DPST-63-74-10

HYDRIDE ORIENTATIONS AND MECHANICAL PROPERTIES OF THIN-WALLED ZIRCALOY TUBING

USAEC-AECL COOPERATIVE PROGRAM

MONTHLY PROGRESS REPORT

OCTOBER 1963

by

R. P. Marshall
Pile Materials Division

Issue Date: December 1963

This document is furnished pursuant to the Memorandum of Understanding of June 7, 1960, between the U. S. and Canadian Governments establishing a Cooperative Program on the development of heavy water moderated power reactors.

E. I. du Pont de Nemours & Co.
Explosives Department - Atomic Energy Division
Technical Division - Savannah River Laboratory
Aiken, South Carolina

Contract AT(07-2)-1 with the
United States Atomic Energy Commission

HYDRIDE ORIENTATIONS AND MECHANICAL PROPERTIES OF THIN-WALLED ZIRCALOY TUBING

USAEC-AECL COOPERATIVE PROGRAM

MONTHLY PROGRESS REPORT*

OCTOBER 1963

INTRODUCTION

Additional study of the orientation of zirconium hydride platelets in thin-walled Zircaloy tubing is being sponsored at the Savannah River Laboratory (SRL) by the Technical Advisory Committee of the USAEC-AECL Cooperative Program. The SRL study will first define the relationship of the fabrication techniques and associated Zircaloy structures to the susceptibility of the tubing to preferred hydride orientations. Second, the work will assess qualitatively the effects of oriented hydride platelets on the mechanical behavior of tubes under several stress conditions. The various types of tubing being used in this program are described in Table I.

SUMMARY OF PREVIOUS WORK

Tests on circumferential specimens of the six types of tubing have shown that the susceptibility to stress orientation of the hydride platelets varied widely between tubing from different fabrication processes and, in one case, between tubing made by different vendors using nominally the same process. Roll-formed tubing (A) was least susceptible and as-extruded (D) or drawn tubing (E) was most susceptible; tube-reduced tubing (B, C, and F) varied widely. The structural factor in the Zircaloy that controls the susceptibility has not been defined, but tubing with similar textures, which were estimated mainly from the anisotropic strain behavior during tensile tests, have shown different susceptibilities to stress orientation of the hydrides.

* The reports in this program are documented as the DPST-(year)-74-(month) series. The first report covered the work in June 1963 and was published as DPST-63-74-6.

SUMMARY OF LATEST WORK

Tests at applied stresses of 26,000 psi showed that longitudinal specimens of the six types of tubing were not susceptible to stress orientation of the hydride platelets.

Study of grain structure and hydride morphology in circumferential specimens indicated that the magnitude of the stress orientation susceptibility may have been influenced by the Zircaloy grain size. The tendency of the platelets to form into "clusters" (heterogeneous nucleation) was increased by higher stress levels and slower cooling rates in some types of tubing but not in others.

DISCUSSION

Longitudinal Specimens

Longitudinal specimens of the six types of tubing exhibited no difference in hydride platelet orientation after cooling under applied stresses of zero or 26,000 psi, Table I. The predominant orientation of the platelets varied depending upon fabrication method of the tubing, with roll-formed (A) and as-extruded (D) tubing exhibiting virtually all platelets oriented circumferentially. The absence of the stress orientation effect in these specimens with 50 ppm hydrogen was in marked contrast to the highly varying susceptibility to stress orientation in circumferential specimens of the same tubing.

Circumferential Specimens

Study of the influences of microstructural factors on hydride orientation was initiated with the examination on circumferential specimens of the relationships between Zircaloy grain size and two aspects of hydride morphology, the distribution and the orientation of the hydrides. The size and shape of the Zircaloy grains were measured by the lineal intercept method and the Mean Planar Grain Diameter was calculated from these data. The plane of observation in these determinations with circumferential specimens was the transverse plane of the tubing, i.e., the plane on which rotation of the hydride platelets was observed during stress orientation. Grain shape was estimated by orienting two lines for counting in a radial direction, two lines in the circumferential direction, and three lines in random directions. Only tubing A exhibited an elongated grain shape, with grains averaging 8 microns long in the circumferential direction and 5 microns wide in the radial direction. The Mean Planar Grain Diameter (MPGD), determined by combining the data from the seven scans just described, varied by a factor of ten in the different tubing (Table II).

Two measures of the susceptibility to stress orientation were used to describe the degree of stress orientation shown by the circumferential specimens. One was the change in the fraction of perpendicular platelets caused by applied stresses of zero and 30,000 psi, $\Delta f_{N(30-0)}$; the second was the value of f_N at 30,000 psi, $f_{N(30)}$. The f_N data were taken from the f_N vs. stress graphs published in last month's report, DPST-63-74-9. The two stress orientation parameters for the different tubing are given in Table II.

Plots of MPGD versus the two correlating parameters for stress orientation are shown in Figure 1. The susceptibility to stress orientation of the hydride platelets was influenced significantly by the grain size of the Zircaloy. The stress orientation susceptibility increased with decreasing grain size. This influence of matrix grain size may actually be related to the number and orientation of the grain boundaries and emphasizes the need for the determination of the location of the hydride platelets within the matrix (intergranular, intragranular, etc.) This study will be undertaken at the earliest opportunity.

The effect of stress level and cooling rate during hydride precipitation on the tendency of the hydrides to form clusters of platelets, i.e., heterogeneous nucleations on a macro scale, was also examined. This effect was briefly discussed in an earlier report, DPST-63-74-8, in regard to the long "chains" of platelets that traversed almost the entire width of tubing D; a photomicrograph of this effect was shown in that report. For analytical purposes, a cluster was defined as a group of platelets in close proximity, without regard to platelet orientation, where the distance between platelets in a cluster was noticeably less than distance to other platelets (or clusters). Thus, the definition "cluster" includes the long chains of platelets, as well as the close association of random platelets. The "average" and "largest" number of platelets in a cluster were estimated by counting a number of examples from each specimen. Typical examples of the data and observed behavior for several sets of tubing specimens are given in Table III.

Analyses of the cluster-size data indicated that in some of the tubing the number of platelets in a cluster (cluster size) was increased by higher stresses and in some of the tubing the cluster size was increased by lower cooling rates. These effects of stress and cooling rate occurred independently of each other, such that some tubing exhibited one effect, some both effects, and some neither effect. The tendency of the platelets to form clusters could not be related to any of the matrix properties, such as grain structure, estimated texture, or susceptibility to stress orientation. Refined techniques or specially designed experiments will be necessary for the development of quantitative information in this area.

FUTURE PROGRAM

Experimental work on this program will be suspended for about two months; in the interim, the measurements of Zircaloy texture by X-ray diffraction will be completed. The experimental work will be resumed in January 1964, with the investigation of the location of the hydride platelets, analyses of the fabrication histories, and correlation of the information developed with the X-ray texture data.

TABLE I

SUMMARY OF STRESS ORIENTATION DATA FOR LONGITUDINAL SPECIMENS

Tubing	Fabrication	Stress, ksi	Orientation of Hydride Platelets[a] f_N	f_{45}	f_p
A	Tube reduced and roll formed	0	.01	.02	.97
		25	.00	.05	.95
B	Tube reduced[b]	0	.10	.17	.73
		28	.10	.15	.75
C	Tube reduced[b]	0	.07	.23	.70
		26	.06	.19	.75
D	Extruded	0	.01	.01	.98
		24	.00	.00	1.00
E	Drawn	0	.05	.12	.83
		26	.04	.10	.86
F	Swaged and tube reduced	0	.09	.27	.64
		28	.10	.27	.63

[a] f_N = fraction of platelets normal to stress axis
f_{45} = fraction of platelets near 45° to stress axis
f_p = fraction of platelets parallel to stress axis

[b] Different vendors

TABLE II

SUMMARY OF DATA ON GRAIN STRUCTURE AND HYDRIDE PLATELET MORPHOLOGY FOR CIRCUMFERENTIAL SPECIMENS

Tubing	MPGD[a] microns	Influence on Cluster Size[b]: Effect of Stress	Influence on Cluster Size[b]: Effect of Cooling Rate	Fraction of Platelets Oriented Normal to the Applied Stress[c]: Δf_N, between 0-30,000 psi	Fraction of Platelets Oriented Normal to the Applied Stress[c]: f_N at 30,000 psi
A	6.1	Large	Large	.28	.29
B	5.2	None	Small	.57	.78
C	8.6	None	Large	.46	.63
D	<2	Very large	None	.83	.95
E	9.2	Large	Very small	.55	.80
F	16	None	None	.31	.41

(a) Mean Planar Grain Diameters were measured by lineal analysis.

(b) Examples of the data on cluster size are given in Figure 1 for Tubing A, B, and D. Where there is an indicated effect, increasing stress or decreasing cooling rate increased the cluster size qualitatively as shown.

(c) These f_N data were taken from the graphs of f_N versus stress shown in last month's report, DPST-63-74-9.

TABLE III

SPECIMEN DATA ON HYDRIDE MORPHOLOGY FOR CIRCUMFERENTIAL SPECIMENS

Specimen	Applied Stress, ksi	Cooling Rate[a], °C/hr	Number of Platelets in Cluster: Average	Number of Platelets in Cluster: Largest
AC-3	0	80	3	5
AC-2	12	55	3	5
AC-8	20	38	10	20
AC-6	26	120	6	12
AC-7	34	50	12	20
BC-3	0	80	3	7
BC-2	14	55	3	6
BC-8	19	38	6	10
BC-6	26	120	2	4
BC-7	33	50	3	6
DC-3	0	80	4	9
DC-2	13	55	3	7
DC-8	19	38	10	30
DC-6	26	120	15	40
DC-7	32	50	15	40

(a) The cooling rate given is the average rate between 260 and 200°C, the temperature range in which hydride platelets nucleated.

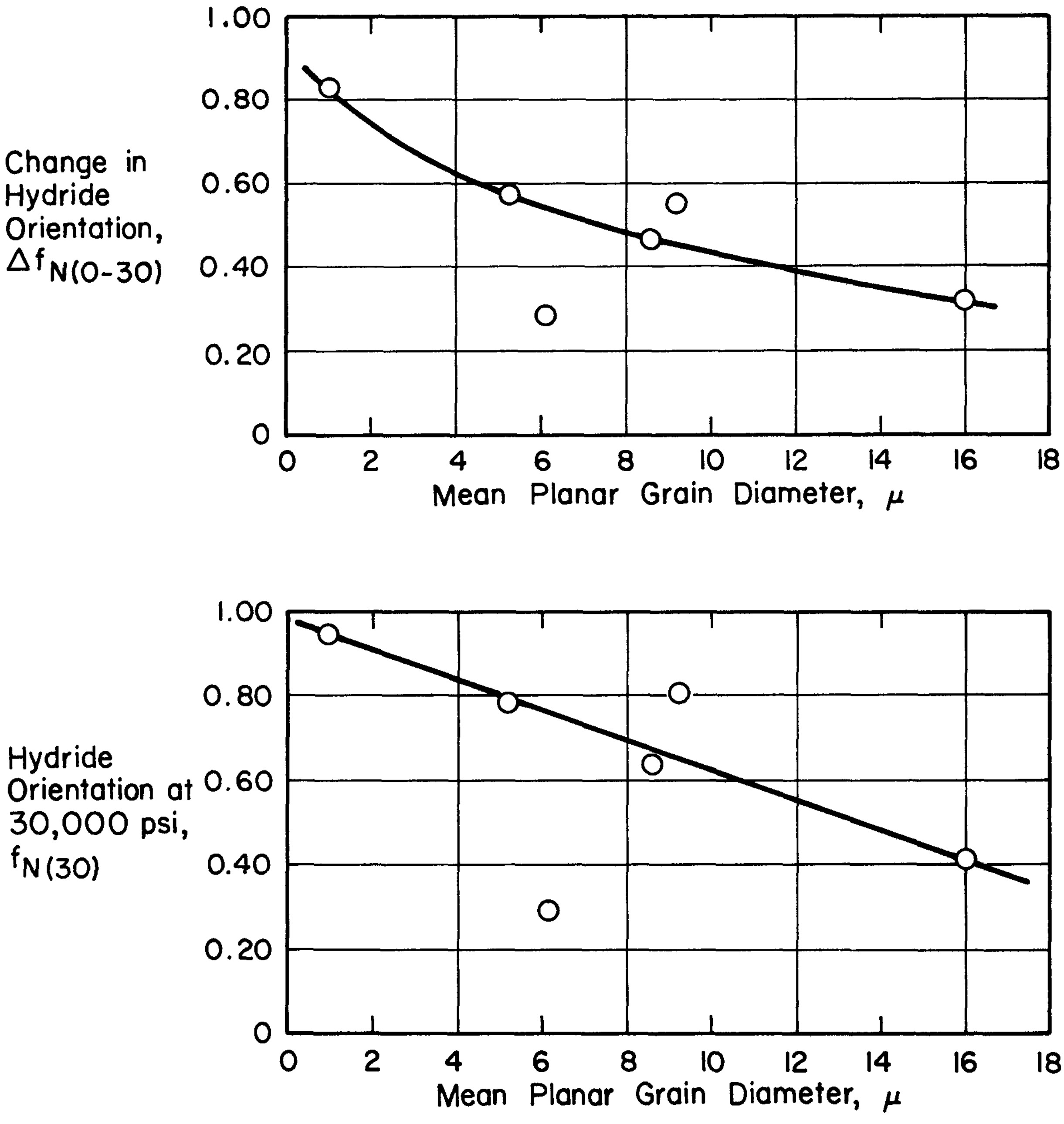

FIG. 1 EFFECT OF GRAIN SIZE ON STRESS ORIENTATION