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LETTERS TO THE EDITORS

Dimensional Stability of Uranium-Chromium Alloys[1]

Limited additions of chromium are known to have a marked effect on the mechanical properties of unirradiated uranium; however, little is known about the dimensional stability of such alloys when irradiated in a preferredly oriented condition. This study was made to evaluate the effect of various additions of chromium from 0 to 1 atomic per cent, covering the solid solubility region of chromium in alpha uranium at room temperature. The experiment was designed to hold grain size and type and degree of preferred orientation constant while varying the chromium content with concomitant changes in the tensile properties.

The alloys were vacuum induction melted in stabilized zirconia crucibles and cast into a magnesia-washed graphite mold. The ingots were heated in a molten salt (425° to 450°C), then rolled in diamond-pass rolls to $\frac{1}{2}$ in. sq rod. The as-rolled $\frac{1}{2}$ in. sq rods were heated to 570°C in a salt bath to permit straightening, then held at 575°C for 2 hr to recrystallize, after which they were water quenched.

Two ingots, one unalloyed uranium and the other a uranium–0.90 atomic per cent chromium alloy, were fabricated under different conditions. The rolling temperatures of these two alloys were 415°C and 465°C, respectively. Uranium rolled at 415°C should have a higher preferred orientation than uranium rolled at 450°C; likewise, a rolling temperature of 465°C should produce less preferred orientation than a temperature of 450°C in a uranium-chromium alloy containing approximately 1.00 atomic per cent chromium. The objective here was to produce a uranium specimen with a preferred orientation approximately the same as that in the uranium–1.00 atomic per cent chromium alloy, and, conversely, a uranium–1.00 atomic per cent chromium alloy with a preferred orientation as low as the normal uranium specimen. In this manner, a separation of the relative effect of preferred orientation and mechanical properties upon dimensional stability might be effected.

The properties of these alloys were determined by chemical, metallographic, mechanical, x-ray and dilatometric measurements. Significant properties are summarized in Table I. The orientation measurements were made by the so-called "rho" method developed at Hanford Atomic Products Operation which consists of measuring peak heights of specific planes in a randomly oriented control and in the test specimen. The ratio of test to control for any plane is the "rho" value.

The significant "rho" values are the (020) and (040) since preferred orientation of these planes results in growth. A high (020) rho value in a surface normal to the longitudinal axis usually indicates the specimen will grow along the longitudinal axis when irradiated. The size of a "rho" value is indicative of the degree of growth in uranium; but no definite conclusion can be advanced unless all "rho" values are considered, because of possible interactions.

An examination of the data indicates that the basic variables of grain size and preferred orientation were reasonably well controlled. There is a pronounced duplex grain size in the

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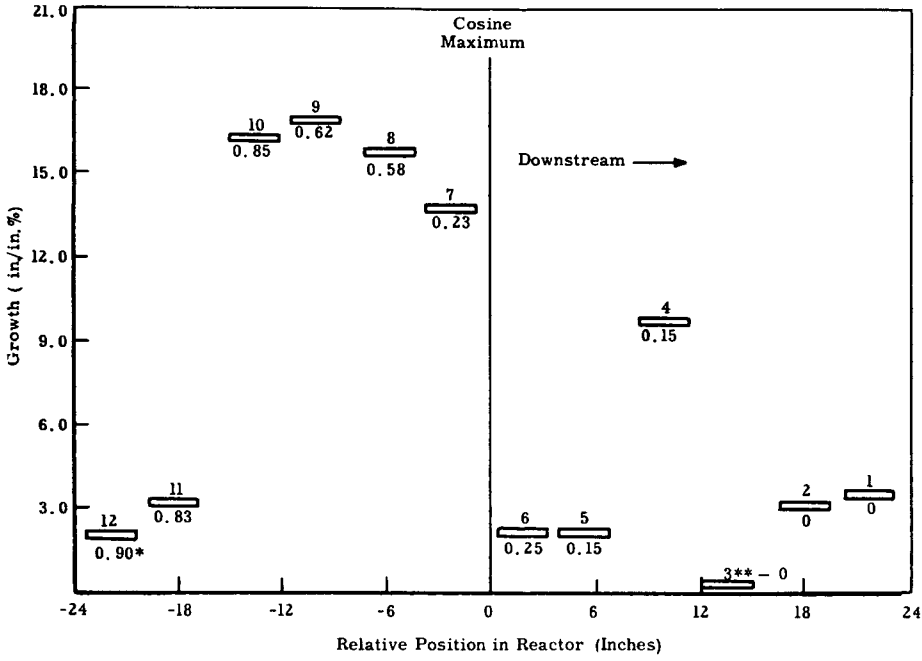

FIG. 1. Specimen growth versus relative in-reactor position. Asterisk indicates atomic per cent chromium; double asterisk, beta-heat-treated.

alloyed uranium rolled at about 450°C; otherwise the grain sizes are consistently in the range 0.015 to 0.030 mm.

Cylindrical specimens previously used for dilatometry were irradiated in a Hanford reactor. Exposures, estimated to be accurate to 15–20 per cent, are given in Table I which contains significant exposure and dimensional instability data.

Examination of the post-irradiation results given in Table I reveals that there are limited differences in burnup, probably due to a cosine flux distribution. Those specimens near the maximum in the flux distribution have somewhat higher burnups than those some distance from the maximum. Due to the limited changes in burnup from specimen to specimen, it does not appear possible to ascribe observed differences in growth to differences in exposure.

The irradiated specimens with some degree of preferred orientation were remarkably free from surface roughening. The only exception observed was the specimen inadvertently beta-heat-treated during the dilatometry test. Pronounced bumping was observed in this instance. Longitudinal striae were observed in those specimens which grew substantially. All specimens except the beta-heat-treated were warped; in some cases the warping was limited; in others it was very severe.

An examination of the changes in dimensions of the specimens discloses that all preferredly oriented samples increased in length and decreased in diameter. The greatest increases in length were accompanied by the most marked decreases in diameter. This is expected since there should be limited changes in volume at the burnup and irradiation temperatures experienced by these specimens. Obviously there is some error in measurements due to the warping; however, the changes observed are too large to be ascribed to warping alone.

The possible interrelation among the variables composition, flux and growth is shown in

TABLE I

PRE- AND POST-IRRADIATION PROPERTIES OF URANIUM AND U-CR ALLOYS

Specimen	Chromium atomic per cent	Grain size, mm	Ultimate tensile strength, 1000 psi	Elongation, per cent	Rho values orientation (020)	(040)	(041)	(130)	(131)	Coefficient of thermal expansion $\times 10^{-6}$	Approximate burnup, per cent	Average per cent change in length	Average per cent change in diameter	Remarks
UC1[a]	0.0	0.015–0.020	105.7	11	2.3	1.5	1.2	2.7	1.9	3.67	0.032	+3.4	−1.8	Surface smooth; warped in longitudinal plane bisecting contact points in inserts.
UC2	0.0	0.015–0.062	114.9	10	4.1	2.7	1.5	3.9	1.4	4.19	0.032	3.1	−1.3	Surface smooth; warped.
UC3[b]	0.0	0.015–0.062	114.9	10	3.0	2.0	1.3	2.9	1.8	4.20	0.032	+0.3	+0.2	Surface bumpy; no warping.
UC4	0.15	0.015–0.020	114.7	7	2.4	1.7	1.2	3.7	1.8	3.91	0.032	10.8	−4.3	Surface smooth; warped.
UC5	0.15	0.015–0.020	114.7	7	3.1	2.1	1.4	4.4	2.0	3.73	0.032	2.2	−1.7	Surface smooth; warped.
UC6	0.25	0.015	125.3	5	2.9	1.7	1.2	5.5	2.3	3.17	0.032	2.2	−0.86	Surface smooth; warped in longitudinal plane bisecting contact points in inserts.
UC7	0.23	0.015–0.020	125.3	5	3.3	1.8	1.3	5.4	2.3	2.93	0.032	13.9	−6.1	Surface smooth; badly warped.
UC8	0.58	0.020–0.033	133.3	6	4.8	2.9	2.0	4.0	1.6	1.65	0.032	15.9	−4.7	Surface longitudinal ridges and valleys full length of specimen; badly warped.
UC9	0.62	0.015–0.020	133.3	6	4.1	2.4	1.8	4.8	1.9	3.02	0.032	16.8	−6.9	Surface smooth; badly warped.
UC10	0.85	0.020	132.8	6	3.8	2.0	1.3	3.8	1.3	2.53	0.032	16.4	−5.8	Surface striated; badly warped.
UC11	0.83	0.020–0.33	132.8	6	3.8	2.4	1.4	4.1	1.4	2.86	0.031	3.2	−0.65	Surface smooth; warped in plane bisecting contact points in inserts.
UC12[c]	0.90	0.020–0.33	134.3	4	4.0	2.3	1.6	3.6	1.6	1.92	0.031	2.0	−0.43	Surface smooth; warped.

[a] Uranium alloy which was rolled at 415°C.

[b] The specimen intended for irradiation was inadvertently beta-heat-treated during the dilatometry test so it is actually randomly oriented.

[c] Uranium–0.90 atomic per cent chromium alloy which was rolled at 465°C.

Fig. 1. Conceivably the lower values of specimens 1, 2, 11 and 12 can be accounted for on the basis of lower flux and lower burnup. If so, these specimens indicate that alloy content has little effect on growth rate.

Results of the experiment are inconclusive insofar as correlating chromium level, orientation, or mechanical or physical properties with irradiation induced dimensional instability. All preferredly oriented specimens increased in length; these increases ranged from 2 to 17 per cent. Nominal to relatively severe warping was observed. The surfaces of the preferredly oriented specimens were consistently smooth. Chromium additions do not appear to improve dimensional stability. Because of inaccuracies in flux measurements, it cannot be concluded that such additions have a deleterious effect on stability.

It is possible that limited changes in orientation, specimen temperature, flux level or, conceivably, composition have much more marked effects than anticipated. If this is the case, substantially more work must be done in controlling these variables. Pole figure X-ray data rather than "rho" values should be used; a more precise measurement of flux is required; and differences in flux level must be minimized. Only through such control will it be possible validly to evaluate composition effects.

Obviously, on the basis of the results obtained it is futile to advance a mechanism to explain the growth. The experiment was not sufficiently controlled to explain the results by twinning, diffusion or dislocation mechanisms.

Hanford Laboratories Operation
General Electric Company
Richland, Washington
M. C. FRASER
G. A. LAST
S. H. BUSH
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High Flux Reactors

The need for intense neutron sources for nuclear research has led to the construction of a large number of research reactors both in the United States and abroad. Several of the older reactors such as Bepo and the Brookhaven National Laboratory reactor are still in constant use, their low power density being compensated by large working volume and ease of operation. The swing in the opposite direction which started with the MTR concept has produced a number of small, high power density reactors used for both basic and applied research. Experience with the MTR has shown the need for greater working volume for engineering research. Only where the size of experimental equipment can be drastically limited can volume be sacrificed for higher flux. Thus, restrictions on volume can still be tolerated in a reactor designed exclusively for specified basic research experiments.

Criteria for the design of research reactors vary with energy spectrum requirements. Access to the fission spectrum in the reactor core is desirable for solid state physics experiments and here power density is the prime criterion. At lower energies, the strength of the neutron flux depends upon the ratio of power density to the slowing down power of the core. In a choice between equal coolants such as D_2O or H_2O, D_2O would obviously be the one chosen in this case.

The thermal neutron flux in a small reactor is that available in the reflector, since access to the core is difficult. The intensity of the thermal flux in the reflector depends primarily on the power output of the core. The choice of reflector is governed by core size. Ordinary water yields the greatest flux peak for neutron sources up to several inches in diameter but