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REPORT ON DATABASE OF GRAPHITE PROPERTIES SUITABLE FOR USE BY DESIGNERS

by

M W Davies

NNC Ltd, U.K.

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Summary

Graphite has been used as a neutron moderator in a variety of different reactors, and there has recently been a renewal of interest in High Temperature Reactors (HTRs) in the world. In particular the European Commission is supporting a number of projects for the development of HTR technology, with a view to creating the technological basis for the industrial emergence of HTRs in Europe by 2010.

Most of the available data on the irradiation behaviour of graphite have been obtained by irradiating small samples in Materials Test Reactors. Unfortunately, almost all the graphites previously irradiated are no longer commercially available. As a result, a planned graphite irradiation programme is being udertaken for the European HTR project. This will allow the 'best' graphite(s) to be chosen, and hopefully provide all the data necessary to allow a full core design to be carried out.

It has therefore been necessary to devise a suitable format for a graphite database which will be included on the SINTER network. A format has been proposed for recording and storing all future 'raw' data obtained from the irradiation programme, and another for presenting the data in a suitable form for the core designer to use directly. The proposed format for each is given in the report.

1 Introduction

Graphite has been used as a neutron moderator in a variety of different reactors. These include the Advanced Gas-cooled Reactors (AGRs), Magnox Reactors, High Temperature Reactors (HTRs), RMBKs, Research Reactors and Materials Testing Reactors (MTRs). The amount of nuclear grade graphite currently manufactured worldwide is relatively small, and broadly consists of graphite for AGR fuel sleeves and prototype HTRs (one in Japan and one in China). However, there has recently been a renewal of interest in HTRs in the world. The design of the Pebble Bed Modular Reactor (PBMR), led by ESKOM (South Africa), and the Gas-Turbine Modular Helium Reactor (GT-MHR) led by an international consortium (Russia, USA, France and Japan) are at an advanced stage. The European Commission is also supporting a number of projects for the development of HTR technology, with a view to creating the technological basis for an industrial emergence of HTRs in Europe by 2010.

The behaviour of graphite in a reactor environment has been extensively studied since the early 1940s and a good understanding of the significant and complex property changes which take place in the material has been gained. Most of the available data have been obtained by irradiating small graphite samples in MTRs. Unfortunately, almost all the graphites previously irradiated are no longer commercially available. In addition, most of the irradiation temperatures investigated will have been $<550^{o}C$, whereas for HTRs the graphite temperatures will be $>550^{o}C$. The behaviour of currently available graphites will therefore have to be determined by experiments in a high flux MTR over the appropriate irradiation dose and temperature range.

It was considered necessary to first of all carry out a review of the current situation regarding graphite for the European HTR project. Part of this work has been undertaken under HTR-M, and involved carrying out a review of available data on the irradiation behaviour of different graphites at high temperatures. This work is the subject of Ref. 1. (Additional work is being carried out under HTR-M1 and involves the irradiation of a selection of currently available graphites in the High Flux Reactor at Petten. Details of this work will be covered in a separate report.)

It is therefore necessary to devise a suitable format for a graphite database which will be included on the SINTER network. A format has been proposed for recording and storing all future ‘raw’ data obtained from the irradiation programme, and another for presenting the data in a suitable form for the core designer to use directly. The proposed format for each is given in the report (the same format might also be used for storing the existing data if this is considered to be of benefit).

2 Graphite data requirements for core design

Reference 1 gives a description of the behaviour of graphite when subjected to fast neutron irradiation. Basically, carbon atoms are displaced from their normal lattice positions into interstitial positions, the displaced atoms leaving vacancies behind them. As the damage process progresses, the net effect is that the graphite crystals grow in the direction perpendicular to the atomic planes (the ‘c’ direction) and contract (shrink) in the direction parallel to the atomic planes (the ‘a’ direction).

The amount of growth and shrinkage depends on the irradiation dose received and on the irradiation temperature. The dimensional change behaviour varies from graphite to graphite. On the macroscopic scale, the core designer has to know the dimensional change behaviour of the graphite(s) used over the relevant dose and temperature ranges. This allows him to determine how the individual components in the core will grow/shrink so that the appropriate clearances etc. can be set at the beginning.

The changes to the crystals also affect all the mechanical/physical properties of the graphite. The most important of these from the design point of view are strength, Young’s modulus, coefficient of thermal expansion (CTE) and thermal conductivity. It is also important to know the irradiation creep behaviour of the graphite(s).

3 Graphite irradiation experiments

The irradiation behaviour of graphites is generally determined using high flux MTRs. The main reason is that they have much higher fast neutron fluxes than the power reactors and therefore a lifetime’s irradiation for a particular core design can be achieved in a fraction of the time. For each irradiation in a MTR, small cylindrical graphite specimens, typically 10-15 mm in length, and 5-7 mm in diameter are located in special carriers, designed such that the graphite is maintained at the specified temperature.

The specimens are individually identified and pre-characterised to obtain the unirradiated properties. The dimensions of the specimens are measured together with Young’s modulus, CTE and thermal conductivity (clearly strength cannot be measured on the samples to be irradiated as this will involve a destructive test, nevertheless, strength measurements can be made on other samples obtained from a block, and the strength distribution obtained should be representative of those which will be irradiated).

Many irradiations in the past have been carried out in stages. After each stage, the carrier is removed and the sample properties re-measured. This allows the property variations to be obtained over the full dose range. If it is not possible or practical to carry out the irradiation in stages, it will still be possible to obtain data over most of the dose range by distributing the samples over the full height of the core and making use of the axial flux shape. At the end of the (single) irradiation period, the samples near the centre of the carrier will have reached the peak dose, whereas the samples above and below will have received a progressively lower dose, and those at the top and bottom will have received the lowest dose.

4 Proposed format for the graphite materials database

As mentioned earlier, a programme of graphite irradiation at high temperature is being carried out under HTR-M1 for the European HTR project. The main reason for this is that almost all the graphites previously irradiated are no longer commercially available, and therefore the necessary data have to be obtained for those that are. Hopefully it will be possible to irradiate a significant number of graphites to the peak dose required, and over the appropriate range of temperatures. The aim is to generate all the data necessary to allow the selection of the ‘best’ graphite(s) for a future European HTR, and to provide the core designer with what he needs to carry out a full core design. As such the data will need to be in a form suitable for the him to use.

It is therefore necessary to devise a suitable database in which the future ‘raw’ data can be stored. It will also be necessary to analyse the data and convert it into a form which is suitable for use by the core designer. The proposed method/format for recording and storing the raw data, and the method for providing the data for the designer are described below.

[Note - Although a significant amount of data have been obtained for various HTR irradiation programmes in the past (Ref. 1), a large part of the data is still subject to confidentiality/secrecy and cannot therefore be published openly. Nevertheless, it should still be possible to incorporate the freely available existing data on the SINTER database as well, if this is considered to be of any benefit. This might be done using the proposed format, or a different one if this is easier to do.]

4.1 Recording and storing of raw data

As mentioned earlier, data on the irradiation behaviour of graphite are obtained by irradiating small cylindrical samples in a specially designed carrier which is loaded into a high flux MTR. First of all, the machined samples will have to be uniquely labelled and pre-characterised i.e. have their unirradiated dimensions and properties measured (length, diameter, mass, Young’s modulus, CTE and thermal conductivity). It is proposed that the data be recorded in a Microsoft Excel spreadsheet like the one shown in Figure 1 (the specimen volume and density are calculated using the appropriate formulae). A separate spreadsheet will be produced for each graphite grade and sample orientation, which will also contain the appropriate details of the graphite i.e. grade, manufacturer, coke source, grain size and manufacturing method (it was also considered appropriate to include a column entitled ‘rig location’ which could be used to record the position of the sample in the carrier and/or the location of the carrier in the reactor).

After each stage of the irradiation, the samples may be re-measured. The data would then be recorded in the spreadsheet in a series of columns as shown in Figure 2 (the columns will be in the same spreadsheet, and next to the columns shown in Figure 1). The appropriate irradiation dose and temperature for each sample will also be recorded. The fractional changes in each dimension/property will then be calculated using the appropriate formulae in columns headed as shown in Figure 3. These columns can be located in the spreadsheet immediately below the corresponding columns shown in Figure 2. This arrangement can be copied for each stage of the irradiation.

4.2 Presentation of design data

In the UK, the irradiation data on Gilsocarbon graphite necessary for carrying out safety case assesments for the AGR cores is contained in a compendium. The data are contained in sections specific to each property. These are:

(i) Young’s modulus (i.e. stress/strain relationship);

(ii) strength;

(iii) dimensional change and dimensional change rate;

(iv) coefficient of thermal expansion;

(v) thermal conductivity;

(vi) irradiation induced creep;

(vii) specific heat and stored energy;

(viii) gas transport properties;

(ix) virgin bulk density and open pore volume.

Each section gives the data in both tabular and graphical form and explains how they should be used, and also states what the limitations are, if any. Where appropriate the variation in a property with dose (at each irradiation temperature) is given as a polynomial fit (polynomial fits for property variations are normally used in finite element models of components to determine their through-life distortions and stresses, which is an extremely important part of the design process). It is proposed that the data needed by the core designer be presented in the database in the same way. In order to do this, the data obtained from the irradiation experiments will have to be collated and post-processed to produce the recommended 'design curves' for each property.

5 Conclusions

Graphite has been used as a neutron moderator in a variety of different reactors, and there has recently been a renewal of interest in HTRs in the world. In particular the European Commission is supporting a number of projects for the development of HTR technology, with a view to creating the technological basis for an industrial emergence of HTRs in Europe by 2010.

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It has been necessary therefore to devise a suitable format for a graphite database which will be included on the SINTER network. A format has been proposed for recording and storing all future 'raw' data obtained from the irradiation programme, and also for presenting the data in a suitable form for the core designer to use directly.

6 References

Ref	Title
1	M W Davies and G Haag. State of the art review of graphite materials and behaviour. HTR-M-02/6-D-3.1.37. NNC Report C6463/TR/011

Table 1 Recording of unirradiated sample dimensions/properties

Graphite materials property database

Direction: Perpendicular (Against grain)

Graphite: PPEA
Manufacturer: UCAR
Coke: Pitch
Grain size: Fine
Process: Extrusion

Rig location	Specimen code	Unirradiated properties							
		Length Lo (cm)	Diameter Do (cm)	Volume Vo (cm3)	Mass Mo (g)	Density ρo (g/cm3)	Young's modulus Eo (GN/m3)	CTE αo (x10-6/oC)	Thermal conductivity Ko (W/m/oC)

Table 2 Recording of irradiated sample dimensions/properties

Irradiation temperature (oC)	Dose EDND (x10E22)	Irradiated properties							
		Length L (cm)	Diameter D (cm)	Volume V (cm3)	Mass M (g)	Density ρ (g/cm3)	Young's modulus E (GN/m3)	CTE α (x10-6/oC)	Thermal conductivity K (W/m/oC)

Table 3 Calculation of fractional changes in sample dimensions/properties

Fractional change							
Length (L/Lo-1)	Diameter (D/Do-1)	Volume (V/Vo-1)	Mass (M/Mo-1)	Density (ρ/ρo-1)	Young's modulus (E/Eo-1)	CTE (α/αo-1)	Thermal conductivity (K/Ko-1)