbles subsequently develop and as the slurry stiffens, the expanding air bubbles produce a cake-like product that rises to the top of the steel mould. Heat developed, due to slaking of the quicklime, triggers an early set of the cement and the “cake” will reach a green strength after approximately two hours. At that time, the cake has developed sufficient green strength to retain its shape and stand on its own, and the mould is removed.

This cake is then sliced horizontally and vertically into the shape of unreinforced blocks or reinforced panels by means of cutting devices -- mainly high-tension wires and profiling plates. The sliced cake is then transported to an autoclave where high temperature saturated steam (pressure = 12 bar, temperature = 390^{o}F) initiates the curing and hardening processes of the aerated concrete material.

The finely ground sand (SiO_2) will react with lime (CaO) and water to form calcium silicate hydrate, a crystalline structure also called tobermorite ($C_5S_6H_5$). After approximately twelve hours of autoclaving, the finished building material is then palletized and shrink-wrapped or banded. It is then ready to be shipped to the jobsite.

3 Material Properties

3.1 General

AAC products are equally suitable for residential construction, multi-story buildings, commercial, and industrial construction. The products are made of natural materials: sand, lime, and water. These raw materials are processed to provide a building material with a large number of air pores; hence, aerated concrete. Fine pores (nearly 70% of the product) and the solid structure of calcium silicate hydrate gives AAC its exceptional material properties.

3.2 Density and Compressive Strength

AAC products (blocks and panels) are produced in densities ranging from 25 to 50 lbs/ft^3 (400 - 800 kg/m^3) and minimum design compressive strengths from 290 - 870 psi (approximately 2.0 – 6.0 MPa). While the densities and compressive strengths are somewhat proportional, they are not exclusive. Table 1 gives the range of densities that are typically associated with the various compressive strengths, as defined in ASTM C 1386 Standard Specification for Precast Autoclaved Aerated Concrete (PAAC) Wall Construction Units.

3.3 Product Sizes and Shapes

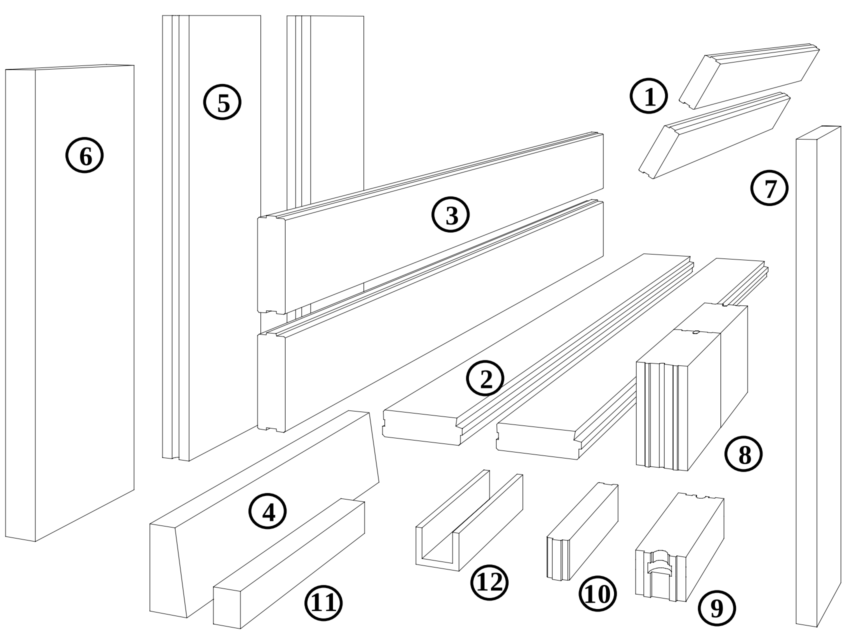
Figure 1 illustrates the typical AAC product shapes. Some AAC manufacturers produce their products in U.S. Customary units while others use metric units. Blocks are typically produced in three standard nominal sizes: a standard 8 inch height by 24 inch length, a 24 inch height by 24 inch length, and a 24 inch height by 40 inch length. Each of these blocks can be produced in thicknesses of 4, 6, 8, 10, and 12 inches.

Reinforced load-bearing panels for floor slabs, roof slabs, walls and non-load-bearing cladding panels are produced in 24 inch widths or heights, in lengths up to 20 feet, and in thicknesses ranging from 6 to 12 inches. Lightly reinforced non-load-bearing interior vertical wall panels are produced 24 inches wide, 3 to 6 inches thick, and up to 10 feet long.

Table 1 Strength Class and Physical Requirements

Strength Class	**Minimum Compressive Strength psi (MPa)**	**Nominal Dry Bulk Density lb/ft^3 (kg/m^3)**	**Density Limits lb/ft^3 (kg/m^3)**
AAC-2	290 (2.0)	25 (400) 31 (500)	22 (350) – 28 (450) 28 (450) – 34 (550)
AAC-4	580 (4.0)	31 (500) 37 (600) 44 (700) 50 (800)	28 (450) – 34 (550) 34 (550) – 41 (650) 41 (650) – 47 (750) 47 (750) – 53 (850)
AAC-6	870 (6.0)	37 (600) 44 (700) 50 (800)	34 (550) – 41 (650) 41 (650) – 47 (750) 47 (750) – 53 (850)

Figure 1 Typical AAC Product Shapes



3.4 Thermal Insulation

Thermal insulation is intended to minimize heat loss during cold weather and minimize heat gain during warm weather. A combination of product porosity and density combine to achieve a very energy-efficient building material, resulting in major energy cost savings. The product porosity provides a low thermal conductivity or higher static R-value. It also allows the building envelope to attain a higher air-tightness than many conventional building systems. The product density gives the material a thermal mass or thermal inertia that enhances its thermal performance. This combination gives the material the ability to protect the interior environment from the extreme exterior elements by its thermal resistance characteristics and the ability to dampen the external thermal peaks by slowly absorbing and dissipating the heat and cold. Table 2 shows the static thermal conductivity for various densities of AAC and Figure 2 illustrates the thermal damping and lag effect.

Table 2 Static Thermal Conductivity

Dry Bulk Density **lb / ft^3 (MPa)**	**Thermal Conductivity** **BTU in / ft^2 in ^{o}F (W/m K)**
25 (400)	0.80 (0.11)
31 (500)	0.97 (0.14)
40 (650)	1.25 (0.18)

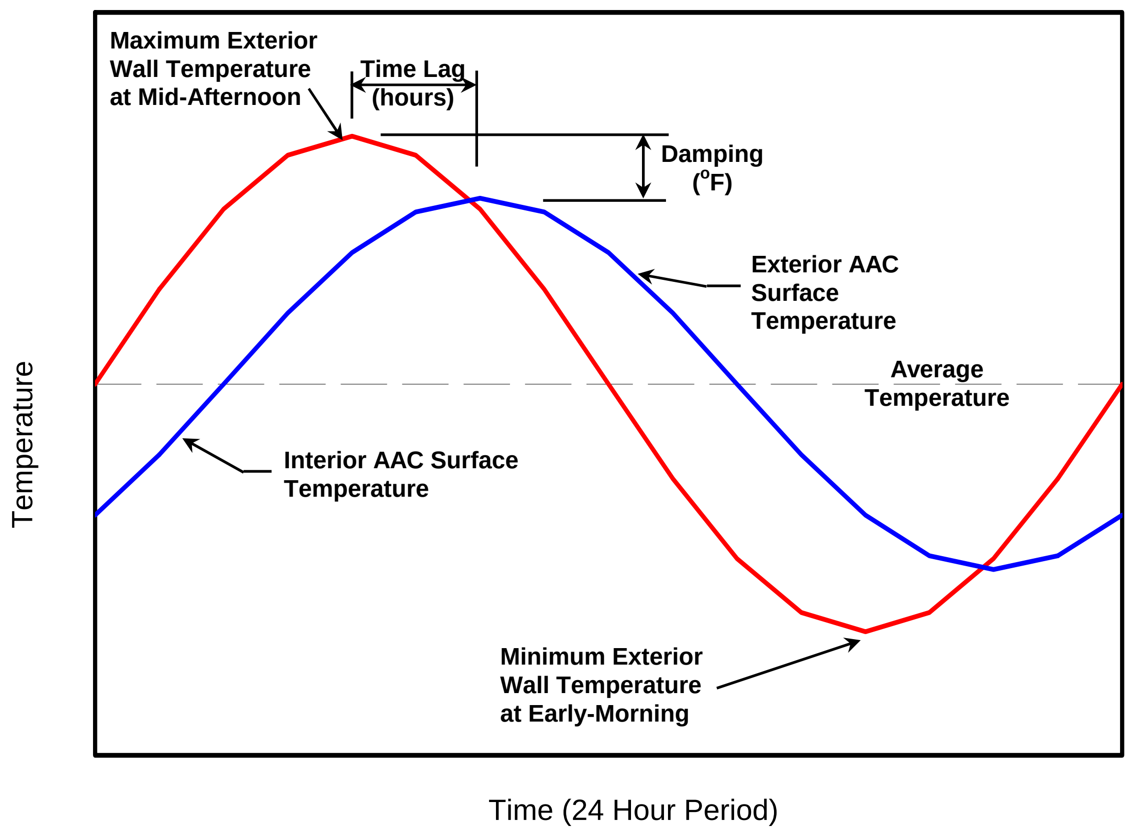


Figure 2 Thermal Damping and Lag

3.5 Fire Resistance

AAC blocks and reinforced panels offer tremendous fire-resistance performance. Fire-resistance tests carried out by Underwriters Laboratories have shown fire ratings of 4 hours for 4-inch and thicker block walls and for 6-inch and thicker reinforced floor panels. The fire resistance classifications for AAC were established using a single component system instead of the composite systems required by many fire-resistant designs. Since walls and floors require penetrations and joints, both though-penetration and joint systems have also been established. The Underwriters Laboratories' fire ratings are shown in Table 3.

Table 3 UL Fire Resistance Ratings

Type of Product	Fire Resistance Rating	Minimum Material Thickness	UL Design Number(s)	Comments
Floor Panels	4-Hour	6" Nominal	K909	Restrained or Unrestrained
Roof Panels	4-Hour	6" Nominal	K932	Restrained or Unrestrained
Block / Wall Panel	4-Hour	4" Nominal Blocks	U919	Non-Bearing
		4" Nominal Blocks and Lintels	U919	
		6" Nominal Panels	U920	Non-Bearing or Bearing
	4-Hour	4" Nominal	U925	AAC Attached to Stud System (Non-Bearing Wall)
	4-Hour	4" Nominal Blocks 8" Nominal Panels	X901	Steel Column Protection
Joint Systems	3-Hour 3-Hour 2-Hour 1 ½ - Hour	Consistent with Requirement for Block or Panels Noted Above	FF-D-0018 FF-D-0020 FF-D-0017 FF-D-0019	Floor-to-Floor
	3-Hour 3-Hour 2-Hour 1 ½ - Hour		FW-D-0013 FW-D-0015 FW-D-0012 FW-D-0014	Floor-to-Wall
	3-Hour 3-Hour		HW-D-0166 HW-D-0177	Head of Wall

Type of Product	Fire Resistance Rating	Minimum Material Thickness	UL Design Number(s)	Comments
	3-Hour 3-Hour		WW-D-0023 WW-D-0024	Wall-to-Wall
Through-Penetration Systems	4-Hour 3-Hour 4-Hour	Consistent with Requirement for Block or Panels Noted Above	C-BJ-1037 C-BJ-8010 W-J-8009	Single or Multiple Commodities

3.6 Acoustic Performance

Acoustic performance of a material is comprised of two major components – sound transmission and sound absorption. The typical Sound Transmission Coefficient (STC) value for 8" thick AAC is approximately 50 and can be increased with the use of thicker material or layered finishes with acoustical attachment hardware. However, the total sound insulation performance of a material must also consider its sound absorption characteristics, described by the Noise Reduction Coefficient (NRC). A typical Noise Reduction Coefficient for unpainted AAC is 0.15 as compared to 0.02 for concrete and 0.07 for concrete masonry.

4 Construction Applications

AAC has been used in a variety of construction projects throughout the United States. It has been used for load-bearing walls and floor / roof systems in elementary and secondary school classrooms, multi-story university dormitories, military base barracks, and various hotel chains. It has been chosen for its material properties and speed of construction. High-rise buildings have utilized AAC for shaft and fire walls due to its tremendous fire ratings. Manufacturing and warehouse facilities have found that AAC non-load-bearing cladding panels provide both an aesthetically desirable and acoustically functional solution for their projects. AAC has been used in single and multi-family construction for its thermal, acoustical, and fire performance. Buildings have been designed for hurricane-force winds and seismic activity, and constructed along the Florida coasts and in high-seismic areas such as California, New Mexico, and Missouri. D.O.T. sound walls have also been designed and constructed with AAC, which was selected for its workability, speed of construction and acoustical performance. Overall, AAC can and has been used in a variety of applications for many different reasons.

5 Building Code Developments in the U.S.A.

Since the construction of AAC manufacturing facilities in North America, the material properties, structural properties, and system performance have been tested and studied throughout the United States. In conjunction with that work, the following design, construction, and materials documents have been developed to define AAC:

- ASTM C1386-98 Standard Specification for Precast Autoclaved Aerated Concrete Wall Construction Units
- ASTM C1452-00 Standard Specification for Reinforced Autoclaved Aerated Concrete Elements
- ASTM C1555-03a Standard Practice for Autoclaved Aerated Concrete Masonry
- ASTM C12 (Draft) Specification for Thin-bed Mortar for Autoclaved Aerated Concrete (AAC) Masonry

- ASTM C27 (Draft) Standard Test Method for the Determination of the Modulus of Elasticity of AAC
- ICC-ES AC215 Acceptance Criteria for Seismic Design Factors and Coefficients for Seismic-Force-Resisting Systems of Autoclaved Aerated Concrete (AAC)
- ACI 523.5R (Draft) Guide for Using Autoclaved Aerated Concrete Panels
- ACI 530-05/ASCE 5-05/TMS 402-05 Building Code Requirements for Masonry Structures

Many of the building code provisions and recommendations that were developed are based on the performances witnessed at the University of Alabama at Birmingham, the University of Texas at Arlington, and the University of Texas at Austin.

6 Conclusions

With the physical properties inherent to AAC and development of the various design, construction, and materials documents, AAC has enjoyed significant acceptance in the United States construction markets. This lime-based, structural material offers a variety of desirable properties for the long-term performance of the building.

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