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Fire Resistance and Performance of Alternative Concrete Wall Systems

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Insulating Concrete Forms (ICFs), also known as stay-in-place concrete forms, and Autoclaved Aerated Concrete (AAC), have become more recognized as alternative concrete wall systems over the past few years. Both residential and commercial construction designs can benefit from these systems. ICFs and AAC systems provide a high R-factor, reduce thermal conductivity, and provide insulated thermal mass to a structure. The fire resistance of ICFs and AAC barrier walls is another benefit of these alternative concrete wall types. A 200- mm thick AAC wall can withstand 4 hours of direct exposure to fire without experiencing any structural damage, and 100-mm units are fire resistance rated for 2 hours. Also, non-loadbearing AAC products can resist fire for approximately 1-hour per 25-mm of thickness. These partitions minimize the risk of fire and make containment easier. This makes AAC suitable for use in shaft walls, area separation walls, and other critical fire-resistance applications. As advantages for ICFs and AAC products become better understood, demand will increase, production processes will improve, and material costs will go down. The cost and benefits of ICFs and AAC products should be analyzed prior to design because of the advantages of these new construction materials.

Key Words: Insulated Concrete Forms, Autoclaved Aerated Concrete, Fire Resistance

Introduction

Statistics from the American Insurance Association show that the largest source of disaster damage to homes is fire. Wind causes the second and earthquakes cause the third most damage to homes. Historically, damage from fires has been many times that from either wind or earthquakes (Vanderwerf, 1995).

Of all construction materials, concrete is one of the most resistant to heat and fire. Experience shows that concrete structures are more likely to remain standing through fire than are structures of other materials. Unlike wood, concrete does not burn and unlike steel, it does not yield or bend. Concrete does not break down until it is exposed to approximately 1000 degrees C, which is far more than is present in a typical house fire (Harmathy, 1986).

Insurance statistics confirm that concrete walls have a higher fire survival rate than wood frame walls. Exterior walls have the ability to remain standing through a fire, rather than collapsing. In most areas of the country, occupants get a reduction in the fire portion of their homeowners insurance if the house has concrete walls, amounting to about $40-$50 per year for a standard 2000 square foot house (Nielsen, 1998).

Background

There are a variety of materials used in the manufacturing and installation of Insulating Concrete Forms (ICFs). These systems combine polystyrene, reinforcing steel, and concrete to provide the insulation and structure in a building system. The types of polystyrene used include expanded polystyrene foam, extruded polystyrene foam, and recycled foam. While polystyrene has not traditionally been used in structural applications, polystyrene forms function as the formwork for the concrete placed within the form's core (Munsell, 1995). In addition to these primary components, polyurethane foam sealants are also important ingredients used in the assemblage of ICF systems. Polyurethane foam sealants keep the forms together until the concrete is placed. As the concrete cures, the ICF systems interlock with the unique shape of the placed concrete. The major difference in ICF systems is in the interior cavity that determines the shape of the concrete. ICF systems are classified according to two characteristics. One is the form of the ICF unit, and the other is the form of the concrete in the finished wall. The units exist in a variety of forms, which are grouped into panel, plank, and block. The differences are their size, method of interconnection, and point of assembly (Nielsen, 1998). Figure 1 illustrates the distinctive features of each.

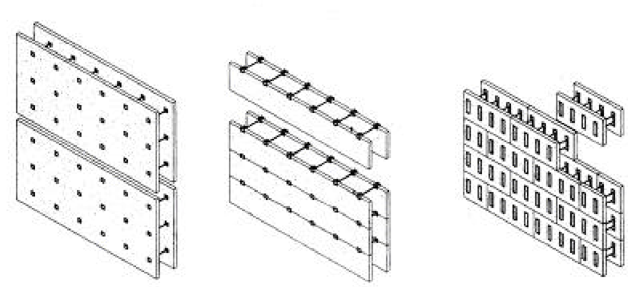

Figure 1. Panel, Plank, and Block systems

Autoclaved Aerated Concrete, AAC, is manufactured by various processes. AAC is comprised of silica sand, cement, lime, gypsum, water, and an expansion agent (usually aluminum powder), which forms a porous microstructure in the concrete (Barnett and Nelson, 1997). The major ingredients go into a mold, filling it approximately one-third, and the expansion agent is then mixed in. Once the "cake" has risen, it is placed in an autoclave to complete drying. This process creates a product that is 70-80 percent air by volume, and with a design weight ranging from 500 kg/m3 to 750 kg/m3. AAC systems are significantly lighter than conventional concrete systems, and therefore require fewer raw materials are needed to produce an equal amount of building volume.

Design flexibility and compatibility with other building systems are requirements of any new building system. AAC standard panels can be combined with light gauge metal, fiberglass, wood, and glass. Many creative designs can be achieved by combining these materials without any loss of functionality. Wall treatments can range from smooth or textured paintable surfaces to wallpapers and tiles.

Fire Testing

Different wall systems withstand disasters in different ways. The most common way to measure resistance to fire is with the fire wall test, described in ASTM E119, "Fire Tests of Building Construction And Materials." These methods are applicable to assemblies of masonry units; composite assemblies of structural materials of buildings; including bearing or other walls and partitions; columns, girders, beams, and composite slabs; and beam assemblies for floors and roofs. They are also applicable to other assemblies and structural units that constitute permanent integral parts of a finished building. Test results are expressed in hourly ratings. This test is performed under laboratory conditions, whereby a gas fire burns at a controlled temperature on one side of a wall until the cool side overheats past certain temperature limits. If the wall maintains its structural integrity, the wall gets a fire wall rating equal to the length of time it was subjected to the flames. However, if the wall fails structurally, i.e. collapse, during the heating, it gets a fire resistance rating instead, indicating the wall might prevent fire from spreading for the length of time it stayed below the temperature limits, but may change composition or deform.

Standard test methods for fire tests of building construction and materials measure the fire-resistive properties of the assemblage materials when subjected to a standard fire exposure, and provides for a relative measure of the ability of the assemblage to prevent the spread of fire. After the assemblage is subjected to the standard fire exposure, it is subjected to a standard fire hose stream of water, intended to simulate the effects of fire fighting efforts. The assemblage must successfully pass both portions of the test in order to achieve a certain fire rating.

A test furnace is used to determine the fire resistance ratings of construction assemblies, and a standard time-temperature curve is used to control the fire exposure of materials under fire testing. Building constructions are exposed to heat in a test furnace under a 44 kg/m2 fire load. The quantity of combustible material per square foot of floor area is commonly referred to as the "fire load." A 44 kg/m2 fire load corresponds to a 7-hour fire temperature duration. Cotton waste is placed on the cool side of the material. Time is measured until gases seep through, cotton ignites, and the temperature reaches 120 degrees C above its original temperature, or failure under a water-stream test occurs.

Fire Rating

The fire resistance of concrete masonry units is based on the "equivalent thickness" it would have if it were solid. A 200-mm thick, standard, hollow concrete masonry unit, CMU, is about 55% solid if one subtracts the area of the voids from the total area. The fire resistance of the unit is based its thickness and aggregate type used to produce the CMU. Graded by the ability of the aggregate to resist high temperatures, Grade A concrete is made with calcareous gravel, trap rock, blast furnace slag and other heat resistant stones for coarse aggregate. The course aggregate in Grade B concrete is quartz, granite, or sandstone, having more volatile matter and combustible material than Grade A aggregate.

Most 200-mm CMU block walls are fire wall rated at two hours or more. Although they rarely fail structurally, i.e. collapse, after that time, they overheat on the cool side. As a frame of reference, a 50-mm x 100-mm wood frame wall with sheetrock on one side and wood siding on the other is generally rated at one hour for fire resistance, after that the wall fails.

Among its numerous benefits, AAC's fire resistance is perhaps its most valuable quality. In load-bearing applications, 150-mm block walls offer a 4-hour fire rating, while 200-mm block offers a 6-hour fire rating, and a 100-mm non-loadbearing interior wall panel achieves a 3-hour fire rating. AAC blocks and panels also meet the most stringent building code requirements. Testing was performed on two AAC walls, one constructed of 100-mm wall panels and the other of 200-mm block. The walls were approximately 300-cm wide and 330-cm tall. The 100-mm panels performed satisfactorily for a Fire Resistance Rating of 3-hours and 10-minutes, while the 200-mm block wall performed satisfactorily for a Fire Resistance Rating of 6-hours and 6-minutes.

Fire test wall temperatures for the 200-mm wall are illustrated in Figure 2. The furnace temperature and the interior wall surface temperature are nearly the same, however the ability of heat to transfer to the opposite side of the wall is minimized from approximately 980 degrees C to 38 degrees C after one hour. Even after 6-hours of elevated temperatures at the interior wall surface, the temperature on the opposite side never reaches 120 degrees C.

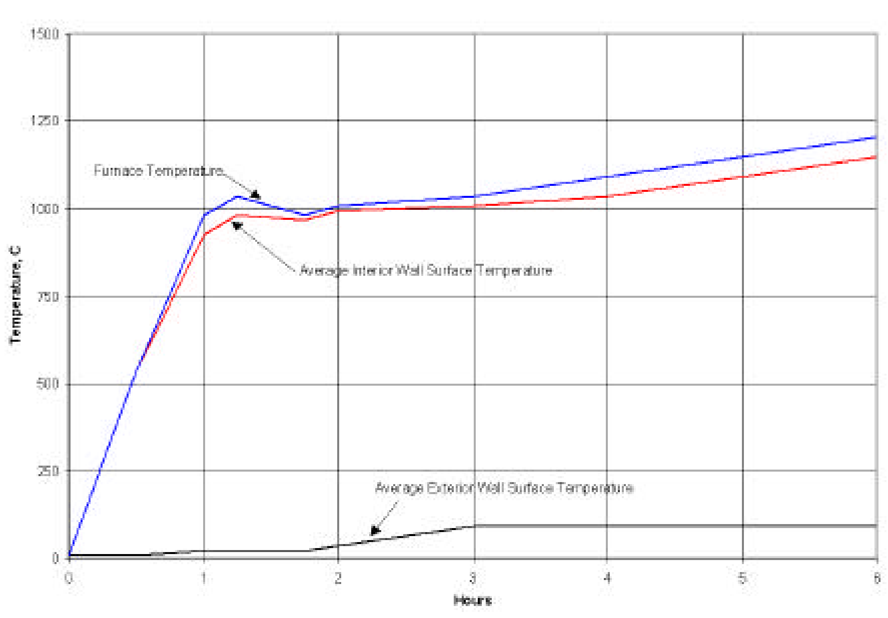

Figure 2. Fire Test Wall Temperatures for 200 mm AAC Panels

When a fire occurs, the low thermal conductivity of AAC also reduces the rise in temperature of the embedded steel reinforcement. The combination of a low thermal conductivity and a low coefficient of thermal expansion are beneficial when AAC is exposed to fire. Water in crystalline form within the material acts as a heat sink. The internal structure of AAC allows steam to escape without causing surface spalling (Wittmann, 1983). The temperature is lower in

AAC than in dense concrete, not only on the non-exposed side but also on the side that is exposed to the fire. The temperature on the exposed side is important because it affects protection of the reinforcing steel in AAC panels.

The practical experience obtained with AAC in fires has shown that the structural parts of AAC are able to continue to serve with minor repairs, which considerably reduce the cost of damage caused by fire. AAC can also be used as a cladding to protect other materials such as steel structures or to increase the fire rating of concrete walls. AAC is non-combustible and due to its low thermal conductivity, heat migration takes place at a slow rate giving AAC excellent fire resistance. Table 1 provides fire ratings for AAC panels and AAC block (Barnett and Nelson, 1997).

Table 1

Fire Ratings for AAC

AAC Block Size		
Height x Length	**Available Width**	**Fire Rating**
20 cm x 60 cm	100 mm	4 hours
20 cm x 60 cm	150 mm	6 hours
20 cm x 60 cm	200 mm	8 hours
20 cm x 60 cm	250 mm	8 hours
20 cm x 60 cm	300 mm	8 hours
60 cm x 100 cm	100 mm	4 hours
60 cm x 100 cm	150 mm	6 hours
60 cm x 100 cm	200 mm	8 hours
60 cm x 100 cm	250 mm	8 hours
60 cm x 100 cm	300 mm	8 hours

When compared to concrete masonry unit construction, all core spaces of a 200 mm CMU wall must be filled to achieve a 4-hour fire rating. Material such as loose dry expanded slag, burned clay or shale can be used to fill the cells. When compared to metal stud construction, four layers of gypsum wallboard are required to achieve a 4-hour fire rating.

Superior ratings are possible because unlike conventional block, AAC is an aerated product. Within each block and panel, air is trapped in tiny cells, so the flame is unable to spread from one cell to another. Also, the ease of construction helps to ensure a monolithic, highly fire-resistant wall. AAC provides benefits to multi-family housing units, hotels, self-storage facilities and malls, which have many rooms in a building. Storage facilities must be compartmentalized, thereby meeting firewall requirements set by Florida building departments.

Insulating Concrete Forms

Concrete walls have proven resistant to allowing fire to pass from one side of the wall to the other. This is especially of interest in areas with brush fires that could spread indoors. “Fire-wall” tests of ICF walls prove that walls can be subjected to continuous gas flames and temperatures of up to 1100 degrees C for as long as 4-hours. None of the ICF walls ever failed structurally, i.e. collapsed. ICFs tested were of the “flat” or “uninterrupted grid” type, having no significant breaks in the concrete layer. Part of the test also measures how well the wall slows the passage of heat and fire from the side with the flame to the other cool side. During these tests, the ICF walls did not allow flames to pass directly through. They also did not allow enough heat through to start a fire on the cool side for 2- to 4- hours. In contrast, wood frame walls typically allow both flame and fire-starting heat through in an hour or less and typically collapse.

Both AAC and ICFs require covering the inside face of exterior walls with plaster or stucco, which can also aid as a fire-resistant coating. Concrete exterior walls probably won't make a fire fighter's job any easier since most fires start within the house however, knowing it can contain the fire and be structurally sound may be of great benefit.

Toxicity

Any organic material, be it wood or plastic, gives off emissions when it is subjected to intense heat or flame. The Southwest Research Institute reviewed the numerous existing studies of fire emissions and concluded that the emissions from polystyrene foams are "no more toxic" than wood (Janssens and Orvis, 1999). Unlike ICFs, AAC is not made of organic materials and has no toxicity associated with burning of the product.

Toxicity test results compare the total sum of toxicity factors (carbon monoxide, carbon dioxide, and poisonous chemicals) found in the smoke of burning materials as compared to the smoke from burning red oak. During a fire, no toxic gases or vapors are ever emitted from AAC. Since sand, water, and lime make up a large part of AAC's composition, AAC is also environmentally friendly. Table 2 compares ICFs to other building materials.

Table 2

Sum of Toxicity Factors for ICFs, AAC, and Other Construction Materials

Material	Sum of Toxicity Factors
Red Oak (the standard)	100
AAC	0
ICF	20
White Pine	50
PVC (poly vinyl chloride)	360
ABS (plastic pipe)	280
Urethane (rigid)	290

Note: **US Testing Co Report No 03298**

At low concentrations, the eyes and skin can be irritated. At high concentrations, death is probable. The inhalation of toxic gases, usually carbon monoxide, and smoke is a major cause of death in fires.

Flame Spread

Flame spread is the tendency of fire to spread along a surface, usually regarding finish materials. The rate of fire spread in a building is greatly influenced by the surface characteristics of building materials. A vertical flame spread helped by convection is usually greater than horizontal flame spread on walls and floor. Nevertheless, a tunnel is used to test flame spread over the surface of building materials. Figure 3 and Figure 4 illustrate vertical flame spread and "Steiner Tunnel" horizontal flame spread tests respectively.

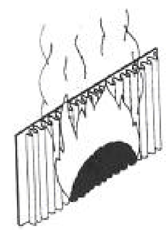

Figure 3. Vertical Flame Spread Helped by Convection

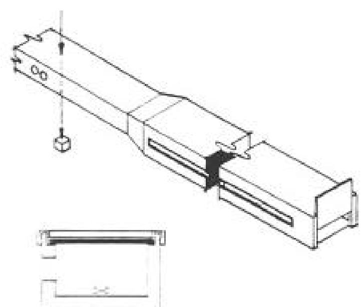

Figure 4. Steiner Tunnel Test

Cellular or foamed plastics are generally not permitted by code to be used in load bearing applications. There are extensive code requirements to be met for the safe use of these materials. However, the foams in ICFs are manufactured with flame retardant additives. If you hold a match to the material, it will melt away. Of course, in a house fire the foam may be subjected to constant flame from other materials burning nearby (wooden floors and fabrics). The "Steiner Tunnel Test," described in ASTM E84, "Surface Burning Characteristics of Building Materials," or more commonly referred to as Underwriters Laboratory Tunnel Test, determines the flame spread, fuel contributed, and smoke developed of building materials when compared to Asbestos Cement Board (rated as 0, 0, 0), and uncoated Red Oak (rated as 100, 100, 100). Test samples used are 50 cm wide by 7.5 m long. This test also measures how much a material carries fire from an outside source. In the test, a tunnel is lined with the test material, a fire is run at one end, then the distance the flame spreads is then measured. The flames travel about one-fifth as far down a tunnel lined with ICF foams as they spread down a tunnel lined with wood. The distance flame spreads from the igniting flame during a 10-minute fire exposure under controlled test conditions in a test tunnel is pertinent to flame spread. The results of the test are compared to the flame spread on asbestos-cement board and the flame spread on an untreated red oak floor under similar fire exposure. Table 3 indicates the results of tests.

Smoke Development

Smoke limits visibility and harms breathing. The inhalation of toxic gases, usually carbon monoxide, and smoke is a major cause of death in fires. The smoke release rate is smoke

Table 3

Flame Spread of ICFs, AAC, and Other Construction Materials.

Material	Flame Spread
Asbestos-cement board	0
AAC	0
ICF	3m
Untreated red oak flooring	30 m
Maximum accepted by Building Codes	23 m

Note: US Testing Co Report No 03298

produced by burning the test material. It normally applies to finish materials and furnishings; however, the smoke development from ICFs is rise for concern.

Because ICFs are flammable, quantifying the amount of smoke that results in the burning of the form is important. Building codes set standards for smoke development, and ICF manufacturers have met such requirements. The amount of smoke developed during a standardized burning test in a test tunnel are compared to the smoke developed by burning an asbestos-cement board and the smoke developed by burning a red oak floor under similar fire conditions during a 10-minute period. The amount of smoke development is determined by the light absorption percentage of the smoke using a photoelectric circuit operating across the test furnace flue pipe.

Smoke development from Asbestos cement board is zero because the product is fireproof. However, because asbestos is carcinogenic, other considerations for fire resistance must be met. Insulating Concrete Forms have more smoke development than untreated red oak flooring, but still meet the maximum accepted by building codes, as Table 5 makes this comparison.

Table 5

Smoke Development of ICFs, AAC, and Other Construction Materials

Material	Smoke Development
Asbestos-cement board	0
Untreated red oak flooring	100
AAC	0
ICF	Less than 300
Maximum accepted by Building Codes	450

Note: US Testing Co Report No 03298

Conclusions

- Alternative concrete wall systems such as AAC load bearing walls, AAC non-load bearing walls, and IFC load bearing walls offer improved fire resistance as compared to conventional CMUs and wood frame wall construction.

- 200 mm thick AAC units can withstand direct exposure to fire without experiencing any structural damage for over 6 hours, and 100 mm AAC units are fire resistance rated for over 3 hours.

- Also, non-load bearing AAC products are fire rated for approximately 1 hour per 25 mm of thickness.

- Other important factors to consider when selecting materials include toxicity, smoke development, and flame spread. Both AAC and ICF wall types meet these standards established by the National Fire Protection Association, NFPA.

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