BEHAVIOUR AND DESIGN OF LOW DENSITY AIRCRETE MASONRY

M C Limbachiya*, C A Fudge+, J J Roberts**

* Professor, Faculty of Engineering, Kingston University- London, UK
+ Aircrete Products Association, UK
** Emeritus Professor, Faculty of Engineering, Kingston University- London, UK

SUMMARY

This paper outlines part of a comprehensive research project carried out by Kingston University's Concrete and Masonry Research Group to assess the behaviour of high performance low-density aircrete masonry, with a declared compressive strength of 2.0N (N/mm^2) and a density of 350 kg/m^3. Performance was then compared with the conventional aircrete masonry blocks with a declared compressive strength of 2.9N and a density of 460 kg/m^3. The first part of the paper concentrates on the fundamental characteristics of low density aircrete (LDA) masonry units, including compressive strength, dimension, density, moisture properties, thermal performance, freeze/thaw resistance. Thereafter, the structural performance of key ancillary components used with low-density aircrete masonry is examined and discussed. In addition, practical issues associated with the use of low density masonry units are also highlighted.

INTRODUCTION

Aircrete originated from Scandinavia in the 1920's and is now used extensively in the UK, with the current European market being over 30 million m^3. At present, sales of aircrete masonry units are approximately 3 million m^3 per annum in the UK and, as blocks they are used extensively by house builders, although there are some sales to other sectors of the construction industry. It is so extensively used that Aircrete accounts for approximately a third of all concrete masonry units used in the UK. Aircrete blocks are suitable for use as load-bearing and non load-bearing masonry walls and contribute significantly towards the thermal insulation required from wall construction. Aircrete units may also be used as outer leaves of masonry external cavity walls, solid external walls, internal partitions and separating walls between dwellings, and walls below ground level.

The main benefit is that acoustic, energy conservation, fire resistance and structural properties are uniquely provided in one product. The lightweight products have very low thermal conductivities, making them ideal materials for external walls where heat loss is of primary importance. Despite their relatively low mass, aircrete products perform well where acoustic performance is required, due to the micro-structure of the material.

There have been considerable developments in product properties and construction methods, which have accelerated in recent years, making available higher strengths, lower densities and larger size units than previously. Innovative methods of construction have also been made possible as a result of modern manufacturing techniques e.g. thin layer mortar jointing and blocks with hand holds in the block perpends.

KEY CHARACTERISTICS CONSIDERED

Compressive Strength

It is widely recognised and accepted that the compressive strength of aircrete is related to its density and increases with increasing density. Commonly produced compressive strengths are 2.9, 3.6, 7.3 and 8.7N (N/mm^2) as indicated in 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 (Wittmann 1993), implying lower compressive strength could be adequate. The compressive strength of Aircrete is nearly independent of specimen size due to its homogeneity (Wittmann 1993). Aircrete achieves its final strength during the autoclaving process without further curing being necessary.

Table 1 Physical Properties of Aircrete Blocks

Aircrete Density	Compressive Strength (N/mm^2)	Density (kg/m^3)	Thermal Conductivity (W/mK)
Low	2.0 – 3.6	450	0.09 - 0.11
Medium	3.6 – 4.5	620	0.15 – 0.17
High	7.0 – 8.5	750	0.19 – 0.20

Thermal Resistance

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 (Callister 2000). 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 (Dubral 1992, Theramalite 2003, Limbachiya and Roberts 2005, Fudge and Limbachiya 2006, Schlegel and Volec 1992) as given in Table 1 above.

Moisture Movement and Resistance to Freezing

Moisture movement through porous building materials is a very complex process and for practical predictions simplifying assumptions may have to be introduced. There are at least three different origins of water in aircrete masonry units. 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 (Dubral 1992). 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 (Mitsuda and Kiribayashi 1992, Wittmann 1993). Although low density aircrete units has a very high

proportion of air, the pores are fine and are not interconnected, therefore, the material offers good resistance to moisture penetration.

Aircrete possesses good resistance to freezing, which is proved by un-rendered 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. Moreover, 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, as well as density.

EXPERIMENTAL PROGRAMME

Given that the efficiency of construction is improved by providing masonry units that are easily manhandled and readily cut, shaped and chased, such as LDA units, there is the potential for simplified external wall construction, which address several of the key aspects of environmentally friendly products. The Concrete and Masonry Research Group at Kingston University undertook extensive research aimed at assessing the behaviour and design of high performance LDA products. The principle objective of the research was to create further value-added outlets for exploiting the environmentally friendly and beneficial properties of high performance low-density aircrete in dwellings in the UK. This paper outlines standard, as well as routine test methods, used to assess thermal characteristics of aircrete masonry units, as well as structural performance of key ancillary components used with low-density aircrete blocks. The declared densities of the 2.0 and 2.9N/mm^2 were 350 and 460kg/m^3 respectively.

As a starting point, dimension, density and moisture properties of test samples were established. Dimension and Density of aircrete masonry units were determined following the procedure described in BS EN 772: Parts 16 and 13, respectively. Moisture properties of low density aircrete masonry samples were also established by measuring the moisture content, water absorption and movement. A minimum of six representative portions from at least three units were tested. For this, after drying to constant mass, the moisture content was calculated as the ratio of the loss of mass during drying to the mass after drying. The moisture content was also measured immediately after removing the blocks from the pallets. After drying to constant mass a face of the Aircrete block was immersed in water for a specific period of time, to evaluate the coefficient of water absorption at 10, 30 and 90 minutes. The results of this test series are given in the paper presented at the 7th International masonry Conference in 2006, organised by the British Masonry Society (Limbachiya and Fudge, 2006).

Thermal Performance

The thermal performance of LDA masonry units was verified by reference to BS EN 1745: 2002, which incorporated testing conforming to BS EN 12664: 2001 using a guarded hot-plate. Thermal conductivity testing, in accordance with BS EN 12664: 2001 was carried out by H + H UK. The results were expressed to the nearest 0.1 W/mK. For this, guarded hot-

plate apparatus in a vertical orientation conforming to the appropriate standard was used. The guarded hot-plate had;

- Heating unit, which consists of guarded section heater surface plates;
- Cooling unit, which consists of cooling unit surface plates;
- Thermocouples consist of heating and cooling unit surface thermocouples, respectively.

A representative specimen of 305 x 305 x 50 mm was prepared from 2.0 N/mm^2 aircrete specimens of 300 x 620 x 200 mm. The faces of which were milled to produce a specimen thickness of 45 mm with plane and parallel surfaces using a diamond toothed rotary milling machine. The difference in thickness across the full width was maintained at less than 2% of the mean thickness (< 0.9mm) and deviation from flatness was less than 0.08mm over the full width.

Structural Performance of Ancillary Components

Lintel Bearings

During this research, a range of proprietary steel lintel bearings, joist hangers, wall ties and fixings were tested to evaluate the structural performance of low density aircrete masonry units- in wallettes prepared with thin joint mortar. The material preparation and testing were carried out in accordance to BS EN 846. Lintels were tested (Figure 1) at bearing lengths of 150 and 300mm, and it was subjected to a uniformly distributed load (4 – point). The mid–span vertical deflection, together with any visible signs of distress in specimens, fixings or supporting member, was recorded.

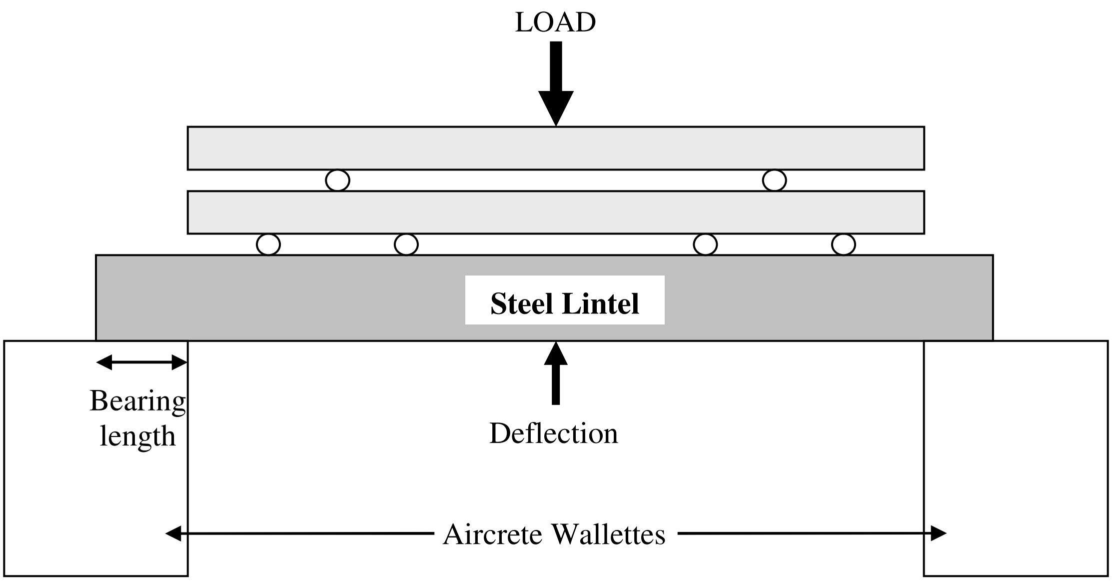

Figure 1 Lintel Bearings Experimental Test Sep-up

Joist Hangers

Joist hangers testing was conducted to ascertain the compatibility of using joist hangers with LDA masonry. The bearing area of the hanger was designed to work with 2.0 and 2.9N Aircrete masonry. Walls of the low strength masonry were constructed and the hangers and joist were incorporated as specified in the test procedure BS EN 846: Part 8: 2000. Stainless steel joist hangers were fixed to a wall (constructed from 2.0N and 2.9N aircrete masonry) and loaded through joists (timber). After construction (with thin layer mortar), the wall specimens were covered in polyethylene sheets and cured for 28 ± 1 day before testing. For all the tests, the timber length was 1m. The loading system applied a vertical load to the specimen. The maximum loads and the mode of failure for all the specimens were recorded. As the load was applied at a distance of 2L / 3 from the joist hanger, the force sustained by each individual hanger would be two – thirds of the maximum failure load. The maximum load value for the timber joist was the value sustained by the timber joist at a distance of 2L/ 3 from the joist hanger, which is the point A, as shown in Figure 2. A pre-load of 1 kN was applied to the test specimen and held for a period of 1 minute. The load was then removed and a load was applied at a rate of 1 kN increase per minute until failure occurred, which was defined as the load at which further deflection occurs without increase in test load. Three joist hangers, positioned at 1, 2 and 3 (from left to right, Figure 3) were used for this testing. The failure load and mode of failure was recorded, and maximum load sustained by the joist hanger was calculated as failure load/3.

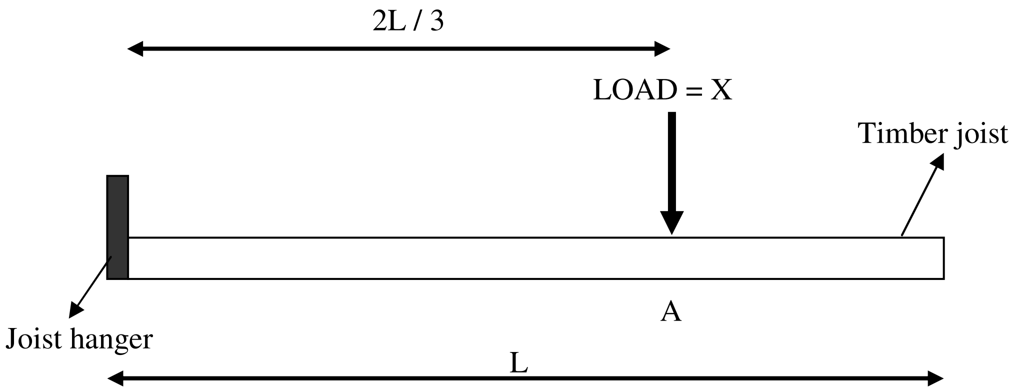

Figure 2 Schematic Representation of Test (Force sustained by joist hanger = X/3)

Figure 3 Typical wallette specimen and joist hanger test set-up

RESULTS AND DISCUSSIONS

Dimension and Density: The test results for dimensions and density are summarised in Tables 2 and 3, respectively. Whilst average values are given in Table 4 below.

Table 2 Dimensions of 2.0 and 2.9N Aircrete Masonry Units

Aircrete	Length (mm)	Width (mm)	Height (mm)
2.0 N	620.0	149.8	249.9
	619.5	149.6	249.6
	620.0	150.0	250.0
	620.0	149.8	249.7
	619.8	150.0	250.0
	619.6	149.4	249.4
2.9 N	440.0	149.6	214.5
	439.6	150.0	215.0
	439.6	149.7	214.5
	440.0	149.8	214.8
	439.8	150.0	215.0
	439.5	149.5	214.8

Table 3 Density of 2.0 and 2.9N Aircrete Masonry Units

Aircrete	Density (kg/m3)
2.0 N	350
	352
	354
	351
	352
	353
2.9 N	474
	475
	477
	479
	480
	477

Table 4 Average Dimensions and Density of 2.0 and 2.9N Aircrete Units

Aircrete	Average values			
	Length (mm)	Width (mm)	Height (mm)	Density (kg/m^3)
2.0 N	619.8	149.8	249.8	352
2.9 N	439.7	149.8	214.8	477

Dimensions given by manufacturers for both aircrete masonry units used were:

- For 2.0N aircrete masonry units- 620 x 150 x 250 mm
- For 2.9N aircrete masonry units- 440 x 150 x 215 mm

On comparison, average measured dimensions for both aircrete units were found to be within 0.3mm of declared dimensions given by the manufacturers. The average values are also within the permissible deviations for use with conventional mortar and thin layer mortar as specified in accordance with BS EN 998: Part 2: 2003. Declared manufacturer's density for 2.0 and 2.9N aircrete unit is 350 kg/m^3 and 475 kg/m^3, respectively. Against this, average measured density for 2.0 and 2.9 N/mm^2 Aircrete were 352 kg/m^3 and 477 kg/m^3 respectively, within 0.57% and 0.42% of the theoretical density value.

Thermal Performance

Results of thermal conductivity tests are summarised in Table 5 below.

Table 5 Thermal Conductivity Test Results (2.0 N/mm^2 aircrete masonry units)

Thermal conductivity (W/mK)	Moisture content % (w/w)	Dry density (kg/m^3)	Mean temperature at test (°C)	Density of heat flow rate (W/m^2)
0.104	3.55	339.1	20.3	70.07

The test result shows that 2.0N Aircrete unit has a very low thermal conductivity of 0.104 W/mK and lower than 2.9N Aircrete (0.11 W/mK). This was expected considering the lower density of 2.0N Aircrete due to its higher porosity as compared to 2.9N Aircrete. The Low Density Aircrete of 2.0N unit has a relatively higher porosity of 70 -85% as compared to ordinary Aircrete, which has 60 – 85% porosity. The high degree of porosity of 2.0N Aircrete masonry unit has drastically improved the thermal resistance.

Structural Performance of Ancillary Components

Lintel Bearing

Lintels bearing were tested at bearing lengths of 150 and 300 mm on 2.0N and 2.9N aircrete wallettes and the test results are summarised in Table 6. Results show that all wallettes can withstand at least a load of 75 kN or a stress value of 1.7 N/mm^2. Furthermore, there was no visible failure and on removal of the load, the deflection reading went back to zero, hence, elastic deflection took place. For 2.0N Aircrete wallette at 150mm bearing length, the deflections were higher than that of 2.9N Aircrete wallette. Also, the deflections were larger in magnitude at 150mm bearing length. The walls, therefore can withstand higher loads, however, due to health and safety implications, the testing was stopped at a load of 75 kN.

Table 6 Lintel Bearing Test Results for Different Aircrete and Mortar Combination

Aircrete	Bearing length (mm)	Max. load (kN) (stress N/mm^2)	Any visible failure	Deflection at 75 kN (mm)	Deflection upon load release (mm)
2.0 N	150	75 (1.7)	NO	7.8	0
	300	75 (0.8)	NO	5.6	0
2.9 N	150	75 (1.7)	NO	6.5	0
	300	75 (0.8)	NO	6.0	0

Note: Thin layer mortar was used in test wallettes production

Joints hangers

The maximum load recorded from the test and the mode of failure for all the specimens are given in Table 7. Figure 4 shows the typical failure mechanism for all the tests. In all cases the timber joists failed, whilst all the 6 wallettes specimens remained totally unscathed. The test results were very consistent with the timber joist failing at loads between 16.1 – 17.5 kN, which equates to the joist hangers being able to sustain at least a minimum load of 5.4 kN.

Table 7 Recorded Failure Loads from the Tests

Aircrete	Maximum Load, kN				Mode of Failure
	Timber joist	*Joist @ positions*			
		1	*2*	*3*	
2.0 N	16.6 – 16.8	5.5	5.6	5.5	Joist
2.9 N	17.4 – 17.5	5.8	5.8	5.8	Joist

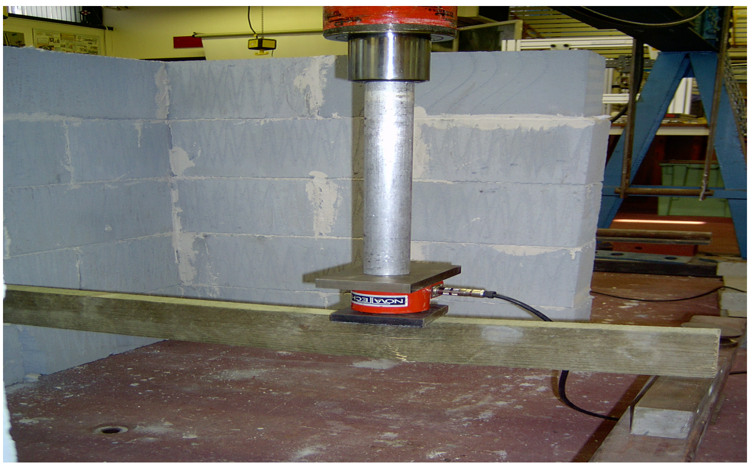

Figure 4 Typical Failure for all Tests Showing Timber Joist Failure

Table 8 gives the test results of testing of metal joist, instead of timber joist on 2.0N Aircrete wallette with thin layer mortar to evaluate the absolute maximum load capacity of the joist hanger. The failure mode of joist hangers was found to be localised with crushing at the front edge of the wall with no visible crack on the wall and the joist hanger was still intact to the wall. This is possibly due to the restrain imposed by design of the joist hanger. Hence, the recorded maximum load of 8.0 kN shown in Table 8 represents the serviceability limit of the hanger and not the ultimate limit.

Table 8 Recorded Failure Loads of Metal Joist Test

Aircrete	Types of mortar	Timber joist	Joist hanger @ position (maximum load, kN)			Mode of failure
			1	**2**	**3**	
2.0 N	Thin layer	24.0	-	8.0	-	Joist hanger

CONCLUSIONS

- Dimension, density and moisture properties of low-density aircrete masonry units were assessed using different standard test methods. The average measured dimensions for both 2.0N and 2.9N LDA masonry units were within 0.3mm of the declared values. Whilst the average measured density for 2.0N and 2.9N Aircrete unit was 350 kg/m^3 and 475 kg/m^3, respectively, which is noticeably within 0.57% and 0.42% of the theoretical or desired value.

- The thermal performance test results show that 2.0N LDA masonry has a very low thermal conductivity of 0.10 W/mK.

- Lintel bearing testing was conducted to ascertain the load bearing capacity for both 2.0N and 2.9N LDA wallettes incorporating thin layer mortar. Test results confirmed that all wallettes can withstand a load of 75 kN or a stress of 1.7 N/mm^2 without any visible signs of failure. Moreover, the deflections observed for the steel lintel during testing were totally elastic.

- The compatibility of using a generic steel joist hanger with 2.0N and 2.9N aircrete has been ascertained using thin layer type mortar. In all tests, the timber joist (with dimensions of 100 x 38 x 1000 mm) failed before the masonry wallette, in which each of the masonry specimens was left totally unscathed. Furthermore, the average maximum load sustained by the timber joist during testing was 16.9 kN, and the serviceability limit of the joist hanger was found to be 8 kN.

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