UNCLASSIFIED
(CLASSIFICATION)

DOCUMENT NO. *BNWL-SA-56*
~~BN SA 56~~

ISSUING FILE

COPY NO.

DATE

May 14, 1965

JUL 16 1965

PROJECT

MASTER

BATTELLE-NORTHWEST

RICHLAND, WASHINGTON

TITLE

THE TENSILE FRACTURE STRAIN OF GRAPHITE
DETERMINED DURING NEUTRON IRRADIATION

AUTHOR

J. L. Jackson

DISTRIBUTION

NAME	BUILDING	AREA
F. W. Albaugh	328	300
T. W. Ambrose	1760	100-D
D. H. Curtiss	1101	100-N
R. E. Dahl	3701-L	300
J. W. Helm	326	300
J. L. Jackson	3701-L	300
M. C. Leverett	1101	100-N
M. Lewis	1101	100-N
W. C. Morgan	3701-L	300
R. E. Nightingale	3701-L	300
A. Russell	1760	100-D
E. M. Woodruff	326	300
H. H. Yoshikawa	326	300
300 Area Files	3760	300
AGR/EGCR (40)		
Extra (25)		

NAME	BUILDING AREA
G. B. Engle	General Atomics
C. R. Kennedy	Oak Ridge National Laboratory

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:
A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.
As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ROUTE TO

PAYROLL NO.

LOCATION

FILES ROUTE DATE

UNCLASSIFIED

(CLASSIFICATION)

(TO BE USED ON UNCLASSIFIED AND OFFICIAL USE ONLY DOCUMENTS)

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

H.C. \$ 1.00 ; MN .50

THE TENSILE FRACTURE STRAIN OF GRAPHITE
DETERMINED DURING NEUTRON IRRADIATION*

by

J. L. Jackson

Pacific Northwest Laboratories

Battelle Memorial Institute, Richland, Washington

ABSTRACT

Graphite, when used as a moderator material, is subjected to neutron damage gradients. These damage gradients can generate internal tensile stresses which could lead to fracture. Other investigations have shown that graphite in tension in an irradiation environment will relieve some of this differential stress by undergoing "irradiation creep". However, no measurements have been reported on the strain which could be accumulated before fracture during irradiation. An investigation of this strain at fracture for EGCR-type AGOT graphite has been conducted. Parallel cut samples were irradiated at $625^{\circ}\text{C} \pm 25^{\circ}\text{C}$ at a nominal strain rate of 0.13% per 10^{20} n/cm². Strains without fracture from 0.37 - 0.42% were obtained, compared to strains at fracture of 0.1 - 0.2% for unirradiated material.

*Work performed for the Atomic Energy Commission under Contract AT(45-1)-1830.

INTRODUCTION

The design and construction of new large graphite-moderated reactors has stimulated investigation of the response of graphite to higher temperatures and neutron fluxes. Calculation of the irradiation-generated differential stresses in large graphite core pieces⁽¹⁾ disclosed the possibility of fracture of graphite by this mechanism. However, the calculations are hampered by lack of data on the response of graphite to stress during irradiation.

Investigations have shown that graphite in tension in an irradiation environment will relieve some of the imposed stress by undergoing "irradiation creep".^(2,3,4) However, there have been no measurements reported on the strain at fracture during irradiation.

This paper will present tensile fracture-strain data for EGCR-type AGOT graphite in an irradiation environment at 625°C.

EXPERIMENTAL

The graphite used in these tests was Experimental Gas-Cooled Reactor (EGCR) moderator material graphitized at about 2800°C and manufactured by conventional methods⁽⁵⁾ from Continental Lake Charles No. 1 coke and coal-tar pitch. The original bars were 16 x 16 inch finished cross-sections and were trepanned for fuel channels. Cores from these channels were further machined to the sample shape shown in Figure 1. The long axis of the sample was parallel to the axis of extrusion of the original bar and the sample shape was selected for easy assembly and disassembly of the strain device. All samples were annealed at 1400°C to remove any stress produced during fabrication. The length of each sample was measured before and after annealing, after assembly, and again after removal from the reactor. The measure-

ments were made using a special jig and dial-gage system accurate to better than $\pm 10^{-4}$ inches.

The sample design has proven to be something less than optimum and 6 of 7 failures occurred near the intersection of the tapered head with the gage section which provides a stress raiser. This means that the stress in the gage section of the sample is somewhat lower than the stress for fracture and consequently the fracture strain may be on the low side.

Several unstressed samples of the different materials used in the strain assembly were irradiated simultaneously in order to monitor their response to the reactor environment.

The strain-unit assembly, shown in Figure 1, has been described in detail.⁽⁶⁾ It suffices to say that the samples were strained by the relatively rapid contraction of the carbon straining section. Each unit was assembled with approximately 0.01 per cent tensile strain and the thermal expansion of all components strained the sample about 0.1 per cent at the $625 \pm 25^\circ\text{C}$ operating temperature. As a result, stress on the samples was partially relieved when the temperature was reduced during reactor shutdown, thereby reducing the probability of inadvertent fracture during discharge and handling operations.

The experiment was heated by the reactor gamma radiation field to a nominal temperature of $625 \pm 25^\circ\text{C}$ with unavoidable fluctuations due to fuel burnup and reactor operation.

Neutron exposures were calculated from the activation of threshold monitors using the effective cross sections developed for the specific reactor positions.⁽⁷⁾

DISCUSSION

The results of the irradiation-strain tests are shown in Figure 2. The numbers, associated with each point, identify individual samples which were irradiated, then measured, and re-irradiated. The left-hand ordinate is the measured strain on the sample in the assembly at room temperature. The right-hand ordinate is the strain of the sample at the operating temperature of 625°C which includes a correction based on measurements of the strain imposed by thermal expansion of the assembly. The curves are determined by the unbroken samples and are a measure of the strain rate imposed by carbon contraction. There are several separate curves since each unit develops a slightly different strain rate due to variations in materials.

For broken samples the points were plotted on the curve using the total exposure for that sample. Thus, the points for broken samples indicate only that the sample fractured below the strain shown but are not the strain at which the samples fractured.

Comparison of the data in Figure 2 with strain data on unirradiated material of the same type brings out several things. First, there were no failures in samples irradiated to less than 1.1×10^{20} n/cm². Three of the samples had strains measured at room temperature in excess of 0.2%. This is much larger than fracture strains measured in the absence of irradiation. Tests on 30 samples of unirradiated material at room temperature yielded a mean fracture strain of $0.14 \pm 0.03\%$. In other tests samples at different temperatures up to 1200°C had strains at failure that averaged 0.15% for 6 samples and all samples failed at less than 0.2%. In the absence of irradiation, the maximum strain to failure is $\leq 0.2\%$, and therefore, these tests show that irradiation induced plasticity increases the available strain.

All samples were then re-irradiated to about 2×10^{20} n/cm² before the next measurements. Of the eight samples taken to this exposure, two survived. One of these samples, Number 6, had a strain of 0.28% measured at room temperature (0.38% at 625 $\pm$ 25°C). This sample, after removal from the reactor, was heated in the straining assembly to a temperature of 600°C, which caused the sample to fail at a measured strain of 0.40%. The other sample that survived, Number 11, had a room-temperature strain of 0.32% (0.42% at 625°C). Continued irradiation of the specimens produces the family of curves shown. Thus, it appears that there is an increase of 0.1 - 0.2% in the available strain before fracture in samples strained during irradiation.

It has been demonstrated by these tests that graphite during irradiation will strain considerably more before fracture than in the absence of irradiation. This increased strain to fracture indicates a marked change in the plastic behavior of graphite in an irradiation field. In order to check this effect, sample Number 11, that had a strain of 0.42% at temperature, was removed from the strain assembly. In this unstressed condition, the sample had a measured permanent set of 0.23%, which indicates an increase in plastic strain of at least 0.2% when compared to the maximum permanent set of about 0.02% in laboratory tests.

It should be pointed out that the strain accumulated before fracture in each sample should not be considered a strain limit.

The amount of strain in the specimen is produced by the applied strain but is also a measure of the irradiation induced plasticity. As shown in Figure 2, the strain rate produced by the assembly is linear, indicating that any irradiation hardening that occurs is not sufficient to interfere with the irradiation induced plasticity, otherwise the strain rate would slowly decrease for each assembly as the dose increased. If all the stress, which is generated in response to the applied strain, were relieved then the specimen would strain

at the imposed strain rate without failing. Since the samples do fail, the stress is obviously increasing in the specimen at a faster rate than it is being relieved and eventually the specimen reaches a stress limit.

Lower mechanical strain rates that approach the irradiation induced creep rates should permit the accumulated stress to remain below the rupture stress of the specimen for a longer period of time and provide a greater total strain before fracture. From a practical point of view, this can only be accomplished in a reasonable period of time by irradiating specimens in higher neutron fluxes at lower strain rates.

Figure 3 is a plot of the unstressed contraction of both the carbon used for the straining piece and the graphite used for the end piece and main body tube. The strain rates shown in Figure 2 are considerably less than that one would predict from the contraction rate of unstressed carbon. Obviously the contraction rate of carbon under stress is different or the main-body cylinder of the strain assembly is compressed. Either or both processes are possible since we know that graphite contracts less under a tensile stress^(2,3,4) and more under a compressive stress.⁽⁸⁾

Further tests are in progress on parallel samples at lower strain rates and on samples taken transverse to the extrusion direction.

CONCLUSIONS

Graphite tensile specimens simultaneously subjected to stress and neutron irradiation exhibited from 0.1 to 0.2% more strain at failure than samples subjected to stress alone. This increase in available strain, as compared to that found in the absence of irradiation, should relieve some of the radiation induced differential stress predicted for large graphite core pieces.

ACKNOWLEDGEMENT

The author is indebted to Dr. H. H. Yoshikawa for the original idea for such a test and W. E. Hart for his excellent technical assistance.

REFERENCES

1. Hulbert, L. E. and Redmond, R. F., "Numerical Results for EGCR Moderator Element Stress Problems," BMI-1526 (1961).
2. Losty, H. H. W., et al., "The Irradiation Induced Plasticity of Graphite," Proc. Fifth Carbon Conference, Vol. 1, Pergamon Press (1962), pp. 266-273.
3. Perks, A. J. and Simmons, J. H. W., "Radiation-Induced Creep in Graphite," Carbon, 1, pp. 441-449 (1964).
4. Jackson, J. L., USAEC Report HW-SA-3592, to be published.
5. Eatherly, W. P. and Piper, E. L., "Manufacture" in Nuclear Graphite (Nightingale, R. E., ed.) Academic Press, New York (1962), pp. 21-51.
6. Jackson, J. L., USAEC Report HW-SA-3737, to be published in Carbon.
7. Dahl, R. E. and Yoshikawa, H. H., "Neutron-Spectra Calculations for Radiation-Damage Studies," Nucl. Sci. Eng., 17, pp. 398-402 (1963).
8. Morgan, W. C., "Effect of Low Compressive Stresses on Radiation-Induced Dimensional Changes in Graphite," Carbon, 1, pp. 255-261 (1964).

DRIVING EDGE

BO-7320-001

AEC OF RICHLAND WASH

-8-

FIGURE 1

Sectional View of the Irradiation-Activated Strain Device

BN-SA-56

FIGURE 2

Specimen Strain vs Exposure

FIGURE 3

Component Length Changes vs Exposure