REFRACTORIES IN WARSHIP BOILERS

BY

W. PARNHAM
(*Admiralty Marine Technology Establishment*)
(*Naval Auxiliary Machinery Division*)

Introduction

Brickwork and other refractories in warships have been a source of concern for a long time now. The very first edition of the *J.N.E.*'s predecessor—*Papers on Engineering Subjects*—dated August 1920 had an article entitled 'Fire Bricks and Fire Clay', and the following extract is as true today as it was then:

> '. . . In commercial practice the qualities [of refractory linings] required are mainly resistance to withstand high temperature and rough usage which, given a suitable material, can be surmounted by suitable dimensions and construction. Rapid changes in temperature can, moreover, be avoided in general.
>
> In water tube boilers for Naval purposes, on the other hand, considerations of weight and furnace volume, the unavoidable rapid changes of temperature, the necessity of rigidity to withstand the strains caused by the rolling and pitching of the vessel and the occurrences of vibratory burning or pulsation are such as to render the experience and practice regarding refractories employed in shore practice of little use.'

The *J.N.E.* of January 1956 stated:

> 'The refractory parts of boiler furnaces for ships of the Royal Navy have for years been regarded as components necessarily requiring frequent replacement.'

and again in December 1967 we find the comment:

> 'A more perplexing problem in ships is to be found in the saturated pass where the castable insulation tends to fall down.'

Boilers are still with us, and will be until the end of the century at least, and, who knows, we may yet return to them in new construction ships. However, as some in the gas world may not have seen a boiler for years, the following is a very brief reminder of the refractory arrangement in our boilers, and the common problems with it.

Refractory Arrangements and Common Problems

Furnace Lining

A typical warship's furnace has a 110 mm thickness of dense firebrick backed by 40 mm of high-temperature insulation and 25 mm of calcium silicate block insulation. The bricks are held together with a high-temperature jointing cement, and the whole assembly is held against the casing by diamond-headed keys of heat resisting steel which are slotted into eyelets welded on to the casing.

A ready-use mouldable plastic refractory is used to shape the burner openings in the front wall. This is done by ramming lumps of the material one on top of the other to build up a wall, and then shaping the quarl by ramming it around a former. It is secured at intervals by ceramic keys slotted into metal clips which fit into eyelets welded on to the casing.

Gas Pass Lining

Gas passes are normally lined with a 50 mm thick layer of castable refractory. This is an aggregate with hydraulic cement which, when mixed with the correct amount of water, may be cast or poured behind shuttering.

Slagging

Until recently Furnace Fuel Oil was used. Depending upon its origin, this contained varying amounts of contaminants such as vanadium oxide, sulphur, and sodium, and there was also some salt present if sea-water ballasting had been used. When the boiler was alight, deposits with a comparatively low melting point impinged on, and combined with, the surface of the brickwork forming low-melting point compounds called 'slags'. Slagging increases with rising temperature, and the products run down the walls and collect on the furnace floor. As the lining thickness reduces, the retention key and the casing get hotter, the lining becomes increasingly unstable, and eventually fails.

These deposits are sticky at furnace temperature, and some of them are carried by the gas flow to impinge on the leading surfaces of the generator and gas-pass tubes. If left to increase, they build up to cause 'birdnesting' and can eventually completely block the spaces between the tubes. Approximately 50 per cent. of this will dissolve in hot water, and regular water washing and scraping will keep tube deposits to a minimum. When this is being done, the brickwork must be protected by a water-resistant skin as otherwise the dissolved deposits will soak in and induce early failure on re-flashing.

With the introduction of dieso as a boiler fuel, slagging problems have been considerably reduced. The other remedial measure that can be taken is to lower the porosity of the brick but, unfortunately, this encourages spalling which is reduced in a high-porosity brick.

Spalling

As the temperature of the furnace alters, so the bricks expand and contract unevenly through their thickness. The stresses thus caused eventually result in tiny relieving cracks behind the hot face in the bond around the grains, and these cracks widen in time until pieces of brick loosen and fall off. This is 'spalling'

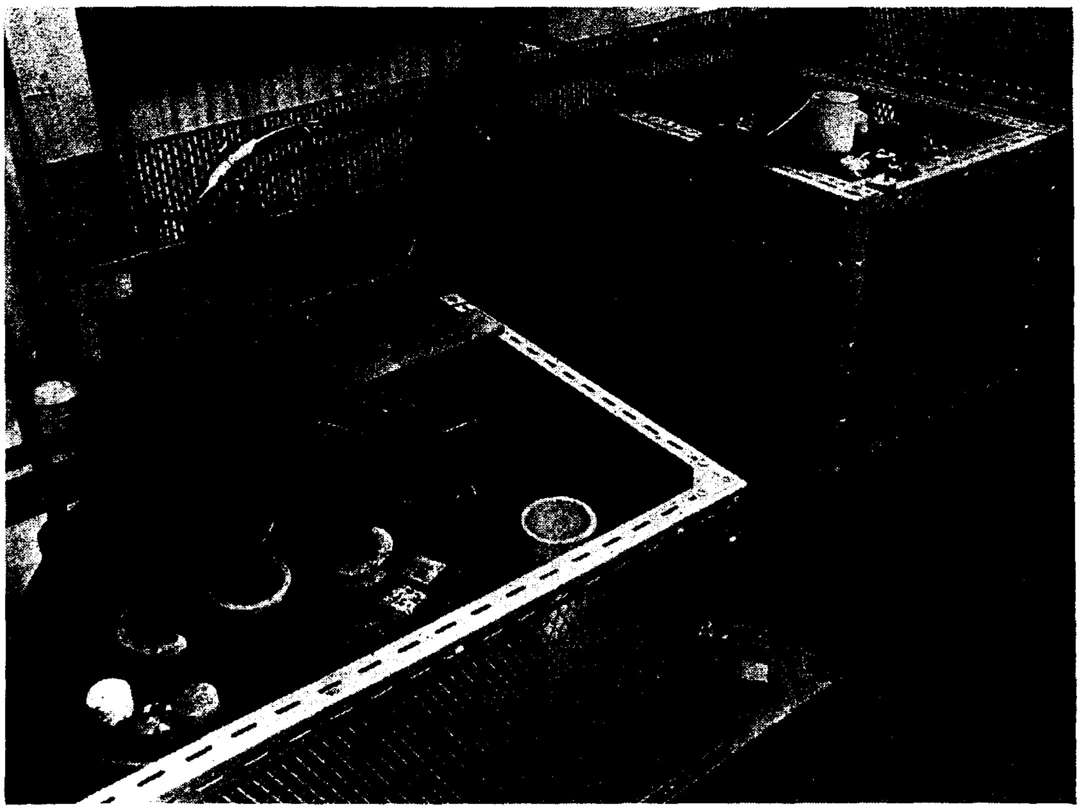

FIG. 1—HIRSCH ELECTRIC FURNACES

and, as has already been mentioned, is reduced by increasing porosity which, however, encourages slagging. Firebricks used in H.M. ships are, therefore, a compromise, with a well-graded open texture and a maximum porosity of 25 per cent.

Quality Control

The following properties all affect the performance of a refractory in service:

Melting point	Thermal conductivity
Strength	Resistance to slagging
Modulus of rupture	Resistance to spalling
Permanent linear change after firing	Workability
Bulk density	Moisture content
Porosity	Grading

Variations in manufacture can cause any or all of these properties to be altered and, in order to ensure a steady supply of good quality refractories, a section was set up at the Naval Auxiliary Machinery Division at AMTE Haslar (ex NGTE, ex AMEE, ex AFES) to test samples, and to determine the most suitable for our requirements.

Specifications were drawn up, and a system of testing for fitness for service was started. As a result, the products of manufacturers with non-existent or inefficient quality control are no longer used, and there has been a definite improvement in the refractory products in use in the Fleet.

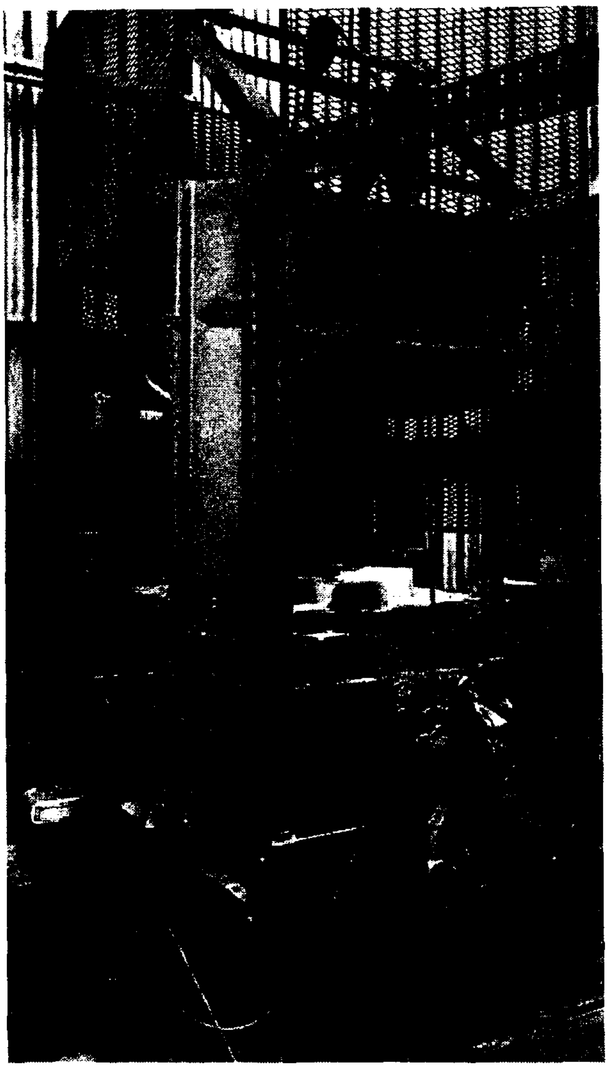

FIG. 2—MEASUREMENT OF THE THERMAL CONDUCTIVITY OF A REFRACTORY

Equipment at Haslar includes:

(*a*) A high load transverse testing machine. This measures the crushing strength, modulus of rupture, and tensile strength of samples, and is capable of exerting a force of about 15 tons.

(*b*) Two Hirsch carbon-resistance electric furnaces which are capable of heating to 1800°C. These are used to measure refractoriness under load and melting point. The furnaces are shown in FIG. 1. In the left-hand furnace a cube of the material under test is placed in the hot zone in the centre, and a standard load is applied by means of the weights which can be seen above. The temperature of the furnace is raised at a standard rate, and the temperature at which 10 per cent subsidence occurs is determined. The right-hand furnace is used to find

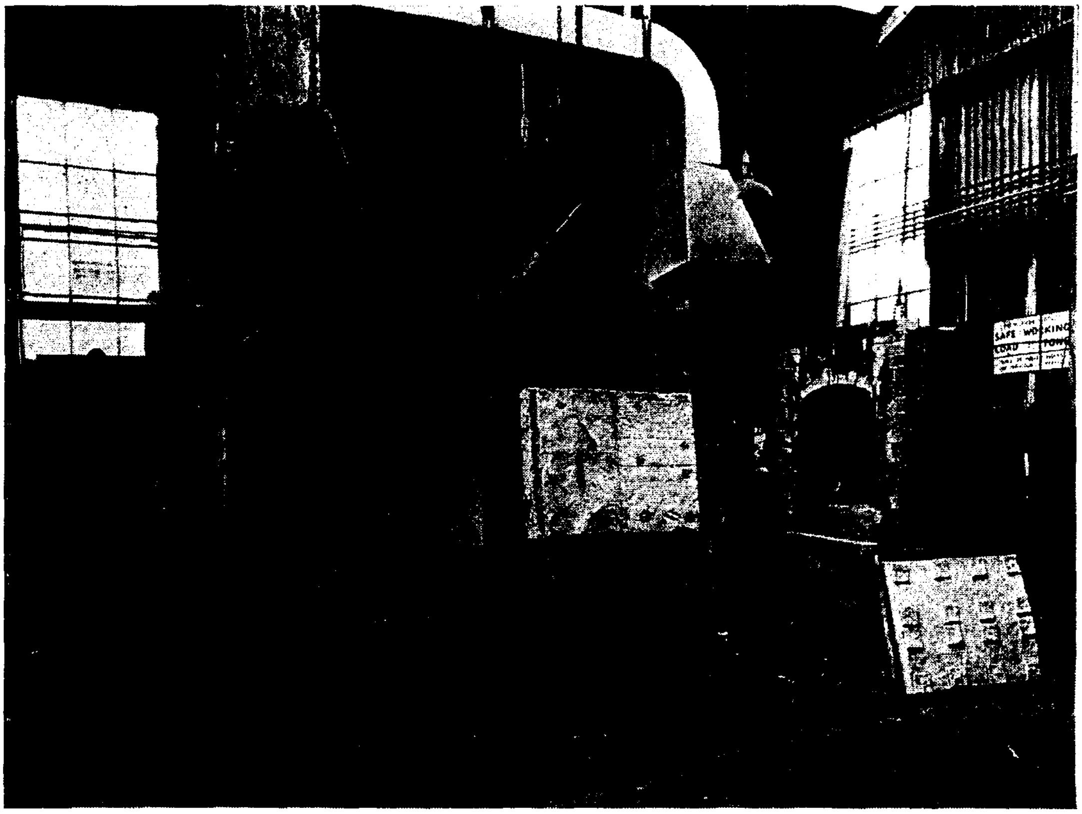

FIG. 3—FURNACE SYSTEM FOR MEASURING SPALLING RESISTANCE

the melting point of the sample. Standard 30 mm cones of the material are cemented to a refractory disc with high temperature cement, and placed in the hot zone of the furnace. The temperature is raised at a standard rate and the point at which the cones soften and bend over is noted.

(*c*) A machine to measure the thermal conductivity of refractory test panels at up to 1400°C. This is shown in FIG. 2. A standard-sized slab of the material (450 × 330 × 75 mm) has thermocouples set into the hot face, the middle, and the cold face, and is then bedded on to a calorimeter in the well of the furnace. The hot face is then heated overnight at the selected temperature (up to 1400°C) and the heat flow and thermocouple readings are taken. From these, the thermal conductivity at various mean temperatures can be calculated.

(*d*) A furnace system for measuring the spalling resistance of bricks. This is shown in FIG. 3. The right-hand furnace is a pre-heat furnace which keeps the brick under test at a hot face temperature of 1600°C for 48 hours. During this time some vitrification of the surface of the bricks will occur, the amount depending upon the quality and method of manufacture. After this, the panel is repeatedly heated and cooled by holding it in front of the left-hand furnace at 1400°C for 15 minutes, followed by 15 minutes of cold air being blown over the hot face at 6000 ft^3/min. Ten cycles of this treatment simulate many hundreds of hours service in a ship. Once the panel has cooled enough it is dismantled, and each brick is lightly scraped with a trowel. Spalled pieces of firebrick drop off and the percentage weight loss is the measure of resistance to spalling. Also in this picture can be seen two of the ceramic fibre test panels. The one in the centre shows a trial which used four square modules of blanket glued on to the casing and, in the right-hand panel, the protective patches mentioned under the heading 'Ceramic Fibres' can be seen.

(*e*) A gas-fired furnace for measuring the strength and permanent linear change of a refractory on first firing.

Trial of Castable Quarls

An example of a recent trial at NAMD Haslar is the evaluation of Midcast castable refractory to replace plastic refractory. Plastic refractory is used to form the quarls in the front wall of a boiler, but it suffers from many disadvantages, the main ones being that it shrinks on drying, it must be installed as late as possible before flashing up, and if it is not dried, baked, and fired correctly it will almost certainly fail prematurely. On the other hand castable refractory has no drying shrinkage, and can remain in an unfired condition indefinitely. The Y.100 boiler at Haslar has had castable quarls in place for over two years and the whole front wall is still firmly retained with no signs of failure. The quarl edges are sharp and the surfaces true and smooth, and a recommendation has been made that this system be tried in an operational ship.

Ceramic Fibres

The other aspect of refractory work at NAMD Haslar is the evaluation of new materials, and currently the most exciting is a ceramic fibre to replace castable refractory. This is a compound of alumina silicate which has been melted, and then blasted into fluffy fibres by high velocity gases. These fibres are collected in layers and processed into several forms such as blanket, board, paper or rope, all of which are 1/20th the weight of brick, have excellent resistance to vibration and temperature fluctuations, and a very low thermal conductivity.

It has been extensively tested at Haslar, and the results have been most encouraging. The fixing arrangements are fairly novel, as it is possible to glue 300 mm × 300 mm modules of it direct to metal casings or to existing brickwork. The standard method for larger sheets, however, is to weld threaded studs at intervals on the casing and press the material over them. It is then held against the casing by a nut/washer/nut arrangement, and the exposed metal is protected by a glued ceramic fibre patch.

Apart from surviving deliberate gross maltreatment during the trials at Haslar, this arrangement has been to sea on an inspection door in the gas pass of a Y.160 frigate. It successfully steamed many hundreds of hours, and was popular with the ship's company because it gave no trouble and its light weight made removal and replacement very much easier. A disadvantage in this role is its susceptibility to damage as its edges have no strength and, in future installations it is intended to protect all edges by a narrow strip of castable refractory. Repairing any damage is, of course, extremely easy, as all that is necessary is to cut a suitable shape from a roll of blanket with a knife and glue it into place.

The next step is a trial with the whole gas pass of one boiler of a Y.136 or Y.160 frigate lined with ceramic fibre, and it is hoped that this will be installed and on trial in 1980. Meanwhile, tests continue at Haslar, the new line of investigation being to evaluate higher grades of the material for use in a furnace, where temperatures of 1550°C can be expected. If the programme goes ahead as expected, there will soon be an entirely new range of insulating material available to the Fleet—light, effective, and easily within the capability of ship's staff to repair as soon as they can get access.