LOW STRENGTH MASONRY UNITS - EVALUATING POTENTIAL APPLICATIONS IN THE CONTEXT OF THE NEW EUROPEAN CODES AND STANDARDS

Professor John Roberts[1], Professor Norman Bright[2]

ABSTRACT

The harmonisation of European Standards for masonry materials under the auspices of CEN TC125 and for the design of masonry under CEN TC250/SC6 has brought together a disparate range of traditions, practices and applications for masonry. To accommodate this broad base of uses, historic national limits have been challenged and the proposed standards include minimum threshold values for properties such as strength. The planned introduction across Europe of the new structural design code Eurocode 6 - EN 1996 for Masonry together with the supporting masonry product standards and test method standards coincides with an increased emphasis on sustainability, energy conservation and the efficiency of the construction process.

This paper looks at the potential applications of low strength masonry, reviews the design information currently available and identifies where new information needs to be provided. It shows that there are a number of opportunities to exploit low strength masonry, particularly in low rise structures, with the potential for improvements in both the construction process and the performance standards achieved.

Key Words: masonry, structure, low strength, energy, lightweight, European Standards

1) Dean, Faculty of Technology,
Kingston University, Penrhyn Road, Kingston upon Thames, KT1 2EE, UK
J.Roberts@Kingston.ac.uk

2) Visiting Professor, Kingston University
Consulting Engineer, Fairview, Stoodleigh, Tiverton, Devon, EX16 9PR, UK
normanbright@fairview.clara.net

BACKGROUND

Low strength masonry has been used extensively from earliest time particularly in the form of unfired earth masonry. Unfired earth walling is still used today across the world in many countries especially where there is no ready access to factory produced masonry for availability /economic reasons. Earth masonry units are essentially hand made and are unlikely to be produced in factories Figure 1.

Figure 1 Manufacture of Earth Bricks
(Kembatta Women's Self Help Centre – Ethiopia)

The most widely available low strength masonry units in Europe are made from Autoclaved Aerated Concrete (Aircrete) which can only be produced under factory conditions Figure 2.

Figure 2 Manufacture of Lightweight Blocks

<u>Aircrete Material Properties</u>

Aircrete is produced in factories by mixing large batches of pulverised fuel ash (fly ash) and/or ground sand with cement and/or lime in a slurry to which a small quantity of aluminium powder and dispersion agent are added. The slurry is discharged to half fill large steel moulds. The aluminium powder reacts with the lime or the lime in the cement to form tiny bubbles of hydrogen. The slurry rises to fill the moulds and sets to a cheese like consistency. The material is cut into block size pieces with wires on a cutting frame and cured in giant autoclaves. The curing regime is steam at more than ten times atmospheric pressure for approximately eight hours.

When the blocks are removed from the autoclaves they are ready for use as soon as they have cooled.

The embodied energy in Aircrete is relatively low. The energy input of autoclaving is off set by the energy savings in use due to the thermal insulation provided. Waste material produced during manufacture is recycled in the manufacturing process. Energy used in transport to site is less than that for alternative masonry materials.

Current production technology combined with market and regulatory requirements in the UK have led to the current minimum compressive strength of 2.8N/mm^2 and the associated wall thicknesses for common applications.

Applications

In the UK lightweight concrete blocks came into widespread use in the late 1940's and early 50's. They were predominately 100mm (1/2 brick) thick and the lowest block strength was 2.8N/mm^2 (400lb/in^2 at the time as metrication was not adopted by the UK construction industry until the late 1960's). Autoclaved Aerated Concrete (Aircrete) blocks were introduced in the 1950's and from their early days provided a minimum strength of 3.5N/mm^2 (400lb/in^2) compared with 2.8N/mm^2 for the common clinker block. Over a period of time 3.5N/mm^2 effectively became the block industry minimum "standard" although such a high strength was not necessary for the majority of applications. For Aircrete, 3.5N/mm^2 implied a density of about 750 kg/m^3 at that time.

When the first national Building Regulations came into force for England and Wales in 1965 (1963 in Scotland) a cavity wall with two leaves of brickwork met the thermal requirements. In January 1977 new thermal Building Regulations came into force (U=1.0 W/m^{2}K) for dwellings so that a 100mm thick Aircrete block was required for the inner leaf of the cavity wall. Alternatively some form of non-structural insulation was placed in the cavity. In mid 1979 thermal requirements (U= 0.6 W/m^{2}K for walls) were introduced into the regulations for "buildings other than dwellings". About 5 years later the thermal regulations for the walls of dwellings were further tightened also to U=0.6 W/m^{2}K. To meet the regulations the Aircrete block density had to be lowered to 450 -500 kg/m^3 and the compressive strength to 2.8 N/mm^2. At this density it required an inner leaf up to 150mm thick to meet the regulations.

Although many people in the construction industry at the time considered that builders would not use anything thicker than the "one hand lift 100mm thick block" for the inner leaf, the use of blocks of greater thickness has become widely accepted and is one of the most used inner leaf constructions for dwellings.

The construction has survived one further tightening of the energy conservation regulations (1991) by using a calculation process known as "trading" and has remained popular until today.

Today

Structural Design Code developments in Europe have proceeded at a snails pace over more than a decade. Concurrently, European (CEN) Product Standards and Test Method Standards have been drafted and some are already published. As with all good codes of practice and standards they are written to codify existing practice without intentionally inhibiting innovation.

The continuing amendments to the Building Regulations (2000) in the UK for energy conservation make it increasingly more demanding for masonry to meet the requirements particularly for single family dwellings.

The majority of dwellings are two storey and predominately they have masonry external cavity walls. The outer leaf is frequently clay brick or, in some regions, stone masonry or reconstructed stone masonry. Rendered exteriors are often used in areas exposed to driving rain. Solid masonry external walling has not been popular.

Most masonry for dwellings constructed in the UK is not designed to comply with the structural design code BS5628 but follows the "simple rules" in Approved Document A of the Building Regulations. This set of rules covers the normal requirements for dwellings but recognises only two strength levels, namely 2.8 and 7.0 N/mm^2. Using BS5628 it is possible to design a 4 storey building of cross-wall construction using a block strength of less than 5 N/mm^2 but it is very common in design offices to over design and select higher strength units than are strictly required by the design code.

The UK construction industry is going through a period when it is being encouraged by the Government to be innovative and the question to be addressed is whether masonry units with the lowest compressive strength of 1.5N/mm^2 allowed in CEN Standard EN 771-4 "Autoclaved Aerated Concrete Masonry Units" can be introduced to the UK?

The use of low strength blocks picks up on the need to adjust UK design procedures to reflect developments in Eurocode 6 and the supporting CEN TC 125 standards. There is a particular opportunity to achieve a significant improvement in productivity by exploiting the use of single leaf low density Aircrete concrete masonry walls. The practice of using such walls has been developed in Mainland Europe but it is recognised that there are some important differences in construction practice. There are clearly opportunities for improvements in productivity by using low strength low density masonry units but these will only occur if the overall structural approach is approved for UK conditions. The efficiency of construction is improved by providing units that are easily manhandled and readily cut, shaped and chased. There is also the potential for simplified external wall constructions which address several of the key aspects of the report on "Rethinking Construction".

As well as addressing the key economic aim of making dwelling and building construction more profitable, low strength units provide a high level of thermal insulation which will assist in meeting the proposed changes to Part L of the Building Regulations, thereby addressing the key environmental need to reduce the consumption of carbon based energy. The fact that these units have a very low density (typically 350kg/m3), have a high air content and often contain waste products such as pulverised fuel ash, also addresses the environmental need to preserve natural resources which would otherwise be consumed by denser products.

Innovations

In recent years different forms of attractive external wall finishes have been developed. These include a form of brick slip and simulated brick finishes which when applied to a solid wall gives a realistic brick appearance.
A major innovation with respect to Aircrete though has been the development of cement based thin layer mortar. The combination of low strength units and very thin joints only 1-3mm thick greatly enhances the thermal performance achieved in practice. The high dimensional accuracy of Aircrete blocks makes them ideal for use with thin layer mortar. Thin joint blockwork gives higher masonry compressive strengths and reaches maximum strength sooner for a given block strength compared with blockwork laid in general purpose mortar. The use of thin joint blockwork with the associated improved speed and accuracy of the jointing can lead to savings in construction time of walls. When the blockwork has been laid in thin layer mortar, thin sprayed proprietary renders and plasters 3-4mm thick which reduce completion times may also be used.
In normal conditions, using thin joint blockwork, it should be possible to construct a full storey height up to 3 metres in a day.

Current Aircrete External Wall Constructions

A common external wall construction is two leaf cavity walling with a clay brickwork outer leaf. Using the current British Standard lowest strength Aircrete blockwork to form the inner leaf a U-value (Thermal Resistance) of 0.6 W/m^{2}K is achieved by the approved calculation method with a leaf thickness of up to 150 mm with a block with a compressive strength of 2.8N/mm^2.
The incoming new Building Regulations are expected in general terms to require a U-value of 0.35 W/m^{2}K for walls.

Figure 3 Solid Wall Construction

Possible Low strength Aircrete Constructions

The clear cavity wall is a common form of construction in Northern Western Europe whereas solid wall construction is more common in Southern Europe Figure 3. The cavity wall has remained popular because the clear cavity is an effective barrier to driving rain. It is also very flexible and can accommodate many different types of masonry unit. The enhanced requirements for energy efficient construction have resulted in thicker low density inner leaves to compliment the dense facing brick typically used in the outer leaf. Blocks with strengths as low as 1.5 N/mm^2 will be permitted in Europe and this will enable the use of material densities of around 350 kg/m3. Two main developments are likely:

- Larger blocks, jointed with thin layer mortar, offering a good compromise between strength, buildability and thermal performance in the inner leaf role. The inherent stability of this wider inner leaf will free the builder from the necessity to build both leaves of a cavity wall simultaneously.
- Large and very large blocks used in solid wall constructions with thin joint mortars and either a cladding system or an applied finish.

A solid 250mm Aircrete block wall with a density of 350 kg/mm^2 in thin joint mortar with provide a U value of about 0.35 W/m^2K without taking into account the contribution of internal and external finishes Figure 4.

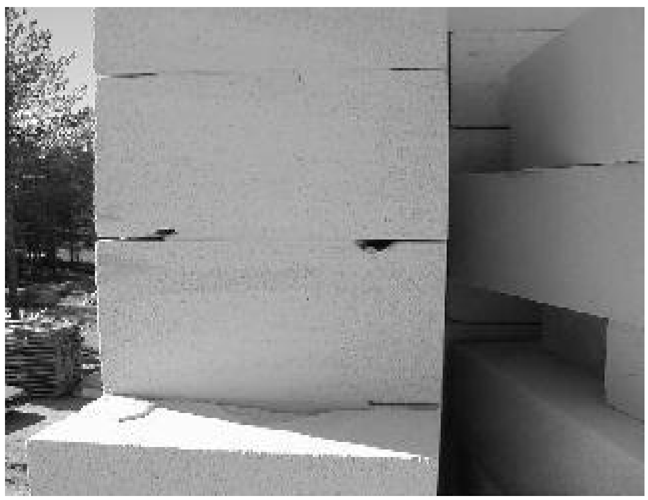

Figure 4 Section Through Unfinished Wall

FACTORS AFFECTING THE RE-INTRODUCTION OF SOLID WALLS IN THE UK

The definition of a single leaf wall contained in BS 5628 is “a wall of bricks or blocks laid to overlap in one or more directions and set solidly in mortar”. For many years the single leaf or ‘solid’ wall comprised of a 9 inch brick wall, i.e. made from 4 ½ inch wide bricks. This legacy is still with us in the UK in that the current housing stock probably contains over eight million solid walled dwellings.

Although cavity wall construction in the UK started before the turn of the century, it really became widespread in the period between the World Wars in an effort to reduce the incidence of rain penetration. Subsequently the use of solid wall declined so much that in

England and Wales it was rarely used, although it continued to enjoy some use in Scotland. In other parts of the world solid masonry walling has continued to evolve and develop.
When the starting point is the established custom and practice of cavity walling, solid walls pose `new' challenges to the `received wisdom' of design and detailing requiring either fresh thinking or the re-discovery of old solutions. The "re-discovery" of solid walls will only occur when the economic as well as the technical factors make sense.

Productivity studies of solid and cavity walls

One major study allowing comparison between solid and cavity walls was carried out at Pitcoudie in Scotland. The productivity studies carried out at Pitcoudie involved two phases with two distinct forms of construction. Pitcoudie 1 used 255mm thick Aircrete blocks laid in one-third bonding to produce a form of modified posted construction. Pitcoudie 2 used double leaf aggregate blocks. For both phases the walls were rendered externally very much in the Scottish vernacular.

The results of the studies generally confirm those of other productivity exercises in showing that the form of superstructure construction is a relatively small proportion (typically 10-15%) of the time and effort expended in completing a dwelling (Anderson et al, Griffith). Studies also tend to show that masonry construction is very consistent - there are not usually big variations in the man hours taken to complete a given task.

The implication of this work appears to be that, within sensible limits, it does not matter too much whether you build a solid or cavity wall; the effort expended is not likely to be too different and any savings from a particular solution are likely to be modest when set against the rest of the effort involved in constructing a dwelling.

Subsequently site monitoring was employed by the Cement and Concrete Association to compare a terrace of three starter homes built using brick-cavity-block construction with dry stacked solid Aircrete blockwork finished internally and externally with glass reinforced cement render. The results of the monitoring indicated that the cavity walls were built faster than the dry stacked solid walls. The lesson would appear to be that you do not change from a well established form of construction with which tradesmen are very familiar without incurring penalties which it takes time and experience to overcome.

The pricing and costing of solid and cavity walls

Many projects are still costed on the basis of materials costs rather than the overall cost of construction. The ability to measure both the material and labour cost in the form of an overall cost is essential to demonstrating the efficiency of construction.
A solid wall has inherently more material in it than a cavity wall. For stability a solid wall would often be at least 250mm thick i.e. perhaps 50mm more material than in a traditional cavity wall. But in the last decade inner leaves are often thicker due to the use of thicker insulation blocks in the inner leaf. When considered with the use of wall ties and facing bricks, the modern cavity wall does look to be becoming the more expensive option, although the cost of rendering a solid wall can be significant.

Rain penetration resistance

A good render system applied to a solid wall is perfectly capable of resisting extreme exposure to driving rain without letting water through the wall. A solid wall built of facing masonry, whether brickwork or blockwork, is essentially porous and will in time allow water through any interface crack between the mortar and unit and subsequently through the mortar and units themselves. The acceptability of the latter depends very much on the level of exposure, its duration and the materials used. Whilst it does appear that solid walls are less prone to cracking than cavity walls, any cracking may cause problems if there are sulphates present in the masonry, which, in the presence of water, may attach to the rendering material.

RESEARCH REQUIRED TO MAKE LOW STRENGTH BLOCKS ACCEPTABLE IN THE UK

Initial Research Programme

Kingston University is about to undertake a research programme looking at the use of low strength blocks. The aim of the project is to provide authoritative support to the use of low strength concrete masonry units in loadbearing walls for houses. The CEN TC125 series of masonry unit standards recognise the widespread use in Europe of low strength units in thicker walls than are currently common in the UK. In particular EN771-4 will allow masonry units with strengths less than the current minimum of $2.8N/mm^2$ to be used. The use of such low strength units will permit lower density units with better thermal conductivities to be used in thicker wall constructions to meet the forthcoming changes to the energy conservation requirements of Part L of the Building Regulations. A critical design aspect is the behaviour of such walls when subjected to concentrated loads and information is also required on lateral load performance. This research will result in authoritative guidance for regulatory authorities and allow the UK construction industry to benefit from the proven good buildability and performance of low strength masonry. Ultimately the work should lead to an amended Approved Document A of the Building Regulations so that UK practice can benefit from the new European standards.

The project will enable a better understanding of the use of low strength Aircrete masonry units in a compatible mortar in loadbearing masonry walls. There are three areas of structural performance which are likely to cause concern to those asked to approve the use of such masonry units:

- where the masonry units act as lintel bearings
- where the masonry units support joist hangers
- performance of wall ties embedded in low strength walls

In addition current design guidance for lateral loading in BS5628:Part I and EN 1996 (Eurocode 6) does not cover units with strengths lower than $2.8N/mm^2$ and information therefore needs to be provided on the characteristic flexural strength.

Figure 5 Lintel Bearing

Lintel bearings

Thicker walls will require the use of wider lintels and therefore the local stress/strength ratio may not be very different from at present Figure 5. It is, however, a matter of concern and confirmatory tests need to be carried out. It is intended to make use of the new European test methods to demonstrate the suitability of low strength Aircrete units for use in the UK. It is believed that the use of these tests to make comparisons with current products will make the results readily acceptable to regulators. It is therefore proposed to use EN845-l as the specification to check alongside UK requirements and use BS EN 846-9 to make comparisons of lintel performance when used in conjunction with standard and low density masonry units. In addition to pressed steel lintels low density Aircrete lintels will be used for comparison purposes. To check the behaviour of the low strength masonry units when acting as lintel bearings, two different generic lintel types (pressed steel and Aircrete) will be tested for flexure, shear and load-deflection characteristics whilst supported on representative samples of walling constructed from low strength blockwork. The testing will be carried out in a way that is consistent with EN 846-9 which specifies methods for determining the flexural and shear resistance and load-deflection characteristics of lintels. The research will also build on earlier research on the structural behaviour of Aircrete Blockwork subjected to concentrated loading.

Joist Hangers

The onus is currently on the supplier of the hanger to indicate which types of unit a particular hanger is suitable for. It is recognised that development work will need to be carried out with the manufacturers.

One generic type of joint hanger will be designed and tested for use with low strength masonry units. The bearing area of the hanger will be designed to work with the 1.5N/mm^2 minimum compressive strength. A wall (or walls) of the low strength masonry units will be constructed and the hangers and joint incorporated as specified in the test procedure contained in EN 846-8. A minimum of 5 tests will be completed on the generic hanger.

Wall ties

Tests will be undertaken to establish that the loads carried in tension and compression are adequate and whether additional embedment is required. A range of tie types will need to be considered. The performance of wall ties will be validated by testing to BS EN 846-5. Three types of tie will be tested, each designed to be embedded in the block rather than the mortar. The tests will be carried out in accordance with BSEN 846-6 which will require the testing of 24 specimens (48 if asymmetric) for each type of tie.

Characteristic Flexural Strength

EN 1052-2 "Methods of test for masonry-Part 2: Determination of flexural strength" will be used to determine the information needed by designers. The flexural strength of masonry is derived from the strength of small specimens tested to destruction under four point loading. The characteristic value is calculated from the maximum stresses achieved by the samples. The flexural strength will be determined using the procedure described in EN 1052-2 which requires 10 wallette specimens to be tested (at least 5 in each direction). The walls will be tested for one mortar designation and two block thicknesses (150 and 300mm), a total of 20 wallettes.

Standard control tests for the Programme

Compressive strength of units with ground surfaces and at 6% moisture content in accordance with EN 772-1. Ten specimens per set.
Moisture content by mass in accordance with EN 772-10.
Dimensions determined in accordance with EN 772-16.
Density determined in accordance with EN 772-13.
Flow value of mortar (2 values per set) determined in accordance with EN 1015-3.
Compressive strength of mortar determined in accordance with EN 1015-11.

OUTPUTS FROM THE PROPOSED RESEARCH

The main beneficiaries of the project will be designers and their clients.
Designers will be provided with a more economic design approach which will enable them to offer cost effective solutions to meeting both the thermal and structural requirements. This is in line with the Egan targets in Rethinking Construction and extends well established practice from mainland Europe into a UK context. Builders will have the benefit of a simplified construction method which offers a high performance standard in a single loadbearing leaf of masonry. Manufacturers will be able to extend the range of applications for which their products can be used. Regulatory bodies will have authoritative evidence which can be used to inform their decision making.
The final aim is enable Approved Document AD 'A' to the Building Regulations to be amended to include rules for thicker units with a lower compressive strength than $2.8N/mm^2$.

CONCLUSIONS

- The introduction of the new European standards for masonry materials provides a good opportunity to examine the innovative use of low strength masonry for dwelling and small building construction in the UK.
- Research is required to enable low strength masonry units to be used with confidence in a UK context.

The authors wish to record their thanks to Cliff Fudge, Technical Director, H+H Celcon Limited for providing photographs.

REFERENCES

Anderson, W.E., Roberts, J.J. & Watt, P. Efficient Masonry Housebuilding - Design Approach. Wexham Springs, Cement and Concrete Association. 1985. p. 2137.

Bright, N. J, (1978) The Structural Behaviour of Autoclaved Aerated Concrete Blockwork subjected to concentrated loading

British Standards Institution BS 5628:Part 1 1992. Code of Practice for use of masonry. Part1. Structural use of unreinforced masonry.

Egan, Sir John , (1998) Rethinking Construction, UK Department of the Environment, Transport and the Regions, pp 47.

EN 1996: Eurocode 6: Design of Masonry Structures, European Committee for Standardisation (CEN) (to be published)

EN 771-4 Specification for masonry units - Part 4 : Autoclaved aerated concrete masonry units.

EN 845-1 Specification for ancillary components for masonry - Part 1 : Ties, tension straps,
hangers and brackets

EN 846-9 Methods of test for ancillary components for masonry - Part 9 : Determination of
flexural resistance and shear resistance of lintels

EN 846-8 Methods of test for ancillary components for masonry - Part 8 : Determination of load capacity and load deflection characteristics of joint hangers

EN 846-5 Methods of test for ancillary components for masonry - Part 5 : Determination of tensile and compressive load capacity and load displacement characteristics of wall ties (complete test)

EN 846-6 Methods of test for ancillary components for masonry - Part 6 : Determination of tensile and compressive load capacity and load displacement characteristics of wall ties (single end test)

EN 1052-2 Methods of test for masonry - Part 2 : Determination of flexural strength

EN 772-1 Methods of test for masonry units - Part 1 : Determination of compressive strength

EN 772-10:1998 Methods of test for masonry units - Part 10 : Determination of moisture content of calcium silicate and autoclaved aerated concrete units

EN 772-16 Methods of test for masonry units - Part 16 : Determination of dimensions

EN 772-13 Methods of test for masonry units - Part 13 : Determination of net and gross dry
density of masonry units (except for natural stone)

EN 1015-3:1999 Methods of test for mortar for masonry - Part 3 : Determination of consistence of fresh mortar (by flow table)

EN 1015-11:1999 Methods of test for mortar for masonry - Part 11 : Determination of flexural and compressive strength of moulded mortar specimens

Griffith, A. Buildability. The effect of design and management on construction. Heriot-Watt University, 1984

The Building Standards (Scotland) Regulations, 1963, Scottish Development Department, Edinburgh

The Building Regulations 1965, Department of the Environment, Her Majesty's Stationery Office, London

The Building Regulations 1976, Department of the Environment, Her Majesty's Stationery Office, London

The Building Regulations 1979, Part FF, Department of the Environment, Her Majesty's Stationery Office

The Building Regulations 1991, Department of the Environment, Her Majesty's Stationery Office

The Building Regulations 2000, Consultation document, Department of the Environment, Transport and the Regions, London

The Building Regulations, Approved Document A, Structure, UK Department of the Environment, Her Majesty's Stationery Office, London

The Building Regulations Part L, Department of the Environment, Her Majesty's Stationery Office, London