10th Canadian Masonry Symposium, Banff, Alberta, June 8 – 12, 2005

A CASE FOR HOLLOW CLAY MASONRY IN MODERN CONSTRUCTION

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ABSTRACT

This paper contains an overview of the historic use of hollow clay masonry units and sets out arguments for increased use of this kind of unit. Hollow clay masonry units, generally in the form of hollow clay tile, have been used in Europe and elsewhere around the world dating back to the mid-nineteenth century. Despite introduction into Canada later in the nineteenth century, this type of unit is no longer manufactured here. The hollow clay brick variation of this type of unit typically has a higher solid percentage of its volume but is currently only manufactured by one brick producer. In addition to the obvious factors related to sustainability, environmental and economic concerns, changes in construction methods and related opportunities are discussed in terms of construction, building envelope performance and structural characteristics.

KEYWORDS: hollow, clay, tile, brick, mortar

INTRODUCTION

Early mechanized manufacture of clay masonry units involved moulding bricks into forms or moulds [1]. This moulding process lent itself to the production of 100% solid units. However, advances in the process led to the use of lower water content clay that was much stiffer and had to be pressed into the moulds to produce a high density unit with smooth faces and well defined edges. The reduced water content and high pressure "pressing" of the brick reduced the time required to sufficiently dry the brick prior to firing and resulted in a denser fired clay body with lower absorption properties. A refinement on this pressed brick process was to introduce a trough along the middle of the bed face; the manufacturer's name was often pressed into the bottom of this trough [2]. Many reasons have been given for introducing the trough or, in brick terminology, "frog". Among these are that mechanical interlocking along the mortar bed improves the bond. Whether true or not, depending on the depth and width of this frog, clay material was saved, drying time was reduced and more uniform firing was achieved through reduced depth of clay from a heated surface.

Mechanized production of hollow clay units began in North America in the latter part of the nineteenth century with the introduction of extrusion processes wherein a ribbon of stiff clay was extruded through a dye; then trimmed and cut into individual units [1]. Modern brick manufacturing still follows this basic process. Cores or cells were created in the brick by rods or bars suspended in the dye to create the continuous voids parallel to the sides of the extruded ribbon or slug of clay [3]. Much of the production of early hollow clay units was in the form of hollow clay tile or simply clay tile classified either as structural or not.

Hollow clay masonry gained some popularity in the form of a hollow clay Terra-Cotta block [2]. The materials were similar to regular clay brick. However, it was about 30% solid and mixed with sawdust which burned off during the firing process to produce a terra-cotta block porous enough to drive a nail into. This type of terra-cotta unit gained popularity in reaction to the great fire in Chicago in 1871. The use of terra-cotta in Canada began in the 1880's as a facing but was used structurally by the 20^{th} century. The use of Terra-Cotta units decreased with the increased use of concrete blocks and structural clay tile and was virtually unused, in Canada, after the 1930s. Clay tile is similar to hollow terra-cotta units with the exception of having no saw dust in it. The first structural clay tile standard in North America was published by the American Society for Testing and Materials in 1921 [3].

In North America, by definition, solid clay masonry is qualified as being considered solid when the cross-sectional areas of all planes parallel to the bedding plane are at least 75% solid. Typically, cylindrical coring of a 90 mm brick unit results in about 85% solid content and virtually all extruded solid brick in Canada include coring for the reasons mentioned above. However, it is only since the latter half of the twentieth century that the forerunner of the modern hollow clay brick was introduced as a significant clay masonry unit. The original requirement that a hollow unit have a net cross-sectional area of not less then 60% of the gross cross-sectional area on any plane [4] has since been modified to range between 40 and 75% for the plane parallel to the plane containing the cores, cells or deep frog [5].

BENEFITS OF HOLLOW CLAY BRICK

Current Situation

Many of the benefits of using hollow clay masonry units as an alternative to solid units are easily understood but will be repeated later for completeness. That hollow clay units do not already account for a large share of the brick market is an indicator of concern related to application in the field. Data gathered in the U.S.A. [6], indicates less than 3% hollow brick production during the 1990's but up to 8% in the early part of this century. These concerns relate both to past experience and the relatively conservative, slow-to-change nature of the construction industry.

In most of Canada, the climate makes freeze-thaw durability a prominent concern, perhaps even the main concern. In exposed conditions, clay tile with its relatively thin face shells and webs, often themselves containing coring (see Figure 1), suffer from deterioration which, in structural applications not only require costly repair but constitute a safety hazard. As societal expectations for thermal comfort and cost of energy both increased, the admittedly significant increase in heat flow resistance of tile did not have a major impact on the much greater insulating requirements. Therefore, an advantage of using tile as a weather-protected backup wall was largely irrelevant. The emerging use of concrete block could economically replace this function.

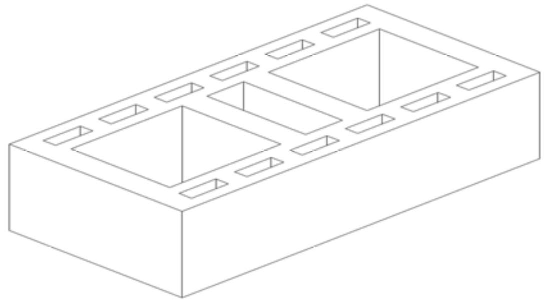

Figure 1 – Hollow Clay Tile

The introduction of through-the-wall hollow clay units during the 1960s and 1970s was an attempt to use single wythe construction to satisfy structural, aesthetic and building envelope requirements [7]. Many buildings were constructed in this manner and some, such as student residences at the University of Guelph, received architectural acclaim. However, by the late 1970's, moisture problems and major deterioration were common, perhaps in part, because of durability problems associated with one through the wall (TTW) producer no longer in business. Regardless of the extent to which the problems were related to the basic design concept, construction and the manufactured units, this experience has had a long residual effect, particularly in Ontario.

With the exception of one manufacturer [8], clay brick producers have concentrated almost entirely on the manufacture of solid masonry units of various sizes. These are principally used as a cladding as opposed to loadbearing applications and the vast majority are used on single family housing and for construction complying with Part 9 of the NBCC [9]. There has not been a demonstrated willingness, which perhaps indicates that there has been no strong need, to look to new markets that might be developed for hollow brick units.

Changing Situations

Environmental issues, sustainability, and "green" building requirements have been discussed for the past two decades, but it is only very recently that serious attention is being given to making related changes in brick manufacturing. Combined with an increasingly competitive marketplace, environmental issues and the consequences of the Kyoto Protocol[10] are driving forces. Some building clients are also beginning to require designers to employ "green" building design.

Use of hollow clay brick is potentially the solution to many of these concerns. Obviously, if a solid brick having 80% of its volume solid is replaced by a hollow brick with 60% solid, a 25% savings in use of clay material is achieved. This enhances the sustainability of clay brick manufacturing. In addition, as the weight of the unit decreases, larger units can be used. This has the advantage of reducing labour cost per unit area of wall surface through reduced length of mortar joints and fewer units to be properly levelled and aligned. In terms of energy, although not quite proportional to the reduced mass of the clay, significant savings also results; this adds to sustainability and also reduces environmental impact. The reduced weight of brick also has additional benefits with regard to transportation as more bricks can be transported for the same loading restrictions. For brick manufacturers, the reduced thickness of solid clay should lead to reduced drying and firing times, which would lead to greater productivity of existing facilities.

The above advantages should be sufficient, in themselves for expanded use of hollow clay brick, provided that other disadvantages are not introduced which outweigh these. However, there may be other, not so obvious potential advantages that could make hollow brick an even more exciting opportunity for the masonry industry.

Over the past generation, the cost of masonry construction has increased significantly, but it is the relative cost of labour versus material that has changed the most. From nearly equal cost, labour now accounts for about double the cost of the material [11]. Therefore, in the long term, competitiveness of masonry can be most influenced by reducing the labour component. Also, in terms of client valuation of masonry as a superior cladding system, moisture problems from rain penetration leading to costly repairs and litigation have had some negative impact on desire of developers to use this system.

Mortaring of hollow masonry units cannot effectively follow the solid bed practice used for solid units. For hollow clay brick, mortaring parallels that for hollow concrete block but, because of the comparatively narrow face shell and web, considerable skill is required and waste and mortar droppings in the cavity and in the brick cells are virtually unavoidable. Therefore, it is suggested that a different mortaring technique is required. A mortar gun [12] (see Figure 2), adapted for a better control of thickness and width of mortar joints, can be used by a mason helper to leave the mason responsible for levelling and alignment of the units. This also has the advantage of essentially eliminating mortar droppings and producing negligible mortar waste.

Figure 2 – Example Mortar Gun

The use of a small amount of mortar with little waste leads to an opportunity to use a better quality mortar. Under good conditions, bond between clay brick and standard mortar along bed joints is typically satisfactory, but hot or cold weather, wet brick or poor mortar can all lead to weak bond [13]. Mortaring of head joints is problematic as partially filled joints are frequently found in practice. In addition, shrinkage (both plastic and drying) has a tendency to reduce bond. Both phenomena allow moisture to penetrate more easily into and through the wall. Use of a lower permeability mortar with better and faster bonding properties, will help to reduce moisture penetration through this critical zone. Therefore, it is suggested that the cost of a higher quality mortar can be offset by reduced volume of mortar. The avoidance of dropping mortar in the cells of the hollow brick and in the cavity is also important for proper drainage if water does penetrate into or through the wall.

Other Applications

Beyond cladding uses, the next most important application of hollow brick masonry is for structural reinforced masonry. Although possible for 90mm units [7], typically larger size units will be used where larger cells provide room for adequate grout and for spliced reinforcement. There are many examples of use of reinforced brick masonry but, as yet, the impact in Canada has not been large. Figure 3 is a photo of a reinforced hollow brick wall used for the 1980's addition to the Canada Brick's (now Hanson Brick) Burlington Plant.

Figure 3 – Reinforced Hollow Clay Brick

In addition to some lack of availability of hollow brick, lack of designer awareness and expertise may be an additional factor in the restricted use of reinforced hollow brick construction. In fact, many of the applications of advanced design and construction approaches have been due to expertise of a few individuals. This is evident by the use of reinforced hollow clay in the western states due to the publications made available by the Western States Clay Products Association [11, 14].

One such example occurred in the early 1960's, where 90 mm clay brick prefabricated panels were used for the walls of a mechanical room addition on the roof of a building in Denver, Colorado [14]. This design approach was made possible by new "tensile strength intensive" exotic mortar and reinforcement. This design system was used for many years thereafter in the Colorado area by George Hanson P.E. of the firm Sallada & Hanson Engineers. This system was then successfully extended to a wide variety of applications.

IMPLICATIONS OF SIZE AND SHAPE

Hollow clay masonry can be provided using basically the same dimensions as solid units, but there is some advantage to using longer and higher units for more efficient bricklaying. Modular units typically in the range of 90 mm high by 290 mm long provide the classic 3 to 1 aspect ratio and each unit covers about 2.25 times as much wall area as a standard modular brick. However, other sizes and aspect ratios can also be effective.

Structurally, for unreinforced masonry, hollow masonry can have a volume and cross-sectional area reduction of 45% while only experiencing a 15% reduction in section modulus. A superficial look at these numbers indicates that there would be a relatively minor effect on flexural strength of walls built using hollow units. However, data [15] shows that the reduction of flexural strength is much larger. It was postulated that this could be due to faster drying out and reduced curing of mortar in the narrow face shells [16]. This phenomena has also been observed for concrete blocks [17]. Therefore, even for bed joint bond, there is a valid reason for introducing a better bond mortar.

In terms of compressive strength based on actual cross-sectional area, hollow clay brick show reduced compressive strength even where the fired clay is expected or tested to be similar. A reason is that the thinner webs and face shells are more slender elements that do not benefit as much as solid brick from lateral confinement by the loading platens of test machines. For prisms and walls, differences are not as large. Regardless of the differences, durability requirements for brick in Canada have resulted in quite strong fired clay material. Therefore, for most applications, this is not a limiting feature.

From a building envelope point of view, use of relatively impermeable brick and fully tooled solidly filled mortar joints have been key to minimizing water penetration. Typically most water penetrates through the mortar, particularly at the head joint. For hollow bricks, the cells provide a break in the flow path for the water so that these bricks may be more resistant to direct flow of water through the brick wythe. However, flow into the brick and down the cells has the potential to produce major leakage unless cells at the base of the wall are properly flashed and drained. As discussed earlier, use of better mortar to reduce water penetration and avoidance of mortar droppings are seen as ways to handle this potential problem.

In the past, construction of multi-wythe solid brick walls depended on the thickness and mass of this barrier to resist rain penetration and accommodate condensation from vapour diffusion and air leakage. These walls were protected (at least partially) by heat loss through the non-insulated walls, which reduced freezing and promoted drying. In modern construction and also in inappropriate retrofitting of existing solid walls, the use of insulation has removed the protection provided by heat loss so that significant damage is often seen at early ages. With this in mind, it may be advantageous to further reduce the mass of modern exposed walls so that the amount of water absorbed is restricted, drainage is optimized, and drying is facilitated. The thin faces of hollow units will hold only small amounts of water close to drying surfaces. Also, the presence of large, open, properly flashed and drained cells in the hollow brick will limit retention of water in the wall.

CONCLUSION

This paper reports on the background leading to the decision to carry out an experimental program on manufacture and use of hollow clay brick units. The sustainability, environmental and economic considerations are compelling provided that durability, structural requirements and building envelope issues are not problematic. The use of hollow brick may be best served by altering some aspects of traditional brick laying but these changes may, in turn, lead to other economic and physical performance improvements. Hollow clay brick construction has existed in Canada for most of the past half century, but its current overall impact is quite small. Research to improve the basic unit and development of design, and construction methods are required. Such work is required to avoid the problems of the past, adapt successful applications from the

U.S.A., and create approaches suitable for the Canadian climate and Canadian construction practices.

ACKNOWLEDGEMENTS

This research was carried out as a part of the mandate of the McMaster University Centre for Effective Design of Structures funded through a grant from the Ontario Research and Development Challenge Fund. The participation of Brampton Brick is gratefully acknowledged.

REFERENCES

1. McKee, H., Introduction to Early American Masonry, Stone Brick, Mortar and Paster. National Trust for Historic Preservation and Columbia University. Washington D.C. 1973.
2. London, M., Bumbaru, D., Traditional Masonry. Heritage Montreal. Montreal, Quebec, Canada. 1986.
3. Plumber, H.C., Brick and Tile Engineering. Brick Institute of America. McLean, Virginia, United States. 1962.
4. American Standards for Testing and Materials, Standard Specifications for Hollow Brick (Hollow Masonry Units Made From Clay or Shale). ASTM C 652-70. Philidelphia, PA, U.S.A. 1970
5. American Standards for Testing and Materials, Standard Specifications for Hollow Brick (Hollow Masonry Units Made From Clay or Shale). ASTM C 652-95a. West Conshohocken, PA, U.S.A. 1997
6. Gregg Borchelt, BIA, Personal Communication.
7. Drysdale, R.G., Jones, L.R., Loadbearing Masonry for Moderate Income Single Family Homes. Fifth International Brick Masonry Conference. Washington, D.C., U.S.A. 1979
8. http://www.ixlbrick.com/architectural/giantbrick/metric.html
9. National Building Code of Canada. National Research Council Canada.1995.
10. Kyoto Protocol To The United Nations Framework Convention On Climate Change. (2005). Retrieved January 11th, 2005, from http://unfccc.int/resource/docs/convkp/kpeng.html
11. Notes On The Selection, Design and Construction of Reinforced Hollow Clay Masonry. (1995). Retrieved November 25th 2004, from http://www.masonryinstitute.com/hollow/
12. www.contractorstools.com/quikpoint.html
13. Drysdale, R.G., Hamid, A., Baker, L., Masonry Structures Second Edition. The Masonry Society. Boulder, Colorado, U.S.A. 1999.
14. Design Guide for Structural Brick Veneer (First Edition). (1998). Retrieved November 25th, 2005, from http://www.masonryinstitute.com/struct_veneer/
15. Allen, M., Watstein, D., Compressive and Shear Strength Tests of Six and Eight-Inch Single Wythe Walls Built With Solid And Heavy-Duty Hollow Clay Masonry Units. Structural Clay Products Institute. McLean, Virginia. 1969.
16. Technical Notes 41 – Hollow Brick Masonry. (1996). Retrieved November 13th, 2004, from http://www.bia.org/BIA/technotes/t41.htm
17. Hamid, A.A., Drysdale, R.G., Flexural Tensile Strength of Block Masonry. Journal of the structural Division, Proceedings of ASCE, Vol. 114, No. 1, January 1988, pp. 50-66.