Seventh Canadian Masonry Symposium
McMaster University
Hamilton, Ontario
June 4-7, 1995

ADAPTATION OF A MASONRY UNIT MANUFACTURED FROM WASTE PRODUCTS TO MODERN PRODUCTION TECHNIQUES

Arie Huizer[1] and Robert L. Day[2]

ABSTRACT

Pulverised coal fly-ash and non-returnable glass products have been combined to produce a masonry unit with properties that satisfied the SW (severe weather) rating as outlined in CAN/CSA-A82.1-M87. In addition to the utilisation of two environmentally unfriendly products, energy savings because of low firing temperatures for a short duration contribute towards the attractiveness of the development. Production of the unit required the dry-press method. Although this method is used extensively in many parts of the world, its application in North America, the United Kingdom and Australia for example is rather limited. In those parts the stiff-mud process is preferred which enables extrusion through a die. This paper includes results obtained to manufacture a fly-ash/glass brick suitable for production with standard stiff-mud equipment by adding a minimal quantity of suitable clay while replacing classified ash with a lower grade bottom ash.

INTRODUCTION

Fly-ash is produced in the coal firing of electricity producing power stations. In this process, the coal is first finely ground in roller mills and then, with a stream of high velocity air, blown into boilers. The temperatures reached in these boilers could be in excess of 1600°C. Some of the ash melts and sinters and is deposited on the refractory walls and crown of the boiler. It is a porous coarse granular product and is known as "bottom ash". The high-volume, high-velocity air stream carries fine particulate ash material through the system on its way to the exhaust stacks. This material is appropriately called "fly-ash" and has a wide range of particle sizes. Larger particles may be removed by mechanical arrestors, while the finer fraction is trapped by electrostatic

[1] Senior Instructor Emeritus of Civil Engineering, The University of Calgary, Calgary, AB, T2N 1N4
[2] Associate Dean of Engineering and Professor of Civil Engineering, The University of Calgary.

precipitators (Anderson and Jackson 1987). The finest fraction is similar to the fineness of Portland cement.

The idea of using fly-ash for brick production is not new (Reidelbach 1970, Slonaker 1976, Slonaker 1978 and Anderson & Jackson 1987). The initial efforts to produce bricks from 100% fly-ash resulted in units that showed some undesirable properties (Day et al 1984, Slota et al 1985, Day et al 1986, Day and Bergman 1988):

rate of absorption too high

high incidence of chippage

high degree of shrinkage on firing

low green strength.

In addition to variations in the manufacturing process, such as drying and firing temperatures, the masonry industry addresses these problems through the introduction of inert stabilising materials, commonly called grog. Crushed brick from the plant's own production is an often used grog. Added to a clay, it modifies plasticity, has a marked effect on moulding and drying characteristics, and lowers firing temperatures. The clay mixture has to be suitable for one of the three principal mechanical manufacturing processes for forming brick. These are:

The stiff-mud process.
In this process the clay is mixed with only sufficient water to produce plasticity, from 12 to 20% by weight. After thorough pugging, the clay is extruded through a die, producing a clay column. This clay column may be solid or cored and is cut to the desired length.

The soft-mud process
This method is particularly suited for clays which contain too much water in their natural state to be used in the stiff-mud process. This is the oldest production method known and was used by the ancient Egyptians. Initially production took place in wooden moulds. More recently, machines have been developed which drop balls of clay into moulds which have been sanded to enable easy release of the green brick. The moulds are then turned over and the bricks are transported to a stacking unit.

The dry-press method
This process is particularly adaptable for clays of very low plasticity. The clay is mixed with 7 to 10% water after which it is placed in a steel mould and subjected to pressures in the range 3-15 MPa. For the screeding of the clay and the release of the green bricks, several methods have been developed which all produce the same result. The green brick is either pressed through the mould or the moulds are hinged is shown in Figure 1.

Since fly-ash has a low level of plasticity when mixed with water, only the dry-press method could be used for the fly-ash/glass unit..

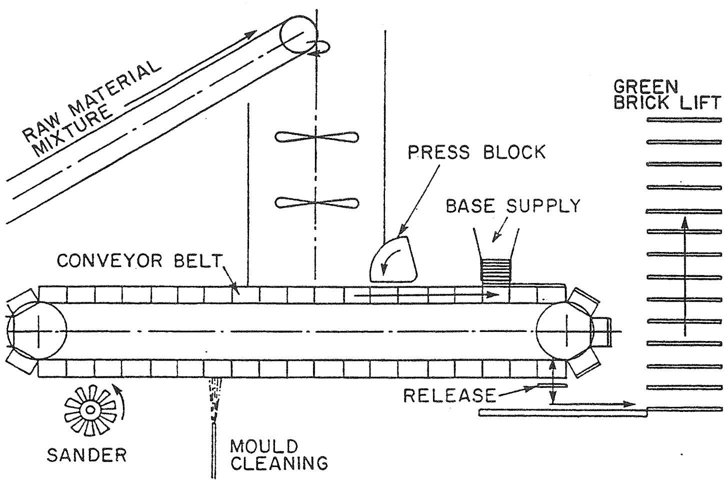

Figure 1
Automated Dry-Press Method

The results of the research on a suitable grog for the production of a fly-ash brick as well as the chemical and physical properties of fly-ash, have been reported elsewhere (Day and Huizer 1994). The manufacturing details that produced a brick which satisfied the Severe Weathering (SW) requirements of CAN/CSA-A82.2-M87 were:

Fly-ash/ Glass ratio 60:40

Moulding Pressure 15 MPa

Drying for 3 days at 20°C

Firing for 3 hours at 900°C

WORLD-WIDE PREFERRED MANUFACTURING METHODS

In order to maximize the utilisation of fly-ash, it would be preferable to manufacture the fly-ash glass unit with production methods favoured throughout the world. As reported, the fly-ash glass unit could only be manufactured using the dry-press method. However, in many parts of the world, different methods of manufacturing are preferred.

North America

In Canada a relatively small number of bricks are produced through the dry-press method. One plant in Western Canada and one in the East manufacture dry-pressed bricks.

In the USA in 1993 the methods of production were (% of production) (Borchelt 1995):

Extruded (Stiff-Mud Process)	85.4%
Moulded (Soft-Mud Process)	13.4%
Dry-Press	1.2%

Australia

The percentages in Australia differ somewhat depending on the State (Page 1995). The overall percentages are:

Extruded (Stiff-Mud Process)	95%
Dry-Press	5%

There was no report of any soft-mud production.

However, in the Sate of Victoria where the frog-type brick is still popular, 40% of dry-press units are reported. In New South Wales, this figure is down to 10%.

The Netherlands

The 1993 figures reported in The Netherlands (Vekemans 1995), show the different methods of production preferred because of clay availability. Most of the Dutch clays are dredged from the rivers and are consequently high in moisture content and more suitable for soft-mud production. The reported percentages are:

Soft-Mud Process	50%
Dry-Press	38%
Extruded (Dry-Mud Process)	12%

The soft-mud production in 1993 was 1,264 million bricks.

The United Kingdom
The relative proportions reported from the United Kingdom are for 1991 (West 1995):

Extruded (Dry-Mud Process)	62%
Dry-Press	25%
Soft-Mud Process	11%
Stiff Plastic	2%

Total production is approximately 3400 million.

Belgium and Germany
Both in Belgium and Germany bricks as well as clay tile are being manufactured (Peirs 1995). The Belgian production of soft-mud was 600,000 m^3, but in both countries, the stiff-mud process is the preferred method.

Southern Europe
In southern Europe, production is largely concentrated on "clay tile" which is large, perforated and hollow and made for a stucco finish. Production methods are essentially through extrusion.

From the above information it is obvious that if the largest amount of fly-ash possible is to be used, the fly-ash mixture should also be suitable for stiff-mud (extrusion) production as well as for the dry-press method. Because of its availability near manufacturing plants, clay was the most likely candidate warranting investigation.

THE DRY-PRESS BRICK

The dry-press brick manufactured from a 60:40 ratio of classified fly-ash/glass was pressed at 15 MPa with a water content of 10%, dried for three days at 20°C and fired for three hours at 900°C. Using these criteria, 10 series of 5 bricks each were made to compare their results with the requirements of CAN/CSA-A82.1-M87, Table 1.

CAN/CSA-A82.1-M87 states that if the Initial Rate of Absorption exceeds 30g/min.194 cm^2, then acceptable corrective measures such as wetting to reduce the suction rate shall be taken. The fly-ash/glass brick might exceed this limit. However, wetting the brick prior to laying has been an acceptable procedure in many parts of the world since the inception of masonry. This method is perfectly satisfactory as long as the brick is thoroughly wetted but not soaked just prior to use. Pressed bricks throughout the world have a relatively high rate of absorption and values such as those quoted in Table 1 are common. Choosing a mortar mix that is compatible to the Initial Rate of Absorption of the brick is a requirement of good workmanship and is covered in CSA Standard CAN3-A371-M.

To study the effect of temperatures on bond, tests were performed using a bond-wrench apparatus that produces results which are comparable to ASTM 1072-86 (Shrive and

Tilleman 1992). Results are shown in Table 2 and appear to indicate minimal effect of higher temperatures when type N mortar is used. Fly-ash/glass 3-brick units were tested at 7 days after having been laid at two different temperatures.

Series	24 Hour Absorption %	5 Hour Boil Absorption %*	Saturation Coefficient**	Initial Rate of Absorption
1	12.9	16.7	0.8	34.6
2	12.7	16.9	0.8	34.1
3	11.6	15.2	0.8	33.7
4	12.1	16.3	0.7	32.9
5	13.2	17.1	0.8	38.4
6	10.6	14.5	0.7	32.7
7	11.9	15.5	0.8	33.4
8	6.9	9.7	0.7	30.8
9	8.3	11.4	0.7	32.3
10	12.4	16.6	0.8	35.2
CSA		17 (max.)	0.78 (max.)	300 (max.)

*-highest individual result was 19.4%
**-highest coefficient was 0.786

Table 1
Final Absorption Test Result

Bond Tests (MPa)						
Series	Laid at 20°C		Laid at 40°C		ASTM	Shrive
	Joint 1	Joint 2	Joint 1	Joint 2		
1	0.7	0.7	0.54	0.53	0.59	0.52
2	0.44	0.55	0.62	0.48		
3	0.76	0.78				

Table 2
Bond Test Comparison

There are two basic methods to decrease further the absorption rates of the unit. Increasing the firing temperatures to 1000°C reduces the absorption properties of the fly-ash/glass brick. It has been shown that the total porosity of clay bricks decreased from around 30% on firing at 900°C to around 20% for firing at 1100°C (Somsiri et al 1985). As shown in Table 3, this finding has been confirmed for the fly-ash brick. However, when the temperature was raised to 1000°C the glass grog started to become very fluid and actually bubbled to the outside face of the brick; a very different brick appearance resulted.

Series	Fired at 950°C				Fired at 1000°C			
	24 hr abs.	5 hr boil	Abs. Coeff.	IRA	24 hr abs.	5 hr boil	Abs. Coeff.	IRA
1	9.1	12.6	0.72	32.1	4.0	6.7	0.6	10.9
2					3.9	6.4	0.61	13.4
3					5.6	7.7	0.73	11.5

Table 3
Effect of Firing Temperature on Absorption

The other method to reduce the water absorption of brick is through the application of a siliconate coating. Such a coating is sometimes applied to brick faces in order to reduce efflorescence and initial rate of absorption. To investigate, various solutions of silicone were sprayed onto the brick face after the bricks had been tested for 24 hour absorption, 5 hour boiling and IRA. The brick face was covered 100% and the bed faces approximately 25%. Table 4 shows the effect of siliconate treatment on the IRA of the bricks. Although these values appear to be very encouraging, there have been some major concerns raised about siliconate and silicone treatment. Grimm and Houston (1974) warned that through silicone treatment false grading of brick for weather resistance may result, permitting use of brick which may not adequately resist weathering.

Siliconate/ Water Solution	Siliconated IRA	Pre-Siliconated IRA
1/300	4.0	34.8
1/400	14.0	34.5
1/500	19.2	34.2

Table 4
Effect of Siliconate Treatment on IRA

Compressive strength of the unit was high. The mean strength obtained was 36.0 MPa; the coefficient of variation was 11%. The requirements of the CSA Standard is 20.7 MPa. In addition, the weight of the fly-ash/glass brick is 1.5 kg as compared to 2 kg of an equivalent clay brick This would reduce the weight of 10 m^2 of single wythe masonry by more than 370 kg.

THE STIFF-MUD BRICK

The present mix is only suitable for the dry-press manufacturing method. The stiff-mud process requires a more plastic mixture than the one available from the use of fly-ash and glass. Classified ash was used for the production of the ash/glass brick. This affects the cost of the unit. Bottom ash, the sintered waste that falls to the bottom of the boiler is a product for which there is virtually no use. It is a considerable environmental problem. In order to satisfy some of these concerns, a research project is in progress addressing the plasticity problems and the use of bottom-ash to make bricks.

Initially attempts were made to improve plasticity through the addition of sodium-based and alkaline accelerators. Although there was some improvement, it was not sufficient to produce a mixture suitable for the extrusion process.

Addition of a suitable clay proved to be a solution that improved the plasticity to the extent that would allow production of extruded bricks. The ratio that proved successful was 50% clay, 30% fly-ash and 20% glass.

Bottom ash is more porous than fly-ash; its use results in bricks that have an even higher absorption ratio. Also, it was expected that the compressive strength of the unit made with bottom-ash would be lower. The ratios investigated and the results of the physical properties of the bricks are given in Table 5. The values for Moderate Weathering and Severe weathering stated in CAN/CSA-A82.1-M87 are included in brackets.

Series clay: bottom-ash: glass	5 Hour Boil (%) (MW 22%) (SW 17%)	Saturation Coefficient (MW 0.88) (SW 0.78)	IRA (30)	Compressive Strength (MPa) (MW 17.2) (SW 20.7)
50:50	25.8 25.4	0.69 0.64	103 149	12.9
50:40:10	24.9 23.5	0.74 0.66	89.5 88.7	15.1
50:30:20	23.4 21.6	0.76 0.72	66.9 55.7	17.0
60:20:20	18.6 19.0	0.73 0.75	48.9 49.2	21.1

Table 5
Clay:Bottom-ash:Glass Results

The results show that by reducing the amount of bottom-ash in the mixture, the physical properties of the bricks appear to improve. The negative aspect of the decrease in the amount of ash is the fact that while the use of an environmentally unfriendly product is reduced, the use of a non-renewable resource, such as clay, is increased.

The main concern should be with the IRA. The water retentivity of the mortar will affect the bonding between bricks. However, if siliconate treatment is applied it would appear that even with the higher proportion of the worst pollutant, bottom-ash, an acceptable product can be produced.

COST CONSIDERATIONS

The cost of manufacturing bricks is dependent of many factors. The type of brick, the type of kiln, dryer and their fuel costs, location, availability of clay, etc. The cost of fly-ash varies depending on the location of the user. Price fluctuations also influence cost. The cost of waste glass just recently moved up from about \$15 per tonne to \$50 per tonne. However, material cost for both the clay brick as well as the fly-ash unit will still be about equal (Day and Huizer 1994).

The actual cost of manufacturing of fly-ash bricks will be less because of firing at 900°C for three hours against firing at 1100°C for about 18 hours. The cost of firing of a fly-ash brick will be about 1/8 of the cost of firing a clay brick or about \$0.005 compared to \$0.04. Other considerations are reduced weight of the unit which should be beneficial to handling as well as the weight of a masonry structure.

It is very difficult to put a price on the environmental advantages of the use of unfriendly materials and reducing the use of non-renewable ones. However, even if the total cost of the fly-ash brick production would be equal to that of a clay brick, environmental aspects should still warrant serious consideration into the possibility of its commercial application.

CONCLUSIONS

Classified fly-ash can be used in conjunction with waste glass as a grog in the ratio of 60:40 to produce a brick with the dry-press method which satisfies the requirements of both the Canadian as well as the USA standards for Severe Weathering. Adding clay to this mixture in a ratio of 50% clay, 30% classified ash and 20% glass, will produce a plasticity which is suitable for the stiff-mud process.

Replacing the more expensive classified ash with the lower grade bottom-ash, produces a mixture suitable for the extrusion method. If the IRA problems are addressed through the application of siliconate it will result in a unit which satisfies the Moderate Weathering requirements of the standards.

Research is in progress to attempt to also satisfy the requirements for Severe Weathering for bricks made with bottom-ash.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding received from Alberta Municipal Affairs and the Natural Science and Engineering Council of Canada.

REFERENCES

Anderson, M. and Jackson, G. (1987), Ziegelindustrie International, October Edition.

Borchelt, J. G. (Gregg), (1995), Personal Communication, USA.

Day, R. L., Joshi, R. C., Slota, R. J., and Langan, B. W., (1986), Materials Research Society Symposia Proceedings, pp. 47-58, Vol. 65.

Day, R. L. and Bergman, J. W., (1988), Proceedings of the 8th International Brick/Block Masonry Conference, Dublin, Ireland, pp. 14-25.

Day, R. L. and Huizer, A., (1994), Proceedings of the 10th International Brick/Block Masonry Conference, Calgary, AB, Canada, pp. 1131-1141.

Grimm, C. T. and Houston, J. T., (1974), Masonry: Past and Present, STP 589, American Society for Testing and Materials.

Page, A. W. (Adrian), (1995), Personal Communication, Australia.

Peirs, G. (Vanni), (1995), Personal Communication, Belgium.

Reidelbach, J. A. Jr., (1970), Proceedings of the 2nd Ash Utilization Symposium, Information Circular 8488, Bureau of Mines, U.S. Dept. of the Interior.

Shrive, N. G. and Tilleman, D., (1992), Proceedings of the 6th Canadian Masonry Conference, Saskatoon, SK, Canada, pp. 283-293.

Slonaker, J. F., (1976), 4th International Ash Utilization Symposium, Morgantown, USA.

Slonaker, J. F., (1978), Conference on Ash Technology and Marketing, London, UK.

Slota, R. J., Day, R. L., Joshi, R. C. and Langan, B. W., (1985), Research Report No. CE 85-15, The University of Calgary, Calgary, AB, Canada.

Somsiri, S., Zsembery, S. and Ferguson, J. A., (1985), Proceedings of the 7th International Brick Masonry Conference, Melbourne, Australia.

Vekemans, H. J. (Harrie), (1995), Personal Communication, The Netherlands.

West, H. W. H. (Timber), (1995), Personal Communication, United Kingdom.