High Performance Bricks from Fly Ash

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ABSTRACT

Bricks whose solid ingredient is 100% fly ash have been manufactured. The manufacturing process uses techniques and equipment similar to those used in clay brick factories. The bricks produced were about 28% lighter than clay bricks. The bricks manufactured from fly ash possessed compressive strength higher than 40 MPa. This exceeds some of the best of load carrying clay bricks available by more than 25% and is several times better than acceptable commercially available common clay bricks. Other important characteristics of the fly ash bricks have been evaluated. These included absorption capacity, initial rate of absorption, modulus of rupture, bond strength and durability. The values of these characteristics for fly ash bricks are excellent and have exceeded those pertaining to clay bricks. Moreover, fly ash bricks have been produced with a naturally occurring reddish colour similar to that of normal clay bricks. The new bricks and process have been patented and the new bricks have been given the name FlashBricks. This paper presents the results of testing and the advantages gained by this type of bricks over conventional clay bricks.

INTRODUCTION

The ever increasing volume of fly ash quantities in the world has not been remotely matched by its utilisation. Australia is an example where such utilisation has been minimal. The most important and popular use of fly ash in Australia has been the partial replacement of portland cement. Australia shares most of the Western countries in similar methods and traditions as far as residential buildings are concerned. These include bricks as the main constituent. It is therefore natural that the brick industry presents an opportunity for the efficient utilisation of the vast quantities of fly ash. Conservative attitudes are among the factors that limited the use of fly ash in concrete to generally a maximum of 25% replacement of Portland cement. This conservatism can be understood in the context of concrete where the ash is mixed raw, and the effects
of high volume replacement are still subject to research and sometimes controversy. It is however not quite justifiable that the brick industry should take similar conservative attitude. Environmental concerns have been raised in some parts of the world where coal is the main power generating resource and where bricks are also the main building material. Such concerns have resulted in legislation that obliges the brick industry to incorporate at least 25% by weight of fly ash and/or bottom or pond ash in the brick making mixture if the industry is within 50 km from a coal power generation plant. Some successful ventures have been reported where fly ash was incorporated in the mixture at the rate of 20 to 50%. Nevertheless, there is only little evidence that incorporation of fly ash in the brick mixture has exceeded the 30% by volume even when the legislation was obeyed. Reasons behind such reluctance are not clear. A most probable reason is the fear of change in many small factories and the ingrained conservatism in the attitude of stake holders of the large producers. Added to this is the fact that with an existing clay brick factory, the incorporation of fly ash is a potential addition of cost. The possible incompatibility of the ash with the clay and shale during the various processes of production including the crucial one of firing may be a legitimate difficulty. At high temperatures beyond 1000°C, the temperature and length of time of firing become very sensitive to the type of ash and of course to the clay and shale if in the same mixture. This would be the case as long as the factory still uses the ash as partial replacement to the main clay and shale ingredients. The situation may become completely different when the ash is the only ingredient of the bricks mixture. Compatibility is no more an issue in such a case. So far, few attempts at manufacturing bricks from more than 80% ash have been made. The author believes that fly ash on its own can be an excellent raw material for brick making. This has now been proven and a patent is taken for the manufacture of bricks from fly ash. The response of the ash to firing temperature at 1000°C and beyond can be accurately controlled even in small factories. The potential savings with this approach are many. These are illustrated in the following sections. Savings in production and transportation costs and producing bricks of superior qualities to those of standard clay bricks are in addition to the environmental solution that such venture may bring about.

BRICK PRODUCTION

The bricks, produced according to the patent, have been given the name FlashBricks. Essentially, the only solid ingredient of the bricks is the ash. The main liquid ingredient is water. Other ingredients that so far are commercially protected are cheap, commonly available and, though essential, are only minor in quantities. The technology, subject of the patent, includes the method of mixing, forming into moulds, curing and firing. These are easily adaptable by existing clay brick factories. The technology uses less energy than that needed in the manufacture of clay bricks. Furthermore, it requires less manpower and less area is needed for material processing than in the case of clay brick production.
Table 1. Items of difference in the production process and expected to make cost difference:

<table>
<thead>
<tr>
<th></th>
<th>Common Load Bearing Clay Bricks</th>
<th>Load Bearing FlashBricks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factory location</td>
<td>On site of raw materials</td>
<td>Any where, preferably on site of coal power station</td>
</tr>
<tr>
<td>Factory location</td>
<td>Must change when material depletes required</td>
<td>No change needed</td>
</tr>
<tr>
<td>Excavation needed</td>
<td>Required</td>
<td>None</td>
</tr>
<tr>
<td>Raw materials qualities</td>
<td>Varies daily</td>
<td>Consistent</td>
</tr>
<tr>
<td>Raw material needed per 1000 bricks</td>
<td>4-5 tonnes of clay and shale</td>
<td>2.75 tonnes of fly ash</td>
</tr>
<tr>
<td>Raw materials wastage per 1000 bricks</td>
<td>1.7-2 tonnes of clay and shale</td>
<td>None</td>
</tr>
<tr>
<td>Grinding of rocks</td>
<td>Required</td>
<td>None to grind</td>
</tr>
<tr>
<td>Mixing dry materials</td>
<td>Required</td>
<td>None</td>
</tr>
<tr>
<td>Additive (subject to provisional confidentiality)</td>
<td>None</td>
<td>Required @ 0.2L/100 kg</td>
</tr>
<tr>
<td>Drying green units</td>
<td>7 days</td>
<td>3 days</td>
</tr>
<tr>
<td>Temperature of firing the units</td>
<td>1000°C- 1300°C (1832 F-2372 F)</td>
<td>1000°C- 1300°C (1832 F-2372 F)</td>
</tr>
<tr>
<td>Length of firing time</td>
<td>1 day-7 days</td>
<td>Few hours (subject to provisional confidentiality)</td>
</tr>
</tbody>
</table>

Table 1 summarises the differences in the manufacturing process between the clay bricks and the FlashBricks. A very important saving that can be readily seen is that of personnel. Since neither excavation nor grinding is needed, the personnel that are usually employed for such operations will not be required. Added to this is the need for continual assessment of the raw materials in the case of clay bricks. Such assessment is not needed in the case of FlashBricks because the ash is analysed continually at the power generation station as a mandatory practice. Thus the personnel involved in the assessment of clay materials will not be required with FlashBricks production. Further market study of the items outlined above is required so that figures may be assigned to total savings with FlashBricks.
So far the production of FlashBricks has been performed in the laboratory. This has been repeated successfully many times and the testing has produced consistent results. Figure 1 shows the moulded bricks in their fresh state.

![Freshly moulded FlashBricks](image)

Figure 1. Freshly moulded FlashBricks

Figure 2 shows a brick that had been cured for two days before firing. The bricks solidify enough to be fired after 24 hours but are best fired after three days of curing. The brick shown in the photograph of Figure 2 is split open to reveal the interior structure. The curing is controlled so that consistency of the material is maintained with no occurrence of cracking. Figure 3 shows a photograph of the bricks after firing. The bricks’ colour after firing is reddish and very similar to that of some varieties of clay bricks. Of course other colouring may be obtained by addition of selected oxides. This, however, was not done with the bricks that are presented here.

TESTING FLASHBRICKS

A series of tests were performed on FlashBricks in order to compare their qualities as load bearing bricks with those made from clay. The Australia and New Zealand Standards AS /NZS 4456:1997 were applied in all the tests reported here. Commercially available bricks that are known to be among the
best in the Australian market were tested and compared to the results from FlashBricks. The results are shown in Table 2.

Figure 2. The interior of a FlashBrick after 2 days of curing

Figure 3. FlashBricks after firing
Table 2. Properties of FlashBricks Compared to Clay Bricks

<table>
<thead>
<tr>
<th>Brick Type</th>
<th>Compressive Strength</th>
<th>Modulus of Rupture</th>
<th>Initial Rate of Absorption (IRA)</th>
<th>Absorption Capacity</th>
<th>Average Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay Bricks</td>
<td>Typical is from 12 to 40 MPa (1740 psi – 5800 psi)</td>
<td>From less than 1 MPa (145 psi) to greater than 2 MPa (290 psi). Default value is 0.8 MPa (116 psi)</td>
<td>Typical range between 0.2 and 5 kg/m²/min.</td>
<td>5-20%</td>
<td>1800-2000 kg/m³ (112-125 lb/ft³)</td>
</tr>
<tr>
<td></td>
<td>Minimum accepted by Australian Standard: 7 MPa (1015 psi)</td>
<td>(5.9-147.5 lb/in²/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FlashBricks</td>
<td>43 MPa (6235 psi)</td>
<td>10.3 MPa (1494 psi)</td>
<td>4.5 kg/m²/min (133 lb/in²/min)</td>
<td>10%</td>
<td>1450 kg/m³ (91 lb/ft³)</td>
</tr>
<tr>
<td>Samples of the best clay bricks in Australian market</td>
<td>34.8 MPa (5046 psi)</td>
<td>3.6 MPa (522 psi)</td>
<td>5.9 kg/m²/min (174 lb/in²/min)</td>
<td>6%</td>
<td>2000 kg/m³ (125 lb/ft³)</td>
</tr>
</tbody>
</table>

The tensile strength expressed in the form of the Modulus of Rupture value is nearly three times the value for normal clay bricks. This is an achievement of considerable importance because it results in much less cracking in the bricks. Such cracking, whether caused by differential settlement, excessive tensile-nature loading, salt crystal growth or freezing and thawing, has been a major concern in the building industry.

The compressive strength is at least 24% better than the very best of the standard clay bricks that are available on the Australian market. This is also of great significance because the new bricks may become the main load bearing elements that would be able to carry several floors more than allowed for the normal clay bricks.

The density of FlashBricks is 28% less than that of the normal clay bricks. This of course has great significance on loading floors, ease of construction, transportation capacity and cost and number of bricks that can be produced per tonne of raw material. Approximately 265 bricks per tonne can be produced from clay bricks, while 365 bricks per tonne can be produced from FlashBricks.
THE INITIAL RATE OF ABSORPTION AND THE ABSORPTION CAPACITY

Two important properties of building bricks are the initial rate of absorption (IRA) and the absorption capacity. The IRA is of great importance for the laying of the bricks and bonding with the mortar. A high IRA results in too quick drying of the mortar and thus weakens the mortar and reduces its adherence to the brick. On the other hand, if the IRA is too low, the surface of the brick adjacent to the mortar would not absorb the excess water and would result in very weak layer of the mortar that would not have penetrated enough into the surface crevices and pores of the brick.

The property of total absorption capacity is also very important for the performance of the brick. A high absorption results in vulnerability to volume changes that would result in cracking of the bricks and structural damage in buildings. It also would lead to cracking in the event of freezing and thawing of the water inside the pores. Too little absorption however is also not desired. This is because rain water, rather than getting partially absorbed by the brick, would tend to run off very quickly towards the joints and may find its way into the building as well as reduce the durability of the mortar joints.

The results obtained for the IRA and the total absorption capacity for FlashBricks indicate excellent performance potential in laying and durability. The ease and efficiency of laying bricks is very much related to the IRA property which also affects the important property of bond to mortar. Due to the importance of bond characteristics, a series of bond tests was conducted on FlashBricks and normal clay bricks.

TESTING THE STRENGTH OF BOND TO MORTAR

The test was done according to ASTM C 1072-00a; bond wrench test. Because the laboratory-made FlashBricks were not extruded, they were compared with solid clay bricks that were produced using press methods. The mortar was a typical mortar mix of 1:1:6, being cement: lime: sand respectively. The water was added such that the flow on the mortar flow table test is between 105-110% in accordance with AS 2701-2001. The wrench bond test is conducted by applying an increasing load via a wrench. The wrench is clamped to a brick which in turn is bonded to other bricks by the mortar, subject of the test. The lower bricks are secured by a frame. The load at which the upper brick gets debonded is determined, and the bond strength is calculated. The apparatus used for this test is illustrated in Figure 4. The loading procedure is shown in Figure 5 (a) and (b).

The formula for the calculation of the bond strength is:

\[ F_s = \frac{6(PL + P_l L_l)}{bd^2} - \frac{P + P_l}{bd} \]
where \( P \) is the maximum applied load (Figure 5), \( P_l \) is the weight of the loading arm, \( L \) is the distance from the centre of the prism to the loading point (Figure 6), \( L_t \) is the distance from the centre of the prism to the centroid of loading arm, \( b \) is the cross sectional width of the mortar bedded area and \( d \) is the cross sectional depth of the mortar bedded area.

![Diagram of ASTM 1072-00 Bond wrench machine](image)

**Figure 4.** ASTM 1072-00 Bond wrench machine (ASTM 1072, 2000)

Each result is the mean of six tests, each of which comprised three-course high bricks. Accordingly, the flexural bond strength of FlashBricks is 0.41 MPa (59.5 psi), compared to the value of 0.18 MPa (26.1 psi) for solid clay bricks that was tested with the same mortar. The minimum required by AS 3700 is 0.20 MPa (29 psi). There is now indirect evidence that the surface texture of FlashBricks is responsible for the enhanced mechanical bonding between the brick and the mortar. This is concluded from the nature of the microstructure of the aggregates made from fly ash by a method that is quite similar to the method used in FlashBricks. The aggregates referred to here are also patented by the author and co-inventor. The manufacturing method produces 'crator' like
impressions that enhance the interlocking between the aggregate and the concrete matrix. A micrograph for a slice of a FlashBrick is shown in Figure 6. Here the surface ‘crator’ like pores are quite evident. It is believed that this texture is mostly responsible for the improved mechanical adhesion with the mortar.

Figure 5. Schematic of the loading procedure of the flexural bond test (a) While loading, and (b) At failure

Figure 6. Details of upper clamping bracket (ASTM C 1072, 2000)
Figure 7. A close-up showing the texture in a slice from FlashBrick.

Figure 8 shows a magnified view of the surface of FlashBrick. The bubble impressions that still exist on the surface are much less than those, that appear in a slice of the interior. Nevertheless these surface indentations are believed to be responsible for the interlocking between the brick surface and the mortar.

Figure 8. A close-up showing the texture on the surface of FlashBrick.
DURABILITY

Resistance to salt attack was evaluated according to Australia and New Zealand Standard AS/ANZ 4456.10. A zero loss in mass after 15 cycles of exposure to soaking and drying in sodium sulphates solution, was recorded. This result was better than that of clay bricks which had a slight mass loss after 15 cycles of salt exposure. This test, although employs sodium sulphates, and thus is a direct indication of the ability to resist sulphate attack, is also indirectly indicative of the ability of the material to resist cycles of freezing and thawing.

CONCLUSIONS

1. The results are indicative of the satisfactory performance of FlashBricks as load bearing elements. This type of bricks uses 100% fly ash without mixing with clay and shale. It, therefore provides a large venue for the disposal of fly ash in a very efficient, useful and profitable way.

2. The mechanical properties of FlashBricks have exceeded those of the standard load bearing clay bricks. Notable among these properties are the compressive strength and the tensile strength. Compressive strength was 24% better than good quality clay bricks. Tensile strength was nearly three times the value for standard clay bricks.

3. Comparison between the bond strength of FlashBricks to mortar and that of comparable shaped and commonly used solid clay bricks showed that the FlashBricks have a bond that is 44% higher than the standard clay brick.

4. There is evidence that the microstructural feature of the surface of FlashBrick is characterised by a rougher texture than that of clay bricks. This characteristic is believed to be responsible for the increased bond strength with mortar.

5. The resistance of the bricks to repeated cycles of salt exposure showed zero loss of mass and indicated excellent resistance to sulphate attack.

6. The density of FlashBricks is 28% less than that of standard clay bricks. This reduction in the weight of bricks results in a great deal of savings amongst which are savings in the raw materials and transportation costs and savings to the consumer, that result from increased number of units and reduction in the loads on structural elements.

7. The process of manufacture of FlashBricks indicate clearly that there is much savings to be done during the making of the bricks. These savings
arise mainly from the uniformity of the raw material and the reduction in firing time as well as from doing away with whole processes of mining, transporting, mixing and grinding, that are necessary in the case of the clay and shale based bricks.

REFERENCES


