INSULATING FIREBRICK – MAXIMISING ENERGY SAVINGS THROUGH PRODUCT SELECTION

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ABSTRACT

Insulating Firebricks (IFBs) are well established products for solving many problems of high temperature heat containment in industries ranging from ceramic production kilns to anodes for primary aluminium. The volatile energy prices of recent years have increased the importance of maximising energy savings in these industries. In order to optimise energy savings the kiln designer needs to know which IFB products provide the minimum energy losses.

The purpose of this work is to quantify the differences in performance that can be achieved by studying a wide range of IFBs currently available on the market. This is achieved through laboratory based measurements of energy losses from standard kiln arrangements constructed with a variety of test bricks. Since different suppliers manufacture IFBs by different techniques (casting, slinger, extrusion, foaming, pressing), the brick microstructures produced can be very different, leading to a wide variety of thermal conductivities in the market within the same class of product. This in turn leads to a wide variation in the ability of the different types of IFBs to control energy loss from the kiln.

This work demonstrates that IFBs can display up to 37% difference in the energy savings achievable depending on their method of manufacture. The work also presents further consequences of the manufacturing method on performance in terms of heating & cooling rates and reduction in CO2 emissions.

BACKGROUND

IFB MANUFACTURING METHODS

Table 1 lists the physical properties of four commercially available Class 23 IFBs, representing the main manufacturing processes used by manufacturers. The ‘Cast’ process uses gypsum plaster as a rapid setting medium for a high water content clay mix, containing some additional burnout additives. The ‘Slinger’ process is a form of low pressure extrusion of a wet clay mix containing high levels of burnout additives, with the additional processing step that the semi-extruded material gets ‘slung’ onto a continuous belt to generate additional porosity, before drying & firing. The ‘Extrusion’ process forces a damp clay mixture containing burnout additives through an extrusion nozzle, where the extrudate is subsequently cut into bricks, dried and fired. The ‘Cement’ process is a form of casting using cement instead of plaster, which leads to a much slower set. Further details concerning these manufacturing processes are available in the literature [1].

The density data reported in Table 1 are the average of measurements recorded on 6 bricks selected from random from a larger batch of product. The remainder of the physical property data is generally an average of three measurements, whilst the thermal conductivity data shown in figure 1 are measured on one sample selected at random from the batch.

Tab 1: Physical Properties of 23 Class IFBs

Manufacturing Process	Cast	Slinger	Extrusion	Cement
Density (kg/m3)	483	611	569	520
MOR (MPa) ASTM C-93	1	0.7	0.9	1.2
CCS (MPa) ASTM C-93	1.2	0.9	1.1	2
PLC (%) after 24hours @1230°C ASTM C-210	-0.2	0	-0.2	0
Reversible Linear Expansion (%)	0.5	0.6	0.6	0.6
Hot load deformation % after 90 mins; 1100°C @ 0.034 MPa ASTM C-16	0.1	0	0.2	0.1

IFB THERMAL CONDUCTIVITY

The different manufacturing methods for IFBs produce products with differing structure & chemistry, which in turn deliver different performance properties [2]. The primary performance parameter for IFBs is their ability to insulate, which in terms of measureable properties is assessed by the thermal conductivity of the product.

Density is sometimes used as a ‘rule-of-thumb’ indicator of the insulating ability of an IFB, but this can be misleading. The difference in thermal conductivity between the different types of IFB is shown in figure 1. It can be seen from these data that the thermal conductivity of the IFBs studied is not directly related to the density. For example, the highest density product (Slinger) has an intermediate set of thermal conductivity values, whilst the IFB with the highest thermal conductivity (Cement) actually has one of the lowest densities of the products studied. So to maximise the insulating abilities of IFBs, product selection should not be made on density values.

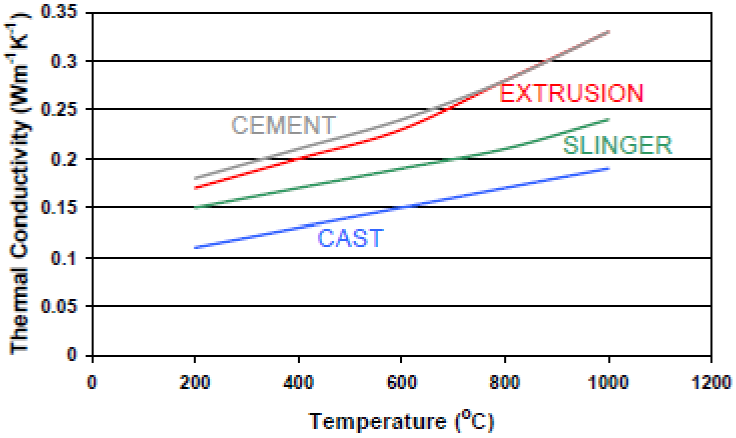

Fig 1. Thermal Conductivity for Class 23 IFBs

Commercially published thermal conductivity data varies in quality and accuracy, with some datasheets omitting the test method, which makes the data misleading when comparing and selecting products. The thermal conductivity data quoted

in this work was measured independently to ASTM C-182. But what is not normally published is how the thermal conductivity data translates to real conditions in service. If one IFB has lower thermal conductivity than another, how does that translate to heat loss in real applications in terms of energy costs? This work serves to answer this question by measuring actual energy use under controlled conditions using different IFBs.

EXPERIMENTAL

We commissioned a kiln builder to manufacture two electrically heated laboratory muffle kilns of identical design and power rating (figure 2). One was lined with the ‘Cast’ IFBs as characterised in Table 1 and the other was lined with the ‘Cement’ IFBs. We selected these two IFBs for the study as these represented the IFBs with the lowest and highest measured thermal conductivity.

For each kiln, power meters were set up between the power source and the kiln, in order to measure the energy usage during the controlled test firings. Two test firings were conducted.

Test 1. Ramp at 3°C/minute from ambient to 800°C, hold for 15 hours, natural cool back to ambient.

Test 2. Ramp at 3°C/minute from ambient to 1000°C, hold for 15 hours, natural cool back to ambient.

RESULTS

The results of the energy usage tests are shown in Tables 2 & 3.

Tab. 2: Results of 800°C Firing Tests with 23 Class IFBs

IFB Type	Cast	Cement
Test 1 (800°C for 15 hours):		
IFB Thermal Conductivity at Hold (Wm-1K-1)	0.17	0.28
Door Temperature during Hold (°C)	59	69
Roof Temperature during Hold (°C)	52	90
Energy Used during Ramp Up (kWh)	2	2.9
Energy Used during Hold (kWh)	9.2	14.4
Total Energy Used (kWh)	11.2	17.3
% Energy Saved by using Cast IFB	35	-

By monitoring the kilns during the tests using an Infra-Red camera (VarioCAM, FPA detector 320x240 pixel, 25mm FOV 32°x25°) the kiln surface temperatures could be measured. Figure 3 illustrates how much heat is wasted through the body of the kiln lined with the higher thermal conductivity IFB and how the surface temperature of the kiln becomes overheated. This behaviour has the combined effect of wasting energy costs and presenting health and safety issues in terms of hazardous working temperatures.

Tab. 3: Results of 1000°C Firing Tests with 23 Class IFBs

IFB Type	Cast	Cement
Test 1 (1000°C for 15 hours):		
IFB Thermal Conductivity at Hold (Wm-1K-1)	0.19	0.33
Door Temperature during Hold (°C)	71	91
Roof Temperature during Hold (°C)	88	123
Energy Used during Ramp Up (kWh)	3.3	4.7
Energy Used during Hold (kWh)	12.7	20.7
Total Energy Used (kWh)	16	25.4
% Energy Saved by using Cast IFB	37	-

DISCUSSION

The results of the monitored test firings have demonstrated that there can be considerable differences in energy requirements to heat up kilns constructed using different types of IFB. With the IFB types studied under our test firing conditions, ~37% less energy was needed to run the test kiln through a 1000oC firing cycle with the ‘Cast’ IFB compared to the ‘Cement’ IFB. This difference in energy usage is a consequence of the different thermal conductivities, which in turn are due to the differences in microstructure & pore size created by the manufacturing processes [2]. Figures 4a to 4c show the microstructure of the ‘Cast’ and ‘Cement’ IFBs used in the study as observed under an electron microscope.

Figures 4a to 4c show that the ‘Cast’ IFB has a much finer microstructure. The ‘Cement’ IFB has large quantities of relatively large holes in the structure, ranging from 700 to 1300 micron. Such large pore sizes are formed when combustible materials are added to the mix for the ‘Cement’ based casting process and are burnt out during the firing process. Typically, expanded polymer spheres of ~1mm diameter are used by manufacturers to create such high levels of porosity in the fired product. This has the effect of reducing density, making the brick light in weight, but does not contribute so much towards the insulating properties of the IFB.

Both the ‘Cast’ and ‘Cement’ IFBs display similar pore sizes in the mid-size range, around 50 micron diameter. This is again due to use of burnout additives. But the ‘Cast’ IFB has a much higher proportion of pore sizes in the <10 micron range. Mercury porosimetry studies [2] indicate a significant presence of even finer porosity than this in the ‘Cast’ IFB. It is this combination of ultrafine pore structure, coupled with an absence of very large pore sizes, which affords the ‘Cast’ IFB with lower thermal conductivity compared to the ‘Cement’ IFB.

IFBs are normally used in applications >1000oC, because at these temperatures they provide the most cost effective insulation available, compared to alternative insulating refractories (figure 5). The structural nature of the products also means that they offer resistance to abrasion in high temperature environments, coupled with chemical resistance (when the chemistry is tailored to cope with specific gases).

At application temperatures above 1000oC, the most important heat transfer mechanism becomes radiation, rather than conduction & convection, which are the more significant heat transfer mechanisms at lower temperatures. The large pore sizes in the ‘Cement’ IFB are inefficient at retarding energy transfer at the infra-red wavelengths involved, and so this type of IFB displays a higher thermal conductivity compared with the ‘Cast.’ Conversely, the microporous structure of the ‘Cast’ IFB, with its small pore sizes, is much more efficient at interfering with energy transfer at infra-red wavelengths, and so this type of IFB displays low thermal conductivity. This is why the microstructure of the ‘Cast’ IFB provides superior insulation compared to the ‘Cement’ IFB.

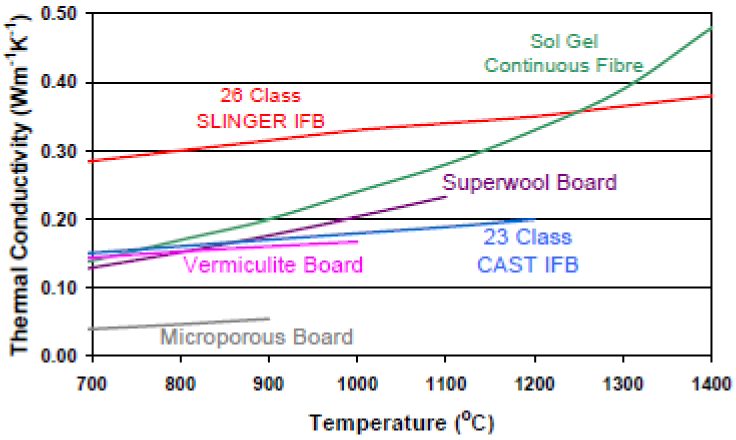

Fig.5: Thermal Conductivity for Various Refractories

ENERGY SAVINGS

The laboratory test results demonstrate the potential to minimise energy usage by appropriate selection of IFB for a kiln lining. To understand how this affects real, full size kiln installations, we ran heat transfer calculations (using the same ‘Cast’ and ‘Cement’ IFB types in the laboratory studies) to assess energy running costs for a typical roller kiln used by ceramic ware manufacturers (Table 4).

Tab.4: Assumptions for Heat Transfer Calculations

Roller Kiln Operating Conditions:	
Heating Section Area (m2)	150
Working Temperature (°C)	1300
Ambient Temperature (°C)	25
Working weeks per year	48
Kiln Efficiency (%)	80
Lining Arrangement:	
Layer 1: Class 26 ‘Cast’ IFB thickness (mm)	114
Layer 2: Class 23 ‘Test’ IFB thickness (mm)	114
Layer 3: Back Up Insulating Board	350

The model of the hot face of the standard lining arrangement (layer 1) was set up based on data from commercially available Class 26 IFBs (JM26, Thermal Ceramics). The backup insulation (layer 3) was set up using data from commercially available bio-soluble fibre board (Superwool 607, Thermal Ceramics). To assess the effect on energy consumption of using different IFB types in the lining arrangement, layer 2 was designated the ‘Test’ layer, into which the data from different IFB types were input. The results of the heat transfer calculations are shown in figure 6.

The Heat Transfer calculations show that the lining arrangement with the ‘Cement’ IFB requires 152 W/m2 more energy to maintain the 1300oC kiln temperature than the lining arrangement with the ‘Cast’ IFB in layer 2. So for the 150 m2 heating area, the difference in energy consumption between the two simulated roller kilns is 22.8 kW. This equates to a saving of ~230,000 kW/year energy using the ‘Cast’ IFB compared to the ‘Cement’ IFB. Assuming a gas price of 0.035€/kWh, this equates to an annual saving of ~€8,000/year. Since the average life of a kiln lining is about

10 years, the total saving over the life of the kiln lining would be ~€80,000.

A 150 m2 heating area in the kiln would need ~8,500 standard sized IFBs. Given the current market price differential between the ‘Cast’ and ‘Cement’ IFBs, although the ‘Cast’ IFB price is higher, in this example this higher price would be paid back in only 4 months. After the initial 4 month payback period, the rest of the 10 year service life delivers continuous cost savings due to the lower energy requirements.

ADDITIONAL IMPACT OF IFB SELECTION

Another important consequence of the energy savings achieved using the lower thermal conductivity IFB is the reduction in CO2 emissions. Using the ‘Cast’ IFB instead of the ‘Cement’ IFB reduces the environmental impact of running the kiln. In the current kiln scenario, as the saving in this example using ‘Cast’ IFB is ~230,000 kW/year, a natural gas fired roller kiln will require 22,000 m3/year less gas to fire it. As natural gas produces 37.8 MJ/m3, then 830,000 MJ/year will be saved. 1 m3 of natural gas produces ~1 m3 of CO2 and so there is a potential reduction in CO2 emissions of ~22,000 m3/year. 1 m3 of CO2 equates to 1.96 kg, which equates to ~43 t/year reduction in CO2 produced or 430 t over the life of the kiln lining.

A further benefit of using the lower thermal conductivity ‘Cast’ IFB against the ‘Cement’ IFB is that the outer temperature of the kiln is lower. In the example calculated in this work, the skin temperature of the kiln utilising ‘Cast’ IFB in layer 2 is 79oC, whereas the skin temperature of the kiln utilising ‘Cement’ IFB in layer 2 is 88oC. The lower surface temperature obtained using the ‘Cast’ IFB produces a more comfortable working environment for operators and minimises the risk of burns due to operators coming into contact with the surface of the kiln, compared to the higher thermal conductivity ‘Cement’ IFB.

The choice of IFB in the kiln lining will also impact other practical aspects of using the kiln in a production environment. Selecting the ‘Cast’ IFB rather than the ‘Cement’ IFB will allow faster heating & cooling rates in the kiln, because the lower density ‘Cast’ IFB has a lower thermal mass. This effect was observed in the energy studies reported in this paper. During both the 800oC and 1000oC test firings, the ‘Cast’ IFB reached the programmed dwell temperature faster than the ‘Cement’ IFB.

CONCLUSIONS

The work reported in this paper has demonstrated the following points:

– Differences in energy use as large as 37% were measured, under controlled laboratory conditions, between IFBs manufactured by different methods.

– When selecting insulating refractory products for furnace linings, close attention should be paid to the reported thermal conductivity of IFB products.

– The density of the products should not be used as a criterion to assess insulation ability, as this may lead to incorrect product selection.

– To minimise energy consumption in the kiln, the published thermal conductivity needs to be measured to a recognised international standard (e.g. ASTM C-182) and be as low as possible. Selecting an IFB due to price alone can turn out to be a false economy and a costly mistake in the long run.

– IFBs manufactured by the ‘Cast’ process offer the lowest thermal conductivity IFBs available today at application temperatures and therefore provide the greatest energy savings.

This paper has quantified the energy savings that are possible when using ‘Cast’ IFBs. The benefits of using the lowest thermal conductivity IFBs available are;

1. Large cost saving potential due to reduced energy usage.
2. Lower CO2 emissions due to the reduced energy usage.
3. Reduced kiln surface temperatures offering operators safer working conditions.

REFERENCES

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[2] Wynn A, Marchetti M, Street JP, Yin T. Insulating Firebrick – Effect of Manufacturing Method on Product Performance. In UNITECR 09 Conference, Brazil, Oct. 13-16, 2009.