# AGR CHANNEL BRICK DURABILITY STUDIES

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## Introduction

In UK Advanced Gas-cooled Nuclear Reactors (AGRs), the graphite moderator is subject to neutron irradiation and radiolytic oxidation which induce dimensional changes and reduce residual strength, respectively. Radiolytic oxidation results in weight loss so that high levels of porosity may develop in some peak rated bricks towards the end of the anticipated core life. This paper reports progress of a series of experiments which explores one aspect of the 'durability' of the moderator bricks at the channel bore wall under high weight loss conditions.

During re-loading operations of an AGR, a stabilising brush (part of the bottom support and reflector assembly of the fuel stringer) interacts with the fuel channel bore wall. The fuel stringer travels at ~ 1m/s. The design of the brush is such that, at the start of life, the length of the fibres is ~2 mm greater than the radius of the unirradiated fuel channel creating an overlap, thereby creating a force to stabilise the fuel stringer. As irradiation shrinkage accumulates, a maximum radial compression of 6 mm may be assumed [1]. The current experiments explore whether the oxidation processes will create a 'friable' brick bore surface that may degrade by interaction with the stabilising brush. Potentially, fine debris and dust may be created increasing the burden on the coolant gas circuit.

## Experimental

An experimental rig has been designed and manufactured to simulate the interaction of the bottom stabilising brush with the channel bore wall. The rig incorporates a section of a brush taken from an unused AGR fuel stringer assembly (Typically, the brush has ~2.2 fibres/mm$^2$ and with each fibre on average having a cross section area of ~0.04 mm$^2$.) Graphite samples of 1 x 4 x 10 cm$^3$ are fixed with the flat face in the vertical plane to the base of an Instron 1195 Testing Machine while the brush (in the horizontal plane), attached to a moving crosshead, travels at 2 mm/min once down one side of a sample. Simultaneously, the load-travel trace is recorded. The extreme edges of the fibres of the brush are used to measure the overlap distance between the brush and the sample face. Three overlap distances are used in this study: 2, 4 and 6 mm. At the conclusion of the test, any debris generated by a single swipe of the brush is collected.

Specimens were prepared with a range of weight losses (currently up to ~25%, but the aim is to achieve ~50%) in a low flow (0.5 lpm) 5%$CO/CO_2$ gas mixture at 900 °C. The oxidation conditions were chosen to promote an even distribution of porosity. In addition to weight losses, pre- and post-oxidation dimensions were measured to calculate the degree of external burn-off, defined by

$$F_e = p_0(V_0 - V)/(M_0 - M)$$

where $V_0$ is the initial volume, V is volume after oxidation, $M_0$ is the initial mass, M is mass after oxidation and $p_0$ is the initial density. At present, $F_e < 10\%$ and most of the surface oxidation is in the form of small fissures. The value of $F_e$ is used to correct bulk weight losses to eliminate the effect of external oxidation.

## Results and Discussion

Results show that for all overlaps, no debris is created (<0.1g) and only superficial damage to the surface occurs. Figure 1 shows an example load-travel trace for a ~24% weight loss sample. The load increases to a peak value as the brush comes in contact with the top surface of the sample, before declining to a steady state value (called base load) for uniform travel across the specimen.

Figure 2 shows the value of base load vs weight loss for all three overlap distances up to ~25% weight loss with best fit lines. Although there is a lot of scatter, there is a general trend that, as oxidation proceeds, the vertical load on the brush increases.

Since no debris is created up to 25% weight loss, the brush samples are not friable, but as oxidation proceeds, it may be expected that the surface of the graphite specimens "softens". To confirm this hypothesis, Rockwell 'A' hardness tests were conducted on a range of oxidised samples. Figure 3 shows the increasing 'softness' of the graphite surface with increasing oxidation. To demonstrate that the samples used in this work are comparable with past thermal oxidation studies and knowledge of radiolytic oxidation, flexural strength testing (3 pt) was conducted on the brush samples as shown in Figure 4. It is common to describe the empirical relationship between strength and oxidation of graphite by the equation

$$\sigma/\sigma_0 = \exp(-bx)$$

where $\sigma$ is the strength, $\sigma_0$ is the as-received strength, b is an exponent and x is the weight loss. For radiolytic oxidation, b is 3.7 ± 0.2 (1 s.d.) [2]. For thermal oxidation, b is recognised to be significantly higher, and in some cases by at least a factor of 2 *e.g.* [3]. The flexural strength of the as-received graphite was 27.15 MPa which compares favourably with the industry accepted value of 27.7 MPa [2]. From Figure 4, the exponent b is found to be 5.3 illustrating the greater reduction in strength for thermal oxidation.

## Conclusions

Samples of thermally oxidised moderator graphite have been shown to be ‘durable’ to the stabilising brush-bore wall interaction up to a weight loss of ~25%. There is evidence that the surface ‘softens’ with weight loss, but it remains resistant to the low forces of the stabilising brush. Therefore, up to 25% weight loss, the increase in the dust burden of the coolant gas circuit is likely to be small.

## References

1. Reed, J. (1996). Private communication
2. Data Sheets for Gilsocarbon Core Graphite (1991). CSDMC/P28
3. Pickup, I. M., McEnaney, B. and Cooke, R. G. (1986). Carbon, 24, [5] 535-543.

## Acknowledgements

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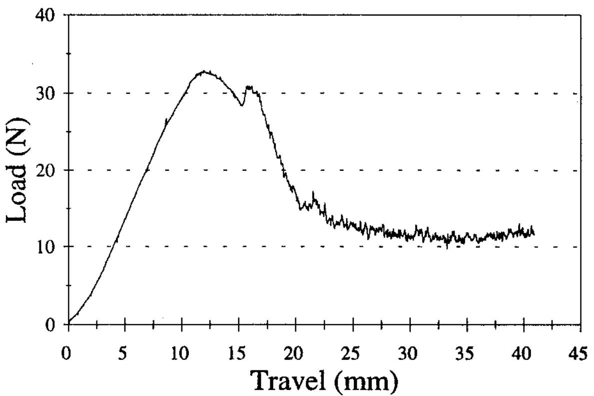

**Figure 1:** A Typical Load vs Travel Trace for a Brush Sample of 23.5% weight loss (6mm overlap)

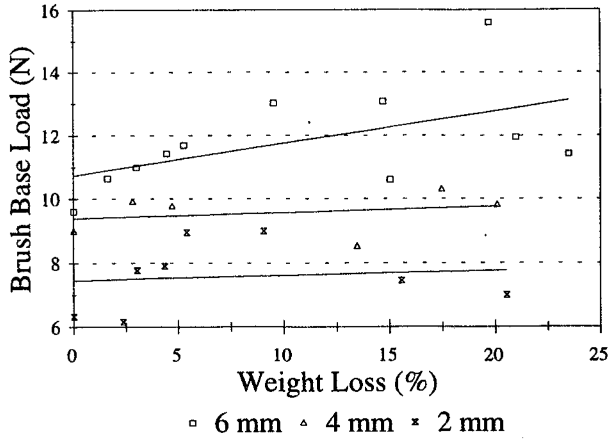

**Figure 2:** Base Load vs Weight Loss with Best-Fit Lines for 2, 4 and 6 mm Overlap.

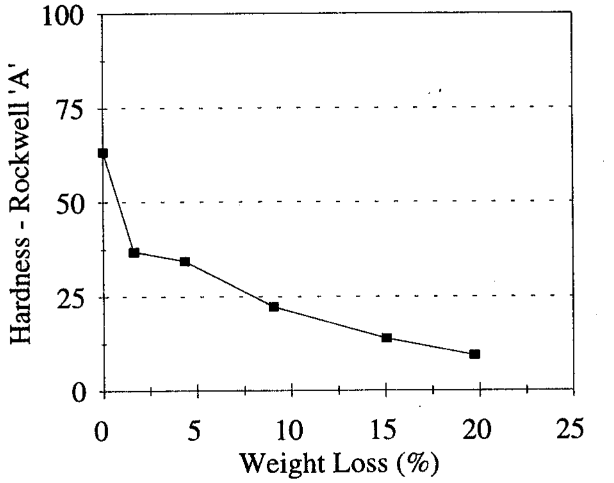

**Figure 3:** Hardness vs Weight Loss for Surface Indentation of Brush Samples.

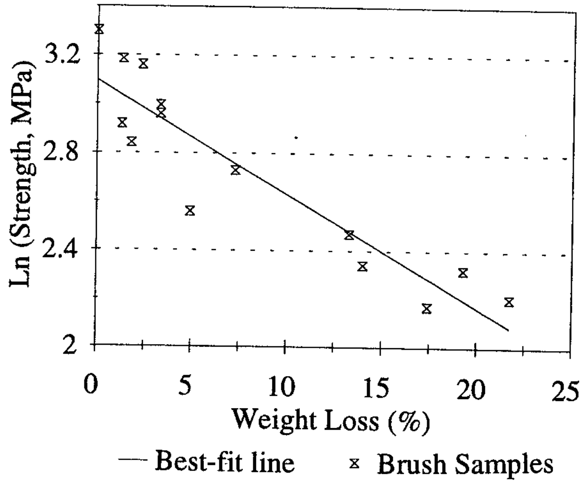

**Figure 4:** A Plot Showing the Variation of Flexural Strength (3pt) vs Weight Loss for Brush Samples