AN OVERVIEW OF FOAMED AERATED CONCRETE - A BUILDING AND CIVIL ENGINEERING CONSTRUCTION MATERIAL

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ABSTRACT
Over the past 20 years foamed aerated concrete has become accepted in many parts of the world as an important material for use in the construction industry. The amount of foamed concrete being used, the number of producers/manufacturers and variety of applications where it can be used have drastically increased. For many applications, foamed concrete can provide cost and performance benefits when compared with traditional building materials. This paper provides an overview of what foamed aerated concrete is and seeks to introduce the material to Nigerian construction industry and researchers through awareness creation. It also highlights the advantages and disadvantages as well as giving an overview of technical specification of the material. Applications for which foamed concrete can be used are discussed, including the use of foamed concrete in building construction, roads, bridges, void filling, ground stabilization and land reclamation.

Keywords: Foamed Aerated Concrete, Compressive Strength, Dry Density, Building blocks.

INTRODUCTION
Concrete is an artificial engineering material made from a mixture of Portland cement, water, fine and coarse aggregates and at times, an admixture is added to improve or modify the property of the material. It is the most widely used construction material in the world. Concrete is the only major building material that can be delivered to the job site in a plastic state. This unique quality makes concrete desirable as a building material because it can be moulded in virtually any form or shape. Concrete provides wide latitude in surface textures and colours and can be used to construct a wide variety of structures, such as highways, bridges, dams, large buildings, airport runways, irrigation structures, breakwaters, piers and docks, sidewalks, silos and farm buildings, homes. Other desirable qualities of concrete as a building material are its strength, economy and durability. The tensile strength of concrete is low, but by using properly designed steel reinforcement, concrete structural members can be made to be as strong in tension as they are in compression. Unlike pure concrete, foamed aerated concrete is either a cement or lime mortar based lightweight concrete, with 75% air void by volume entrapped in the mortar matrix by means of suitable aerating agent. Broadly speaking aerated concrete falls into the group of cellular concrete (microporite being the other). According to Bukoski (1998), the prominent advantage of aerated concrete is lightweight, which economizes the design of supporting structures including foundation and walls of lower floors. It provides a high degree of thermal insulation and considerable savings in materials due to the porous structure. Aerated Concrete (AC) is a precast, manufactured building stone made of all-natural raw materials. It is an economical, environmentally friendly, cellular, lightweight, structural material that provides thermal and acoustic insulation as well as fire and termite resistance. Aerated concrete is available in a variety of forms, ranging from wall and roof panels to blocks and lintels. It can be produced either by creating pores in the concrete through addition of foaming agent in the mix or by adding aerating agents that will react with cement to produce air voids. Foamed concrete can be placed easily, by pumping if necessary and does not require compaction, vibrating or leveling. It has excellent resistance to water and frost, and provides a high level of both sound and thermal insulation. It is very versatile, since it can be tailored for optimum performance and minimum cost by choice of a suitable mix design. Basiuński (2000) noted that aerated concrete is not the same as conventional concrete and does not have the same characteristics. It is much lighter and does not have the same strength as conventional concrete. For this reason, foamed aerated concrete and conventional concrete are generally used for different applications, although there are applications where either may be specified. Aerated concrete can also be described as a cement-based non-organic building material, which could be available in the form of building blocks, reinforced or un-reinforced panels, planks and some other special elements. It is a lightweight cellular material, which has inherent thermal and acoustic insulation as well as insect and fire resistance properties. Aerated concrete blocks can satisfy almost all structural and insulating requirements. There have been several investigations on the properties of aerated concrete in the past. The first
HISTORICAL BACKGROUND OF CELLULAR (FOAMED) CONCRETE

In 1914, the Swedes discovered that a mixture of cement, lime, water and sand expands by adding aluminum powder. This resulted in a material like wood but without the disadvantages of combustibility, decay and termite damage. The material was further developed to what we know today as aerated concrete. Aerated concrete is effectively, concrete with lots of bubbles in it. It is lightweight and energy efficient and is produced by adding a foaming agent to cement slurry and curing it after which blocks or slabs can be cut to required sizes. Although the material is called foamed concrete it is not really concrete at all. Foamed concrete is actually foamed mortar, where the mortar is made from either cement and water, or sand, cement and water. Foamed concrete does not contain coarse aggregate. Bave (1980) noted that aerated concrete has since been refined into a high thermally insulating concrete-based material used for construction both internally and externally. According to Narayanan and Ramamurthy (1999) among the types of fine aggregate that could be used to form aerated concrete are finely ground natural fine aggregate, fine lightweight aggregate, raw pulverized fuel ash, ground slag, burnt shale and others. They need to pass a 600 micron BS sieve even though sometimes fine aggregate up to 1.2mm in size is added. Leitch (1980) stated that besides insulating capability, one of the advantages of aerated concrete in construction is its quick and easy installation since the material can be routed, sanded and cut to size on site using standard band saws, hand saws and drills. According to National Association of Home Builders Research Center (NAHBRC (1998)), commercial production of the material began in 1930. In 1995, more than 31 million cubic meters were produced by over 50 factories worldwide. In 2004, more than 75 million cubic meters were produced by over 300 factories and almost 20 new factories are opened every year.

INTERNATIONAL STATUS

Aerated concrete blocks have been used in Europe for more than 50 years. It has gained popularity throughout the rest of the world and has had a large presence in the Far and Middle East for the past 30-40 years and to a lesser extent, in Australia and South America for the past 20 years. The manufacture of Aerated Concrete is also on the increase in China and plants are under construction in India. According to Holt and Raivo (2005) the world’s current greatest producer of Aerated concrete is Russia. Undoubtedly the areas of massive growth potential are China, India and North America. Like typical concrete blocks, aerated concrete is strong, fire resistant and good sound insulation. However, aerated concrete is also lightweight and energy efficient. Hebel Southeast, a German company with offices in Atlanta, Georgia, brought aerated concrete to the United States of America. It said that commercial production of the material began in 1930. In 1995, over 50 factories worldwide produced more than 31 million cubic meters. And only in the past 5 years it has been introduced to the U. S. market by two important European constructions companies. Builders in the U.S. now use the innovative concrete material which Europeans adopted decades ago. For more than 70 years since its inception, aerated lightweight concrete has enjoyed a reputation for excellent insulation properties and low density. Traditional production of aerated lightweight concrete employs Portland cement, fly ash, lime and fine sands as major raw material components and involves curing products in an autoclave. The production of Aerated concrete (AC) blocks in United Arab Emirate (UAE)
An Overview of Foamed Aerated Concrete – A Building and Civil Engineering Construction Material

was pioneered by Al Jazeera factory for construction materials using the German Technology under the supervision of German Consultants. Since its inception in 1990 with single production plant of large capacity, Aerated concrete blocks from Al Jazeera was successfully accepted all over United Arab Emirate (UAE) and across the Gulf region. Due to this wide acceptance and popularity of the material, Al Jazeera Factory commenced a new production plant for mass production in 1999.

ADVANTAGES AND DISADVANTAGES

There are many advantages associated with the use of aerated concrete. These include:

i. Large variety of sizes: Aerated concrete can be produced in a large variety of sizes, from standard blocks to large reinforced panels.

ii. High Dimensional Accuracy: as a result of its dimensional accuracy, aerated concrete is extremely easy to install, as no ‘thickset’ mortar is required to place components in place.

iii. Lightweight: Aerated concrete weighs approximately 50% less than other comparable building products of the same strength.

iv. Excellent Thermal Insulation: Aerated concrete has a very low thermal conductivity and therefore very high thermal energy efficiency is achieved. This results in savings on heating and cooling costs.

v. Great Acoustic Insulation: The porous structure of Aerated concrete provides a high acoustic insulation.

vi. High fire resistance: Aerated concrete has an extremely high fire rating of at least 4 hours and more.

vii. Termite Resistance: Termites or insects cannot damage Aerated concrete.

viii. High workability: As a result of the excellent size/weight ratio, constructing with Aerated concrete is very rapid. Even though aerated concrete is a solid building material, it can be cut, sawn, drilled, nailed and milled like wood, making it an extremely workable product.

Aerated concrete is well known as an environmentally friendly construction material. Compared to the energy consumed in production of many other basic building materials, only a fraction is required to produce aerated concrete. Raw material consumption is very low for the amount of finished product produced. In the manufacturing process, no pollutants or toxic by-products are produced. Aerated concrete is also completely recyclable. Due to Aerated concrete’s excellent insulation qualities, energy consumption for the heating and cooling of buildings are greatly reduced compared to most conventional wall and roof systems. In the finished structure, no pollutants or toxic substances are released that could affect indoor air quality, even in the event of fire. Large, precisely dimensioned elements of Aerated concrete allow rapid construction. Their greater dimensional accuracy requires less on-site adjustment. The combination of large size and dimensional accuracy allows greatly increased productivity. Due to the lightweight of aerated concrete, reduced equipment demands are realized. Aerated concrete is an inorganic material that contains no toxic substances. It does not slowly decompose and off-gas. Since aerated concrete is both a structural and insulation material, it allows the elimination of other materials that can contribute to poor indoor air quality. Aerated concrete buildings are very energy efficient. This efficiency is due to a combination of high R-value, thermal mass and air-tightness. Aerated concrete is the only product currently available that meets Germany’s stringent energy codes without added insulation. It is well documented that of light frame construction, to perform thermally efficient. A recent study in the U. S. shows that an 8” (20cm) aerated concrete wall performs much better than a conventional wood stud wall system with R-30 insulation. A material’s R-Value is the measure of its resistance to heat flow; the higher the value, the more the material insulates. Aerated concrete is an inorganic, insect resistant, solid wall construction material. The solid wall construction of a building made of aerated concrete provides excellent sound abatement, greatly reducing outside environmental noise, providing a quieter, more comfortable interior for the occupants. Aerated concrete has proven to be a very durable material. There are many structures worldwide constructed with aerated concrete, over 50 years old that are still in excellent condition. Aerated concrete will not rot, warp rust, corrode, or otherwise decompose. Aerated concrete provides a very low maintenance building, saving considerable time and money in upkeep over the life of the building. Although there are many advantages resulting from using aerated concrete in construction, there exist also some disadvantages. Some of these are:

i. Aerated concrete has to be covered with specially designed materials (plaster) in order to prevent its erosion by water.

ii. Formulation and production of appropriate foaming agent constitutes an important factor in the production of aerated concrete.
APPLICATIONS OF FOAMED CONCRETE

Foamed aerated concrete is used in the following areas:

TRENCH REINSTATEMENT.

Foamed concrete is an ideal material for trench reinstatement (the filling of trenches dug in roads when pipes are laid or repairs are carried out). The traditional methods of filling trenches in the roads, i.e. the use of granular fill materials, result in settlement and damage to the road and potentially, to the pipes. With foamed concrete there is no settlement, and because the foamed concrete is very fluid, it will fill any voids and cavities in the trench sides (Fig. 1).

![Figure 1: Foamed Concrete used in Trench Reinstatement. (Source: EABASSOC, UK)](image)

Also, the excellent load spreading characteristics of foamed concrete means that axle loads are not transmitted directly to the services in the trench, so the pipes are not damaged by the weight of traffic. Traditional granular backfill materials require compaction. Foamed Concrete does not require compaction, so there is no need to use compactors. This is important since the use of such tools can cause vibration related illnesses (health hazards) among the workers.

BRIDGE ABUTMENTS

Foamed concrete is particularly suitable for bridge abutments because it does not impose large lateral loads, which can be a problem when using traditional granular material. With traditional abutments, there is a lot of sideways pressure against the bridge walls caused by the materials used and their compaction. Using Foamed Concrete, the lateral load is practically eliminated, so the bridge walls do not have to be as thick. This in turn means that the wall foundations can be made less massive. Huge cost savings can be achieved by reducing the thickness of the walls, and the size of the foundations.

![Figure 2: Foamed Concrete used in Bridge Abutments. (Source: EABASSOC, UK)](image)

Traditional abutments also experience settlement, both due to compaction of the aggregates by trafficking, and due to the sinking of the whole structure into the ground if the subsoil is soft. Such settling and sinking cause subsidence of the road, which necessitates costly repair work. When lightweight Foamed Concrete is used, there is no settling, and sinking is reduced by adjusting the weight of the abutment by the choice of a suitable mix design.

VOID FILLING

Foamed Concrete is also very useful for void filling. As it is very fluid, it will pour into even the most inaccessible places. It can be used for planned work, but also in emergencies to provide stability and support very quickly.
Foamed concrete has been used to fill old sewers, basements, storage tanks and voids under roadways caused by heavy rain. It can be applied even through small openings making the work much easier and cheaper than other methods. If necessary, it can also be pumped into position over considerable distance.

**ROOFING INSULATION**

For many years foamed concrete has been supplied for roofing insulating in the Middle East. A low density mix is chosen and the resulting air content gives the material excellent thermal insulation properties. The low density also has the advantage that it does not significantly add to the overall weight of the roof.

A typical specification for roof insulation is shown here:

![Typical Layout of Roof Construction in Foamed Concrete](Source: BUILDING GREEN, USA)

5. Tiles with expansion joints filled with sealant. 4. Mortar.
3. Waterproof membrane
2. Lightweight Foamed Concrete laid to falls (50 - 200 mm or more)
1. Structural Slab

Roofing is probably the most widespread application of foamed concrete. Foamed concrete has two benefits when it is used for roofing; namely (i) it provides a high degree of thermal insulation and (ii) it can be used to lay a flat roof to falls, that is to provide a slope for drainage. When foamed concrete is used for flat roofs, it can be made strong enough to support foot or even vehicular traffic on the roof. Slopes made from foamed concrete are also much lighter than slopes made from mortar screeds. This means that a roof with a slope made of foamed concrete imposes lower loading on the structure of the building.

**ROAD SUB-BASE AND WIDENING**

Foamed Concrete can be used to make a road structures less heavy. This helps solve the problem where the traditionally heavy road structures cause severe settlement of the road, particularly in areas of soft ground. By constructing the road sub-base from a lightweight material, the overall weight of the structure can be greatly reduced.
As Foamed Concrete is very versatile, with a wide range of densities, it has proved to be an ideal, cost effective material for solving this problem.

WALL CONSTRUCTION
Foamed Concrete is used to cast in situ walls. These can be made either by using traditional shuttering or hollow polystyrene moulds. This provides a quick and cheap method of building, with the added advantage of excellent thermal insulation (Narayanan et al. (2000)). A wall made from 1200kg/m³ density foamed concrete provides the same level of thermal insulation as would a wall made from dense concrete that was 5 times as thick and made from 10 times the quantity of materials as the foamed concrete wall.

More recently reinforced foamed aerated concrete has been used to build structural and non-structural walls in houses and apartments. While it is possible to build walls from pre-cast foamed concrete elements, foamed concrete can be used much more efficiently by casting entire foamed concrete walls in-situ. Foamed concrete walls are said to be both lightweight and low in cost.

TUNNELLING
Foamed concrete is an ideal material for tunnel construction and repair. It is used both for the filling of voids created and exposed during tunneling, and for grouting the finished work, including gaps behind the tunnel lining. Due to its flowable characteristics, foamed concrete completely fills the smallest of voids as it is installed at very low pump pressures. Also, due to its high plasticity, the foam concrete slurry can be pumped over long distances through flexible hose or pipe, either as a finished product, or with the pre-formed foam injected near the point of placement. The low density of foam concrete is an important factor when backfill grouting of steel, fiberglass, and PVC pipes, whether in a tunnel or slipline rehabilitation. Reducing the buoyancy force on the pipe during backfill prevents floatation and deformation of the liner.
FLOOR CONSTRUCTION
Foamed Concrete provides very good material for floor construction. It is ideal for building sub-floors quickly and cheaply and can be used for levelling terrain and raising floor levels as well as for insulation purposes. It is also used in constructing artificial turfs in stadia.

LIGHTWEIGHT PRE-CAST BLOCKS
The traditional method of making lightweight pre-cast blocks involves the addition of aluminum powder to a wet mortar mix, followed by autoclaving. This is not popular due to the pollution it causes.

GROUND WORKS
Foamed concrete has been used in various types of ground projects, including stabilizing embankments after landslides, highway widening schemes, land reclamation and filling in of harbours. As it does not sink into soft subsoil, redevelopment can begin much sooner after application than can using traditional methods. For similar reasons, it is also ideal for road foundations.
FIRE BREAKS
The excellent fire resistant properties of foamed concrete make it an ideal material for fire breaks in buildings where there are large undivided spaces. It is used to prevent flame penetration through the services void between floor and ceiling in modern construction, and also to protect timber floors in old houses.

SOUND INSULATION
Foamed concrete reduces the passage of sound, both from background noise and due to impact. It is, therefore, an ideal material for internal walls and suspended floors in multi-storey buildings, especially ones with communal use.

LAND RECLAMATION AND HARBOUR FILL
Land reclamation is another area of application of foamed concrete. Here, it displays the advantage of not sinking into the soft sub-soil in the way traditional materials will do. This means that the site can be developed much earlier than usually possible.

STRENGTH CHARACTERISTICS AND TYPICAL PROPERTIES OF FOAMED AERATED CONCRETE

<table>
<thead>
<tr>
<th>Application</th>
<th>Dry Density Range kg/m³</th>
<th>Compressive Strength Range N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof insulation Screen</td>
<td>400-600</td>
<td>1.0 - 2.5</td>
</tr>
<tr>
<td>Structural Walls</td>
<td>1200-1600</td>
<td>6.5 - 2.0</td>
</tr>
<tr>
<td>Non-Structural Walls</td>
<td>800-1600</td>
<td>3.0 - 10.0</td>
</tr>
<tr>
<td>Floor Slabs</td>
<td>1200-1600</td>
<td>4.5 - 10.0</td>
</tr>
<tr>
<td>Raising Floor Level</td>
<td>400-1200</td>
<td>1.0 - 4.5</td>
</tr>
<tr>
<td>Fire Breaks</td>
<td>400-1000</td>
<td>1.0 - 3.5</td>
</tr>
<tr>
<td>Decorative Panels</td>
<td>1000</td>
<td>3.5 - 5.5</td>
</tr>
<tr>
<td>Trench Reinstatement</td>
<td>1200</td>
<td>4.5 - 5.5</td>
</tr>
<tr>
<td>Road Sub-Base</td>
<td>400-1000</td>
<td>1.0 - 3.0</td>
</tr>
<tr>
<td>Bridge Abutments</td>
<td>400-1600</td>
<td>1.5 - 10.0</td>
</tr>
<tr>
<td>Void Fill</td>
<td>400-1600</td>
<td>1.0 - 10.0</td>
</tr>
<tr>
<td>Ground Stabilization</td>
<td>600-1000</td>
<td>2.0 - 5.5</td>
</tr>
<tr>
<td>Harbour Fill</td>
<td>400-1600</td>
<td>1.0 - 10.0</td>
</tr>
</tbody>
</table>

Source: ‘The Use of Foamed Concrete in Construction and Civil Engineering; Conspectus 2001’

The above table is only a guide as aerated concrete could have dry density range up to 1800 kg/m³. Also, for foamed concrete with dry density value of 400 kg/m³, the 7-day compressive strength and the thermal conductivity is expected to be in the range of 0.5-1.0 N/mm² and 0.10 W/mK respectively. The modulus of elasticity and drying shrinkage of the same grade of aerated concrete should be in the range of 0.8-1.0 kN/mm² and 0.3-0.35 % respectively. For foamed concrete with dry density value of 1600 kg/m³, the 7-day compressive strength and the thermal conductivity is expected to be in the range of 7.5-10.0 N/mm² and 0.62-0.66 W/mK respectively. The modulus of elasticity and drying shrinkage of the same grade of aerated concrete should be in the range of 10.0-12.0 kN/mm² and 0.07-0.06 % respectively. Table 2 below gives the spread of the expected values of typical properties of foamed aerated concrete. From the table, it is observed that the higher the dry density, the higher the compressive strength, the thermal conductivity and the modulus of elasticity; but the lower the drying shrinkage value.

DEVELOPMENT NEEDS
Worldwide inflation, scarcity and high cost of building materials generally and the need to drastically reduce critical housing shortages have encouraged the search for alternative, innovative and cost effective building materials. Although aerated concrete was initially envisaged as an insulating material, there has been renewed interest in its structural characteristics in view of its lighter weight, savings in materials and potential for large scale utilization of wastes like pulverized fuel, non fuel ash. This translates to reduced construction labour / equipment cost; this is a primary cause of concern for the building and construction industry.
An Overview of Foamed Aerated Concrete – A Building and Civil Engineering Construction Material

Table 2: Typical Properties of Foamed Concrete compiled by the British Cement Association (Basiurski, J.R (2000))

<table>
<thead>
<tr>
<th>Dry Density (kg/m³) Dry</th>
<th>7-Day Compressive Strength (N/mm²)</th>
<th>Thermal Conductivity (W/mk)</th>
<th>Modulus of Elasticity (kN/mm²)</th>
<th>Drying Shrinkage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>0.5 - 1.0</td>
<td>0.10</td>
<td>0.8 - 1.0</td>
<td>0.30 - 0.35</td>
</tr>
<tr>
<td>600</td>
<td>1.0 - 1.5</td>
<td>0.11</td>
<td>1.0 - 1.5</td>
<td>0.22 - 0.25</td>
</tr>
<tr>
<td>800</td>
<td>1.5 - 2.0</td>
<td>0.17 - 0.23</td>
<td>2.0 - 2.5</td>
<td>0.20 - 0.22</td>
</tr>
<tr>
<td>1000</td>
<td>2.5 - 3.0</td>
<td>0.23 - 0.30</td>
<td>2.5 - 3.0</td>
<td>0.18 - 0.20</td>
</tr>
<tr>
<td>1200</td>
<td>4.5 - 5.5</td>
<td>0.38 - 0.42</td>
<td>3.5 - 4.0</td>
<td>0.11 - 0.19</td>
</tr>
<tr>
<td>1400</td>
<td>6.0 - 8.0</td>
<td>0.50 - 0.55</td>
<td>5.0 - 6.0</td>
<td>0.08 - 0.07</td>
</tr>
<tr>
<td>1600</td>
<td>7.5 - 10.0</td>
<td>0.62 - 0.66</td>
<td>10.0 - 12.0</td>
<td>0.07 - 0.06</td>
</tr>
</tbody>
</table>


From the review of the existing situations and global trends in the development and study of aerated concrete, there is the need to consider how this technology can be transferred to Nigeria and employed locally. The local development of this technology will introduce into Nigeria new challenges in structural engineering materials sourcing, development and studies. Aerated concrete building components and construction materials have not been developed in Nigeria and many other nations in Africa. This is because we are addicted to the use of conventional construction materials like sandcrete blocks, concretes etc. Aerated concrete industry could be developed in Nigeria and the sub-region to provide jobs and the development of small and medium scale enterprises (SME) around it. Furthermore, the development of home grown aerated concrete production technology based on the study of existing foreign technologies will not only catapult the country to limelight in the use of the material but will also carry along with it the desired economic gains to the construction industry in general. Considering the advantages of aerated concrete usage in the construction industry, it is very imperative at this point in the history of Nigeria and the sub-region to develop “our version” of the product for the industry.

**BENEFITS TO NIGERIA**

Presently in Nigeria, foamed aerated concrete is not being used or employed in the construction industry. If introduced, apart from being a source of employment generation at the SME level, buildings and structures where aerated concrete is introduced will give enhanced economic benefits. The resultant high economic value in the use of aerated concrete is derived from lightweight of members, reasonably high compressive strength, comparatively large sizes of members, excellent thermal insulating properties, great acoustic insulating properties, termite resistance value and high workability, low labour inputs.

**CONCLUSIONS**

From the foregoing, the following conclusions are made:

1. Foamed aerated concrete is ideal for a wide range of applications and could be produced with a range of densities from 400kg/m³ to 1600kg/m³ and a range of compressive strengths of 1.0N/mm² to 15N/mm².

2. The use of foamed aerated concrete results in low usage of raw materials and energy when compared with analogue conventional concrete materials.

3. Foamed concrete exhibits good dry shrinkage and modulus of elasticity values; its thermal conductivity values being better than that of conventional concrete materials.

The production method(s) and investigation of the properties of locally produced aerated concretes are being investigated by the authors in the Department of Civil and Environmental Engineering, University of Lagos.
REFERENCES


