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EFFECT OF NEUTRON IRRADIATION ON MATERIALS
SUBJECTED TO MULTIAXIAL STRESS DISTRIBUTIONS

QUARTERLY PROGRESS REPORT
FOR THE PERIOD APRIL 1 THROUGH JUNE 30, 1963

Contract AT(04-3)-167
Project Agreement No. 13
U.S. Atomic Energy Commission

August, 1963

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GENERAL ATOMIC
DIVISION OF
GENERAL DYNAMICS

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PREVIOUS REPORTS IN THIS SERIES

GA-3410—April, May, June, 1962

GA-3724—July, August, September, 1962

GA-3882—October, November, December, 1962,
January, 1963

GA-4287—Annual Summary Report, April, 1962,
through March, 1963

INTRODUCTION

The primary program objective is to determine the effect of irradiation on tubes subjected to multiaxial stress distribution, and the manner in which irradiation affects the use of a flow parameter to correlate tensile data with those on other stress distributions. A detailed description of the program is presented in the annual summary report (GA-4287).

MATERIAL AND IRRADIATION

A block of A-302B steel with a well-known past history was cut to ASTM standards, and specimens were machined to ASTM designations where applicable. Composition, treatment, and other details are discussed in GA-4287. Irradiation was in the Engineering Test Reactor (Idaho Falls) to doses of 6.6×10^{18} to 190×10^{18} nvt (fast). Capsule details and dosimetry information are given in GA-4287.

EXPERIMENTAL PROGRAM

Charpy Impact Tests

Tests have been completed for the dose range 3.2 to 8.3×10^{18} nvt, and results are reported in GA-4287. Out-of-cell handling of Charpy specimens which have received a dose of $\sim 1 \times 10^{20}$ nvt is believed feasible. Since these specimens have a high activity (45 r at 12 in.), some modification of previous techniques must be made. Only a limited number (approximately 6) will be handled.

Tensile Tests

Tensile tests have been completed on all specimens which can be handled out of cell. The dose range covered was 6.5×10^{18} to 13.3×10^{18} nvt at temperatures of 0° , 66° , and 149°C (Fig. 1). The most obvious

Fig. 1--True stress-true strain curves for irradiated A-302B steel (irradiation expressed in units of 10^{18} nvt fast)

effects of irradiation are to decrease the uniform strain and to increase the yield point. A very important effect is that strain hardening was decreased over nonirradiated values at all test temperatures. At 0°C and 66°C in the material receiving over 10×10^{18} nvt, yielding is followed by plastic flow and necking at a stress level below that necessary to produce yielding. Thus, under this combination of dose and ambient temperature, any localized stress exceeding the yield point would cause immediate failure. The variation in yield-point shift with dose and test temperature is given in Fig. 2. A 25°C temperature curve was obtained by interpolation for the purpose of comparing the results of this investigation with earlier work. Cottrell⁽¹⁾ found a dependence of yield-point shift of the form:

$$\Delta\sigma_y = A(\phi t)^n,$$

where $\Delta\sigma_y$ = shift in yield point (in kg/mm²),

A = constant (includes grain-size effect),

ϕt = dose ($\times 10^{18}$ nvt),

$n = \sim 1/3$.

A better fit of the data was obtained with $n = 0.42$, but the data were not considered accurate enough to warrant a change from the usual one-third exponent. The material involved was a mild steel irradiated below 100°C. Nichols and Harries⁽²⁾ found with a similar material that a better fit of their data was obtained with $n = 1/2$. Analysis of the data of this investigation results in a best fit of

$$\Delta\sigma_y = 9.5 (\phi t)^{0.45},$$

where (ϕt) is in units of 10^{18} nvt fast neutrons. Previous work^(1, 2) had indicated a possible saturation effect above 5×10^{18} to 10×10^{18} nvt, but no saturation effect of $\Delta\sigma_y$ with increasing dose is apparent up to a fast-neutron dose of 13.3×10^{18} nvt, which is the highest dose tested.

Fig. 2--Increase in yield point versus integrated fast-neutron dose

Notched Tensile Tests

Standard ASTM E23-60 notched tensile specimens were tested to failure at 0° , 66° , and 149°C . The ultimate tensile strength (maximum load divided by original area at the notch) is presented as a function of test temperature in Fig. 3. Owing to differences in testing-machine characteristics, the nonirradiated specimens were tested at strain rates of 0.002/min, while the irradiated specimens were tested at 0.02/min (one exception being tested at 0.0002/min). With the strain-rate dependence established, the data for the nonirradiated specimens were corrected to a strain rate of 0.02/min. The increase in ultimate tensile stress ranged from 12 kg/mm^2 at 149°C to 18.5 kg/mm^2 at 0°C for a dose of 8.4×10^{18} nvt and from 18 kg/mm^2 at 149°C to 33.5 kg/mm^2 at 0°C for a dose of 14.3×10^{18} nvt. The use of the Bridgeman technique to determine true stress under triaxial loading for comparison with standard tensile specimens loaded uniaxially was not attempted owing to the difficulty of photographic recording in a radiation field.

Biaxial Tests

Specimen-handling techniques are being developed and equipment is being prepared for biaxial tests on nonirradiated specimens utilizing radial- and axial-strain measuring devices. Biaxial testing was deferred until experience was gained in handling irradiated tensile specimens which have a similar configuration. Of particular importance is the pacing of internal pressure rise to the rise in axial load. The axial load will be controlled by the constant head motion of the testing machine and the flow properties of the specimen. The internal pressure will be adjusted by manual flow-control valves to a previously determined function of the axial load.

Fig. 3--Effect of notch and dose on ultimate tensile strength

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2. Nichols, R. W., and D. R. Harries, Brittle Fracture and Irradiation Effects in Ferritic Pressure Vessel Steels, United Kingdom Atomic Energy Authority Paper 114, 1962.