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ADVANTAGES AND IMPLICATIONS OF LOW DENSITY AIRCRETE PRODUCTS FOR THE CONSTRUCTION INDUSTRY

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Abstract: Low Density Aircrete (Density ≤ 450 kg/m^3, compressive strength ≤ 3 N/mm^2) has been used extensively for the construction of dwellings in many parts of Europe. In the UK, however, lack of availability has restricted the use of Low Density Aircrete. Recent developments in Eurocode 6 and the supporting CEN TC 125 standards require adjust ment to the UK design procedures, allowing greater utilisation of Low Density High Performance Aircrete. The material has considerable advantages, which include its economical, mechanical and physical properties. It is usually manufactured using pulverised fuel ash, which is an industrial by-product. The potential for using Low Density Aircrete for the UK and indeed global construction industry is therefore highly promising with substantial economic and environmental benefits. Furthermore, calculations show the termal insulating (shielding for hot climates) properties of this material.

Keywords: Low Density Aircrete, Sustainable Masonry.

INTRODUCTION

Aircrete was developed in Sweden in 1924 and first used in the late 1950's [1] as an alternative to building with timber. Currently over 30 million m^3 of the material is produced annually. In the United Kingdom it is used extensively by major house builders with block sales of approximately 2.9 million m^3 per annum. It is so extensively used that Aircrete (mainly medium and high density) now accounts for a third of all concrete blocks in the UK. Aircrete is also known commercially as AAC (Autoclaved Aerated Concrete), Celcon, Durox, Thermalite and Topblock. Aircrete blocks are suitable as vertical load-bearing elements and provide the thermal insulation expected from typical UK wall construction. Aircrete blocks may also be used as non load bearing outer leaves of masonry walls, external walls and walls below ground level, where adequate care is essential to ensure their durability and protection from effects of the environment [2]. The lightweight porous structure and consequent faster build-speed of Aircrete blocks mean even foundations can be constructed quickly, easily and cost-effectively handle creating an extremely effective moisture barrier with significant thermal insulation properties. Their porous cellular structure (porous) and durability [2,3] make them a recognized alternative in most below ground situations. Aircrete

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is also now more popular than timber or solid concrete floors in new housing at ground level, and is increasingly the preferred solution for upper floors too. Aircrete's superior thermal performance in most cases eliminates the need for expensive cavity insulation in many cases. Aircrete is produced by mixing cementitious materials, cement and/or pulverised fuel ash (PFA), lime, sand, water and aluminium powder. The final process involves autoclaving for approximately 10 hours at high temperature and pressure [4-6]. Hence, the material is also known as Autoclaved Aerated Concrete. Aircrete is comprised of 60 % to 85 % of air by volume (70 – 85 % for low density Aircrete). The solid material part is a crystalline binder, which is called Tobermorite by mineralogists. Besides the binding phase Tobermorite, grains of Quartz and some other minerals are found in minor amounts. The chemical composition of Tobermorite comprises of silicium dioxide, calcium oxide and water. It is Tobermorite, which provides the high compressive strength of Aircrete in spite of the high proportion of pores in this construction material. This is why low density is sufficiently strong for the construction of dwellings in spite of its considerably high air content.

PHYSICAL ATTRIBUTES OF AIRCRETE

Table 1: Physical Properties of Aircrete Blocks

Aircrete Density	Compressive Strength (N/mm2)	Density (Kg/m3)	Thermal Conductivity (W/mK)
Low	2.0 – 3.5	450	0.09 - 0.11
Medium	4.0 – 4.5	620	0.15 – 0.17
High	7.0 – 8.5	750	0.19 – 0.20

Thermal conduction is the phenomenon by which heat is transported from high to low-temperature regions of a substance. The high degree of porosity of Aircrete has a dramatic influence on thermal conductivity; increasing pore volume will, under most circumstances reduce thermal conductivity and increase thermal insulation. Heat transfer across pores is ordinarily slow and inefficient [7]. Internal pores normally contain still air, which has extremely low thermal conductivity - approximately 0.02 W/m-k. Furthermore, gaseous convection within the pores is also comparatively ineffective. Hence Low Density Aircrete has outstanding thermal insulation properties [3,8-15] as shown in Table 1. The compressive strength of Aircrete is related to its density and increases with increasing density [1,16]. Commonly produced compressive strengths are 2.8, 3.5, 4.0, 7.0 and 8.4 N/mm^2 (MPa) as indicated on Table 1. In the UK compressive strengths > 4 N/mm^2 are commonly used, however, in Europe lower strength Aircrete has been successfully utilised for the construction of dwellings [16], implying lower compressive strength will be adequate. The compressive strength of Aircrete is nearly independent of specimen size due to its homogeneity [16]. Aircrete achieves its final strength during the autoclaving process without further curing being necessary. The cellular structure [17-19] of the material ensures a lightweight construction. During installation, most Aircrete blocks can be lifted with one hand providing significant productivity advantages. The higher porosity of Low Density Aircrete ensures that the material is extremely lightweight (density ≤ 450 kg/m^3), thus, it is even easier to handle in comparison to medium and high density Aircrete. As a result transportation costs would be reduced and furthermore, houses would be built much more quickly.

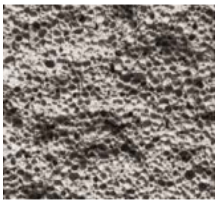

Figure 1: Cellular structure of Aircrete with levels of porosity up to 85 %.

The combination of the internal structure and the stiffness characteristics of Aircrete enable sound reduction performance for walls and partitions often superior to other types of masonry [3-5].Sound absorption is a property relevant to particular applications. When exposed to sound, the aerated internal structure of Aircrete provides good sound absorption properties. Therefore, lower density Aircrete should impart superior sound insulation properties. Moisture movement through porous building materials is a very complex process [20,21] and for practical predictions simplifying assumptions have to be introduced. There are at least three different origins of water in Aircrete. Immediately after autoclaving Aircrete contains typically about 30% water by weight of the dry material. This excess water is lost under normal conditions to the surrounding air after a few years [3]. If the relative humidity of the surrounding air increases temporarily, Aircrete will take up water again by absorption and capillary condensation. If the surface of a structural element is in contact with liquid water the material absorbs water quickly by capillary suction [4,20,21]. Although Low Density Aircrete has a very high proportion of air, the pores are fine and are not interconnected, therefore, the material offers good resistance to moisture penetration. Vapour resistivity of Aircrete is approximately 60MNs/gm. The resistance to freezing of a construction material is determined by its pore size distribution and, in particular, the percentage, size and shape of capillary pores and the mechanical strength of the inner pore walls [16,22,23]. If the pores of the material become filled with water, which then freezes, the ice which has a volume 9% greater than water will cause pressure on the pore walls. When the tensile strength of the wall material is exceeded, cracking occurs. If the pores are filled with water to a critical degree, and if there is repeated freeze/thaw cycling, the whole structure may eventually be destroyed. Aircrete possesses good resistance to freezing, which is proved by unrendered buildings, situated in areas where frequent freeze/thaw cycles occur, remaining undamaged. The reason for the good resistance is that the included spherical pores are almost all closed, meaning the material has comparatively low capillary suction and therefore the moisture content does not normally reach the critical degree. With Low Density Aircrete, the greater free volume of the material is better equipped for dealing with the pressures caused by freezing of water. Furthermore, as discussed earlier, as the pores are not interconnected, this radically reduces the possibility of water absorption. The high freeze thaw resistance in essence is due to the aerated internal structure of the material. The resistance to frost is superior to that of many stronger denser masonry materials although the degree of resistance is to some extent dependent on strength and density.

Durability and Fire Resistance

The resistance of Aircrete to attack from sulfates likely to be found in soils and ground water is high [2,21,24] and related to the strength and density. Aircrete has excellent resistance to sulphate attack up to sulphate concentrations of 600 mg/l in the water. For higher concentration levels special protective precautions are necessary [2,21]. One method of protection to Aircrete in subsoil is to apply protective coatings usually based on bitumen [16]. Aircrete is non - combustible and has Class O [10] surface spread of flame. Consequently all Aircrete products provide excellent fire protection and satisfy the requirements of the Building Regulations [4-8] and in so doing ensure:

1. An adequate means of escape.
2. Internal surfaces of the building inhibit the spread of flame.
3. The structure of a building is sufficiently fire resistant to the spread of fire and retain its stability for a reasonable period of time.
4. The external surfaces of the building offer adequate resistance to the spread of fire from one building to another.

Aircrete blocks are classified as non-combustible in accordance with the Building Regulations. It is often sufficient to require that materials should not be readily ignitable and that their tendency to spread flame be limited. The surface spread of flame tests in BS 476 :

Part 7 defines spread of flame as the "propagation of a flame front over the surface of a product under the influence of imposed radiance". Aircrete (of all densities) limit flame propagation.

Workability and Dimensions

All Aircrete products have exceptionally good workability and are easy to cut, shape and chase using ordinary woodworking tools. This makes them ideal for closing the cavity at reveals and for cutting around and over joists, or for special shapes such as infills. Blocks are easily cut using hammer and bolster or wood saw. A straight cut ensures less wastage and reduces the need to make good. Hammer and wood chisels can be used for chasing-out. Woodworking drill bits can be used to accommodate wall plugs before fixing screws. Due to its higher porosity and lower strength, low density Aircrete has good workability properties. This substantially reduces waste. Aircrete blocks are produced in a range of thickness from 60mm to 355mm with a range of face dimensions. The most common work face dimensions are 440 or 620mm long by 215mm high. Other work face dimensions are also available ranging from coursing bricks 215mm long by 65mm high to large format blocks 620mm long by 440mm high.

Reduction of Thermal Transmittance (U) Using Low Density Aircrete

It can be demonstrated that the higher the compressive strength of Aircrete, the less thermally efficient the blocks are.

For 2.8N/mm^2 (compressive strength) blocks: Thermal Conductivity = 0.11W/mK [1]

For 4 N/mm^2 (compressive strength) blocks: Thermal Conductivity = 0.14 W/mK [1]

For 7.0 N/mm^2 (compressive strength) blocks: Thermal Conductivity = 0.19 W/mK [1]

The requirements of Part L of the Building Regulations became more stringent from 1 April 2002 in order to reduce CO_2 emissions from buildings [1,2,4,5,8,9]. There is greater attention to air leakage and cold bridging with the introduction of Robust Details developed with industry. Aircrete blocks continue to provide wall and floor constructions that meet and exceed the regulatory requirements. The following calculation using the Target U-Value Method [8] shows how the selection of Low Density Aircrete helps to reduce the thermal transmittance of dwellings. Two other Elemental and Carbon Emissions Methods also exist. The Target U-value Method gives more flexibility than the Elemental Method in selecting areas of windows, doors and roof lights and in the insulation levels of different elements of the building envelope for the design of new dwellings. It can be used for any heating system and can take solar gain into account. Using this method, a dwelling complies if the Target U-

value is not less than the average U-value, where the average U-value is defined as the area weighted average U-value of all exposed elements of the dwelling. Exposed elements include walls, roofs, floors, windows and doors, including elements adjacent to unheated spaces.
The Target U-value (UT) may be calculated using the equation:

$$UT = [0.35 - 0.19(AR / AT) - 0.10(AGF / AT) + 0.413(AF / AT)]$$

where UT is the Target U-value prior to any adjustment for heating system performance or solar gain, AR is the exposed roof area, AGF is the ground floor area, AF is the total floor area (all storeys) and AT is the total area of exposed elements of the dwelling (including the ground floor).

R is the thermal resistance $= \frac{t}{\lambda}$

where t is the thickness and λ is the thermal conductivity
therefore if:

λ = 0.19 W/mk (for 7 N/mm^2 compressive strength Aircrete)
U = 0.63 W/m^2k (if wall thickness = 300mm)
λ = 0.11 W/mk (for 2.8 N/mm^2 compressive strength Aircrete)
U = 0.37 W/m^2k (if wall thickness = 300mm)

At the time of writing there is no available data regarding the thermal conductivity (λ) for 2 N/mm^2 compressive strength aircrete. Therefore, given the above information, it is assumed to have a value of $\lambda = 0.09$ W/mk. Thus,

If λ = 0.09 W/mk (for 2 N/mm^2 compressive strength Aircrete)
U = 0.3 W/m^2k (if wall thickness = 300mm)

The following calculation considers a semi-detached dwelling [2]. Suppose the wall construction is to be a cavity wall with a brick outer leaf, a cavity partially filled with 17mm of Celotex and a 115mm Aircrete inner leaf finished with 13mm dense plaster internally. This gives a U-value of 0.4 W/m^2K, which is higher than would be required in the Elemental Method but the designer still wishes to use it. The U-values of the remainder of the elements are as in table 2. The heating system is based on a gas boiler with an efficiency of 85%. The area of windows and doors is equal to 25% of the total internal floor area. The total area of North-facing glazed openings is 6.82m^2 and the total area of south facing glazed openings is 8.88m^2. The U – Values and areas of exposed elements are as follows:

Table 2: U – Values of exposed elements

Exposed Element	Exposed Surface Area	U - Value	Rate of Heat Loss per Degree
Wall	80.3	0.40	32.12
Roof	44.4	0.20	8.88
Ground Floor	44.4	0.25	11.10
Windows	18.4	2.2	40.48
Doors	3.8	2.2	8.36
<u>Total</u>	<u>191.3</u>		<u>100.94</u>

The average U – value = 100.94 / 191.3 = 0.53

The target U – value is:

$$UT = [0.35 - 0.19 (44.4 / 191.3) - 0.10 (44.4 / 191.3) + 0.413 (88.8 / 191.3)]$$

$$= 0.48 \text{ W/m}^2\text{K}$$

In the following calculations, the average U-values are calculated for the same two-storey dwelling assuming walls constructed using different Aircrete materials of strengths 2, 2.8 and 7 N/mm^2. Calculations are included for walls constructed from thin joint and conventional mortar. It has been reported that the use of thin joint mortar can reduce the U-value by 10% [25-27]. For thin joint mortar it is assumed λ = 0.88 W/mK and the average total volume of mortar in a wall constructed with thin joint mortar is 1.5% (assuming 3mm thick mortar joints). For conventional mortar λ = 0.90 W/mK and the average total volume of mortar per wall is 6.7% (10mm thick mortar joints). For each calculation, the values for the roof, windows and doors from Table 2 have been kept constant, therefore, the variable factors were the values for the wall and ground floor. For wall calculations, the effect of mortar was taken into account. Thermal Transmittance U – Values for different Aircrete material are as follows (unrendered and unprotected):

Table 3: U – Values for different Aircrete Wall Thickness (mm)

Aircrete strength N/mm^2	200 mm TJ	200 mm CM	225 mm TJ	225 mm CM	250 mm TJ	250 mm CM	300 mm TJ	300 mm CM
2	0.61	0.71	0.58	0.66	0.55	0.62	0.51	0.57
2.8	0.67	0.76	-	-	-	-	0.55	0.61
7	0.94	1.02	-	-	-	-	0.72	0.77

Dimensions (in mm) refer to the wall thickness – single leaf and unrendered.
TJ = Thin Joint Mortar
CM = Conventional Mortar (cement-lime-sand typically 1:1:6 ratio)

From the results it can be seen that dwellings constructed from the lower strength / density material have a lower thermal transmittance (U-value). The U-value for a dwelling constructed from 7N blocks is up to over 50% higher than one constructed from 2N blocks. Also, as the thickness for thin joint mortar is significantly less than that for conventional mortar (3 as opposed to 10mm), this results in dwellings constructed from conventional mortar having U-values approximately 10% greater than those constructed using thin joint mortar. The average U-value of a typical dwelling with a wall construction comprising a cavity wall with a brick outer leaf, a cavity partially filled with 17mm of Celotex and a 115mm Aircrete (med / high density) inner leaf finished with 13mm dense plaster internally was 0.53 [2]. For a dwelling constructed with solid, 300mm thick 2N Aircrete blocks with thin joint mortar, the U-value was 0.51. Therefore, the utilization of low density Aircrete eliminates the necessity for cavity wall construction. This would not only save money but also reduce the building time, hence, increasing productivity whilst simultaneously reducing carbon energy consumption. Although, the U – value (0.51) is higher than the calculated target U – value (0.48), it is expected that rendering will reduce the final average U – value to at least the target value.

Conclusions

- The strength of low density Aircrete (AAC) is sufficient to construct two storey domestic dwellings.
- Low density Aircrete offers excellent thermal resistance and in many instances solid Aircrete walls could abrogate the need for cavity wall insulation.
- Low density Aircrete offers excellent resistance to frost and sufficient resistance to sulphates.
- The low density of Aircrete results in rapid construction speeds.
- Using PFA to produce Aircrete reduces the need for waste to be disposed of in landfill sites.
- The usage of AAC contributes to sustainable construction.

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