OAK RIDGE NATIONAL LABORATORY LIBRARIES
3 4456 0549379 3
CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-665

MECHANICAL PROPERTIES OF THE UO_2-TYPE 347 STAINLESS STEEL CERMET FOR CORE B OF THE FERMI REACTOR

J. T. Venard
R. W. Swindeman

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.

NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report. The information is not to be abstracted, reprinted or otherwise given public dissemination without the approval of the ORNL patent branch, Legal and Information Control Department.

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.

ORNL-TM-665

Contract No. W-7405-eng-26

METALS AND CERAMICS DIVISION

MECHANICAL PROPERTIES OF THE UO_2-TYPE 347 STAINLESS STEEL CERMET FOR CORE B OF THE FERMI REACTOR

J. T. Venard and R. W. Swindeman

Date Issued

OCT 24 1963

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U. S. ATOMIC ENERGY COMMISSION

OAK RIDGE NATIONAL LABORATORY LIBRARIES

3 4456 0549379 3

MECHANICAL PROPERTIES OF THE UO_2-TYPE 347 STAINLESS STEEL CERMET FOR CORE B OF THE FERMI REACTOR

J. T. Venard and R. W. Swindeman

ABSTRACT

The mechanical properties of the fuel-bearing portion of the Fermi Reactor Core B fuel element have been investigated. Data are presented on the variation with temperature of elastic modulus, yield strength, tensile strength, and elongation of the UO_2-type 347 stainless steel cermet. Strain-fatigue data at 1150°F, 120 cycles per hour, are also discussed. Typical microstructures before and after test are illustrated and discussed.

INTRODUCTION

During the initial design period of the Fermi Reactor Core B fuel element, it was pointed out that very little information was available on the mechanical properties of a UO_2-type 347 stainless steel dispersion. These same early studies pointed out that the conditions most likely to be met in the element were those of high thermal stress and cyclic loading.

As a result of the above, a variety of tests were performed on simulated fuel plate material containing depleted UO_2. The testing consisted of tensile tests to generate data on elastic modulus, yield and tensile strengths, and ductility vs temperature. Isothermal strain fatigue was also investigated.

SPECIMEN DESIGN AND COMPOSITION

Sheet tensile specimens were taken from fuel plates fabricated by procedures similar to those developed for the Core B fuel element.[1] The fuel plates consisted of 36 wt % spheroidal UO_2 (105–149-μ diam)

[1] J. H. Cherubini, R. J. Beaver, and C. F. Leitten, Jr., Fabrication Development of UO_2-Stainless Steel Composite Fuel Plates for Core B of the Enrico Fermi Fast Breeder Reactor, ORNL-3077 (April 4, 1961).

dispersed in silicon-bearing type 347 stainless steel powder, pressed, sintered, and coined. The resulting cermet was then clad with wrought type 347 stainless steel by a roll-bonding process. The specimens were oriented both parallel and transverse to the plate rolling direction. The sheet specimens were provided with stainless steel pads at the shoulders to minimize yielding at the pinhole. Figure 1 gives sheet specimen dimensions and tolerances.

Strain-fatigue specimens were prepared by brazing a fuel plate section between two stainless steel half rounds and machining to the dimensions shown in Fig. 2.

EQUIPMENT AND PROCEDURE

The elastic modulus vs temperature data were obtained by incrementally loading sheet specimens in a dead-load creep frame. Precision extensometers were attached to the specimen gage portion. The room-temperature dynamic modulus was obtained on an Elastomat.

A Baldwin 12,000-lb testing machine was used for tensile testing.

Strain-fatigue tests were performed in a test frame incorporating a pneumatic valve operator loading system with controlled cycle time and a high magnification extensometer to control the strain limits. This machine is a somewhat modified version of the one used for relaxation testing by Kennedy and Douglas.[2]

In all cases, elevated-temperature tests were performed in resistance-wound furnaces; and, except for the tensile tests, the specimens were protected from oxidation by a blanket of flowing argon.

RESULTS AND CONCLUSIONS

The elastic modulus (E) vs temperature for the UO_2-type 347 stainless steel cermet is plotted in Fig. 3; a similar curve for type 347 stainless steel is given for comparison. A dispersion of 36 wt % UO_2 in type 347 stainless steel results in a structure made up of approximately 30 vol % oxide and 70 vol % stainless steel. This fact, along with the observation from Fig. 3 that a curve corresponding to 80% of E for type

---

[2]C. R. Kennedy and D. A. Douglas, "Relaxation Characteristics of Inconel at Elevated Temperatures," Am. Soc. Testing Mater., Proc. 60 (1961).

UNCLASSIFIED
ORNL-DWG 63-2309

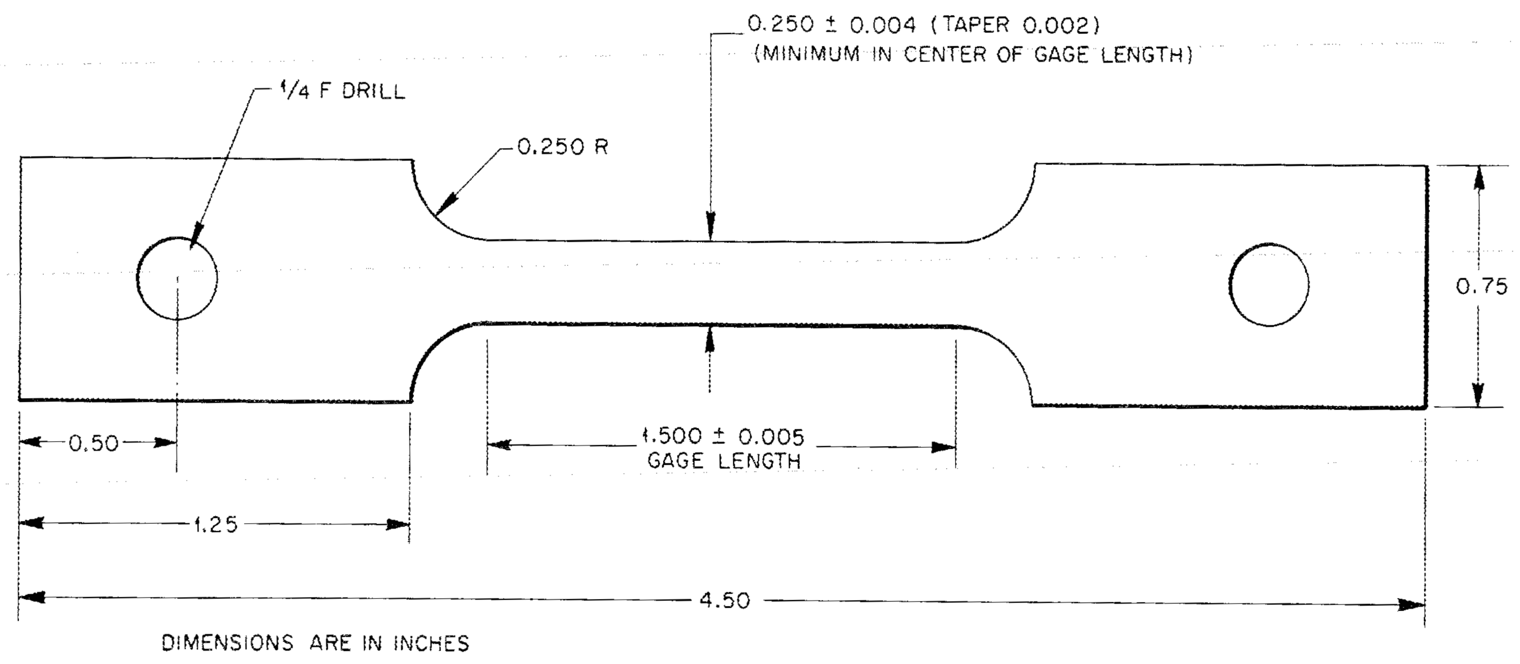


Fig. 1. Type 347 Stainless Steel-UO_2 Tensile Sheet Specimen.

UNCLASSIFIED
Y-39096

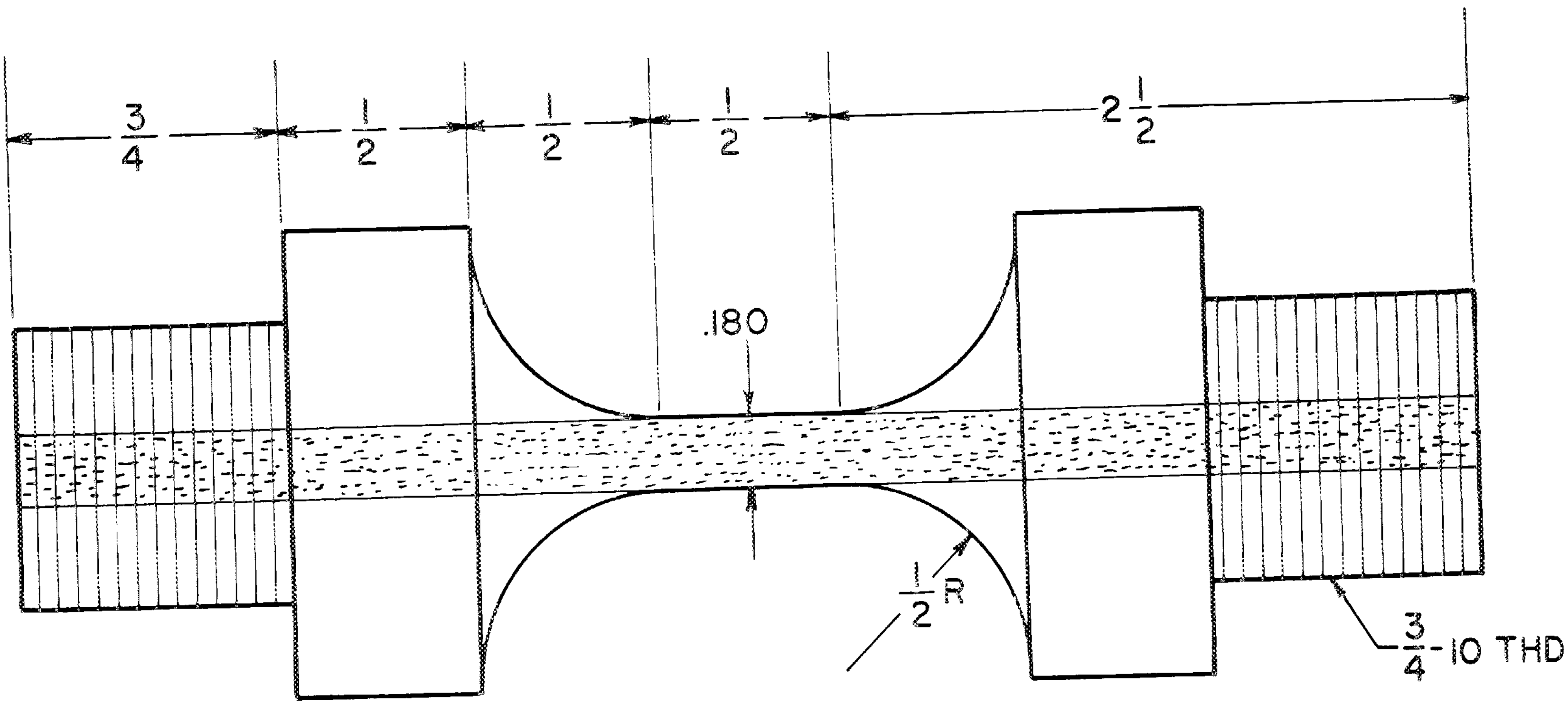


Fig. 2. Type 347 Stainless Steel-UO_2 Fatigue Specimen.

UNCLASSIFIED
ORNL-LR-DWG 70208

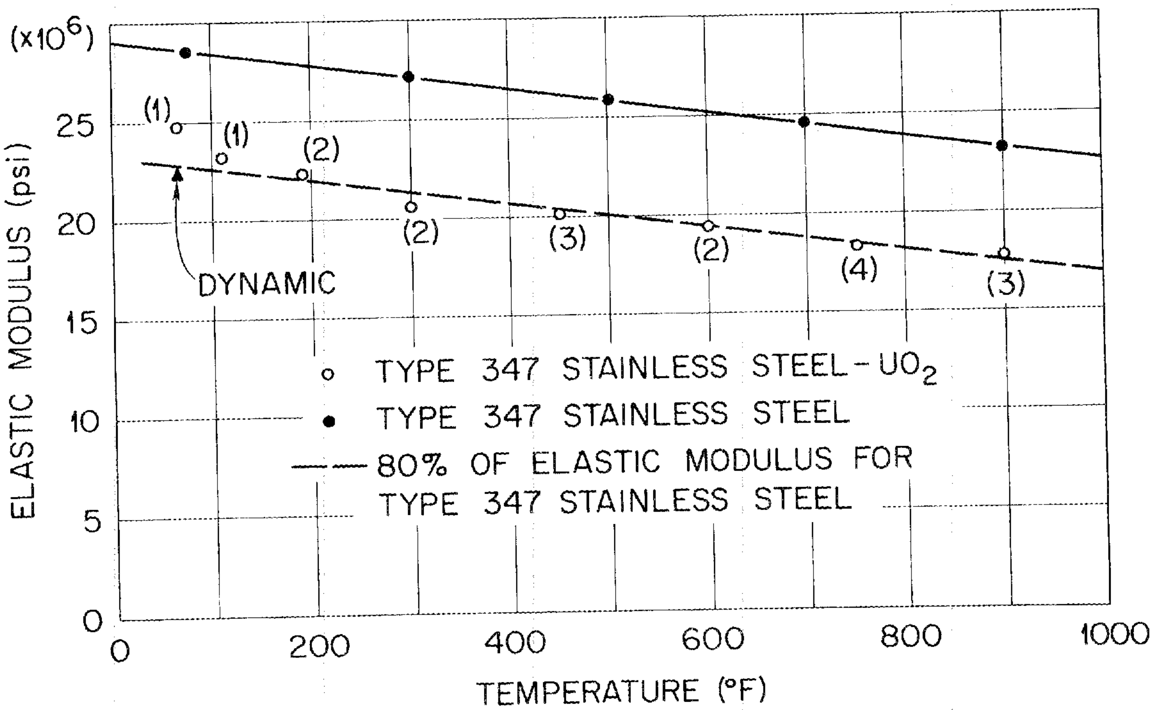


Fig. 3. Elastic Modulus vs Temperature for Type 347 Stainless Steel—36 wt % UO_2 and Type 347 Stainless Steel.

347 stainless steel fits the observed values of E for UO_2-type 347 stainless steel, leads one to believe that the UO_2 offers little contribution to the resistance to elastic loading.

The tensile properties of UO_2-type 347 stainless steel, yield strength, tensile strength, and elongation at fracture are presented graphically in Fig. 4. Values for strength and ductility seem to follow normal trends with temperature. Ductility is quite low at all temperatures.

All tensile data have been tabulated in the Appendix, and Figs. 5–7 present some typical tensile curves.

Figure 8 shows typical photomicrographs of the fuel-bearing structure prior to testing. Figure 9 shows the microstructure of a specimen after tensile testing at 1000°F. By observing the difference in etching behavior of the oxide particles, it is seen that, adjacent to the machined surface, some of the UO_2 has been converted to U_3O_8.

A section taken at the fracture edge of a 1000°F tensile test and a high magnification photomicrograph of an individual particle are given as Fig. 10a and b, respectively. In this case, UO_2 deeper in the specimen was converted to U_3O_8 from oxygen entering at the fracture surface. The inset shows a partially oxidized particle.

Strain-fatigue tests were run at 1150°F and 120 cycles per hour. The results, plotted as stress range vs number of cycles to failure and plastic strain range vs number of cycles to failure, are shown in Figs. 11 and 12. Also shown on these curves are strain-fatigue results for type 347 stainless steel and UO_2-type 347 stainless steel dispersions taken from the literature.[3,4] Two specimens, the results for which are not included in the figures, failed by buckling due to specimen instability.

---

[3]E. E. Baldwin, G. J. Sokol, and L. F. Coffin, Jr., "Cyclic Strain Fatigue Studies on AISI Type 347 Stainless Steel," Am. Soc. Testing Mater., Proc. 57, 567–81 (1957).

[4]W. D. Valovage and R. A. Siergiej, Mechanical Properties of Stainless Steel-UO_2 Dispersion Fuel Elements, KAPL-1590 (July 7, 1959).

UNCLASSIFIED
ORNL-LR-DWG 70209

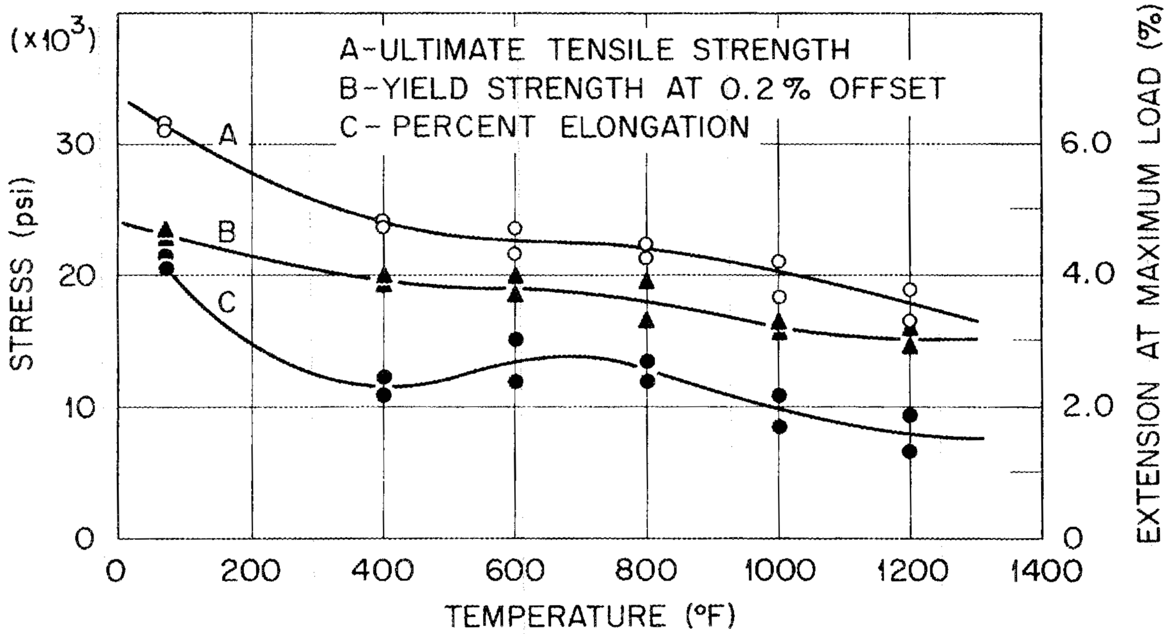


Fig. 4. Tensile Properties vs Temperature for Type 347 Stainless Steel—36 wt % UO_2.

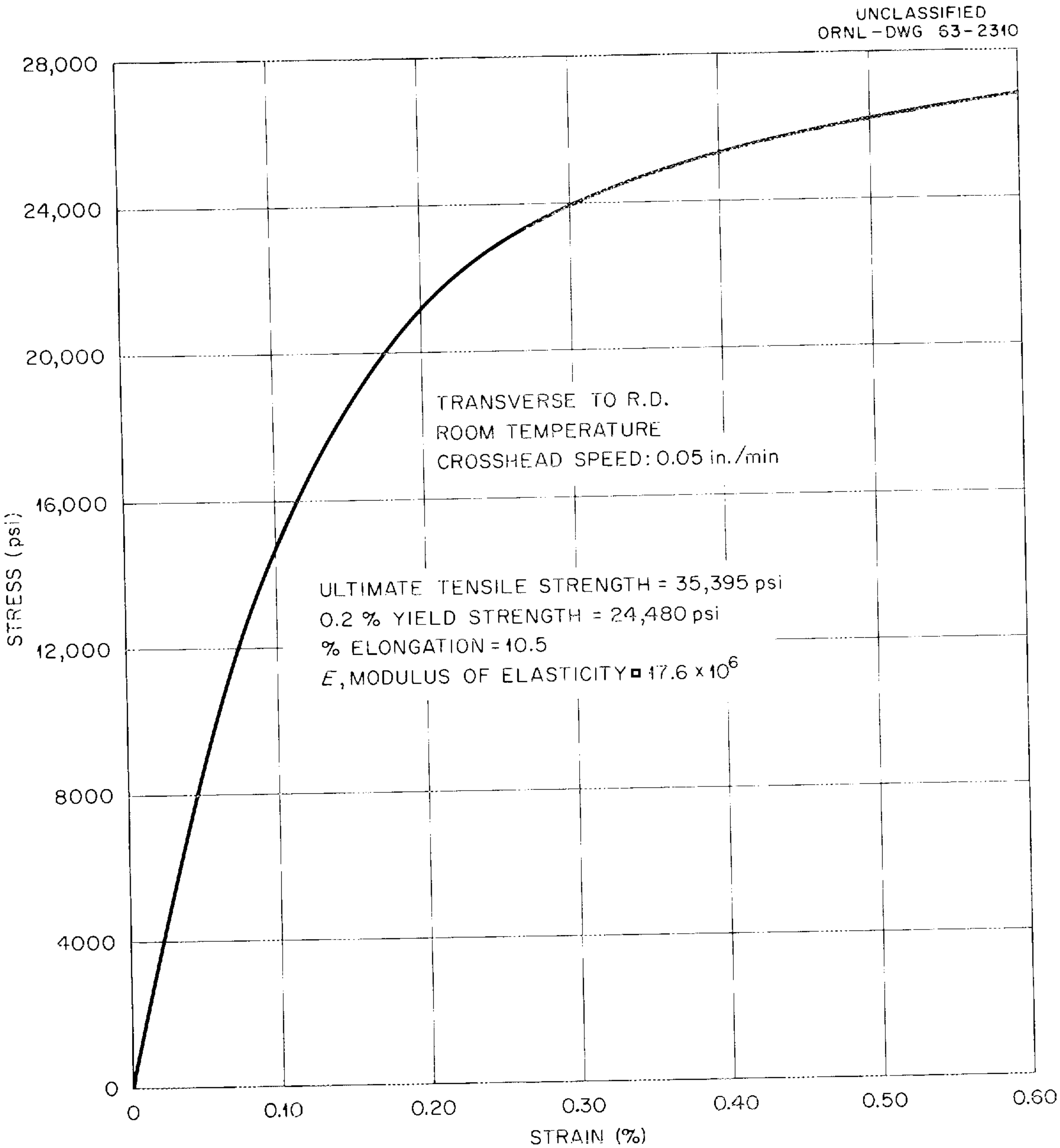


Fig. 5. Typical Tensile Curve 36 wt % UO_2–Type 347 Stainless Steel Cermet.

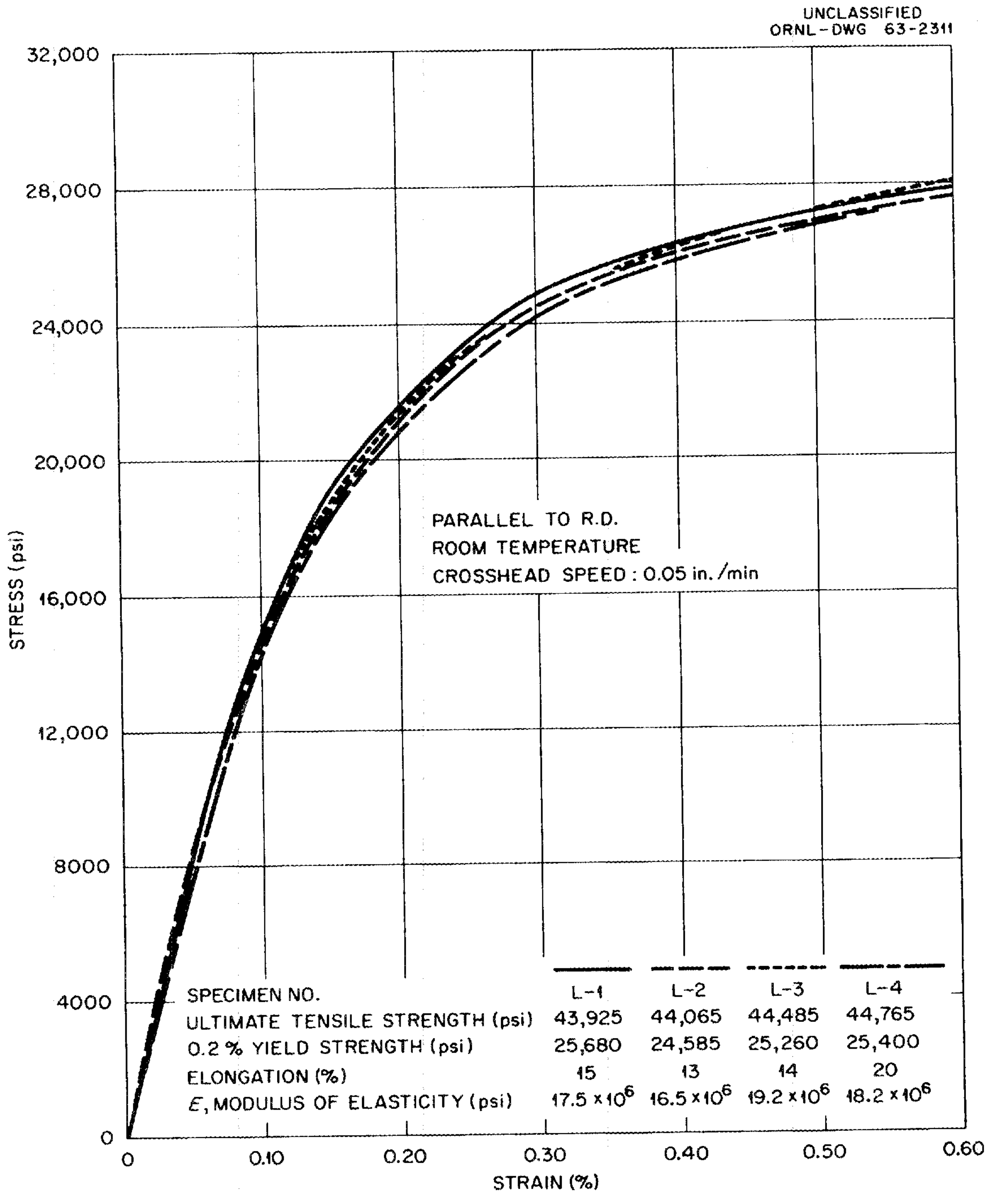


Fig. 6. Typical Tensile Curves 36 wt % UO_2—Type 347 Stainless Steel Cermet.

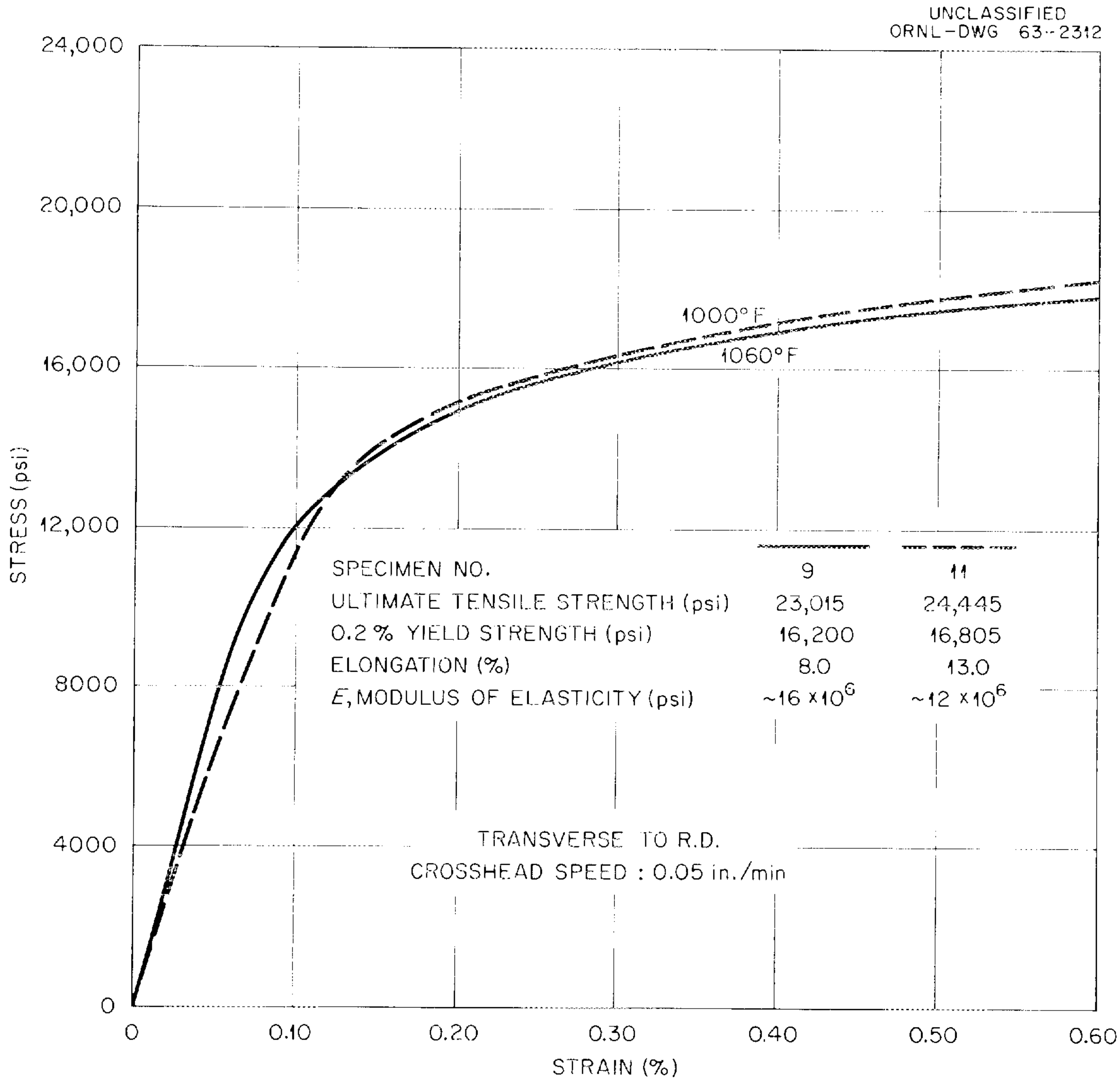


Fig. 7. Typical Tensile Curves 36 wt % UO_2—Type 347 Stainless Steel Cermet.

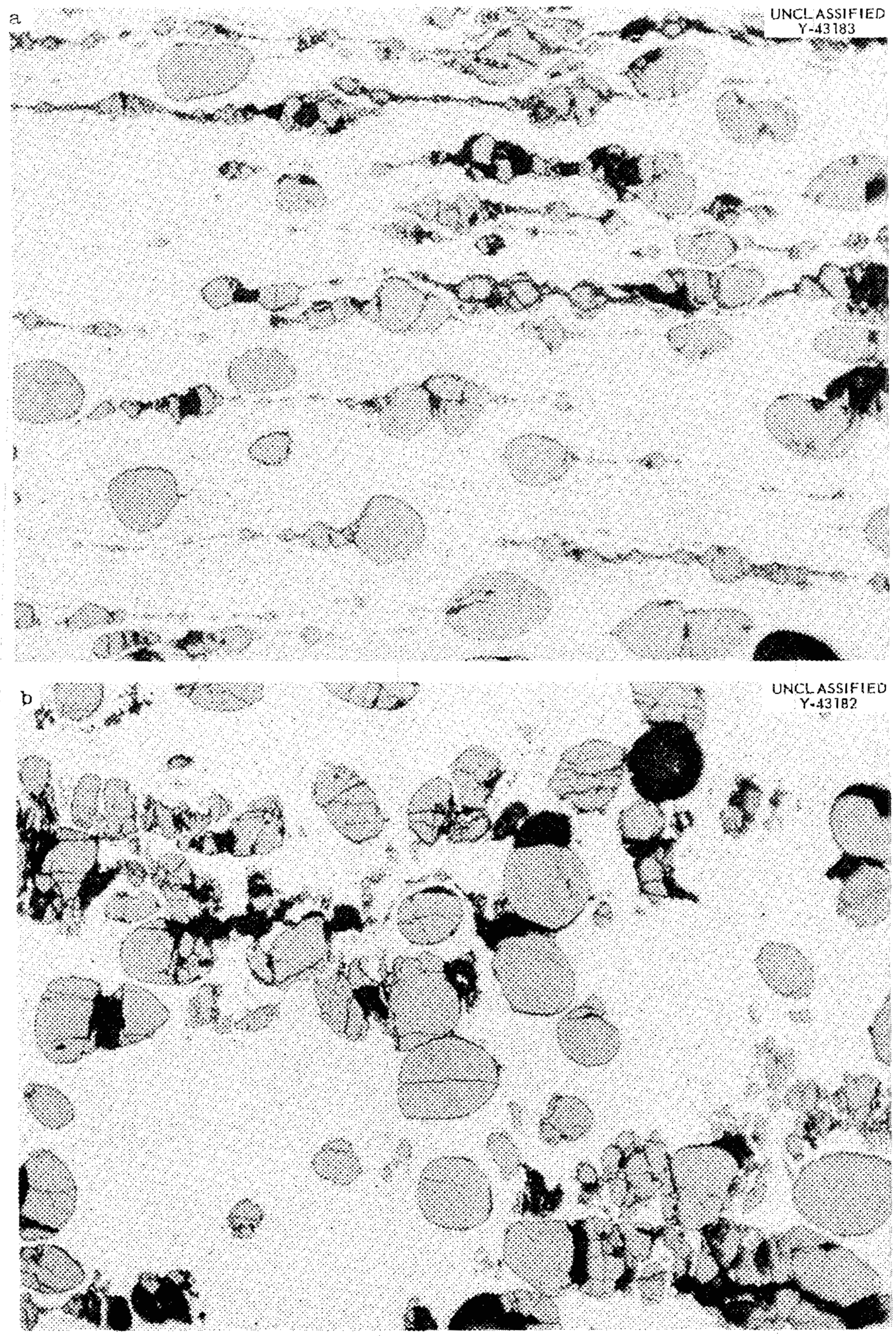


Fig. 8. Typical Microstructure of 36 wt % UO_2—Type 347 Stainless Steel Cermet; As-Polished; 100X. (a) Surface parallel to rolling direction. (b) Surface transverse to rolling direction. Reduced 20%.

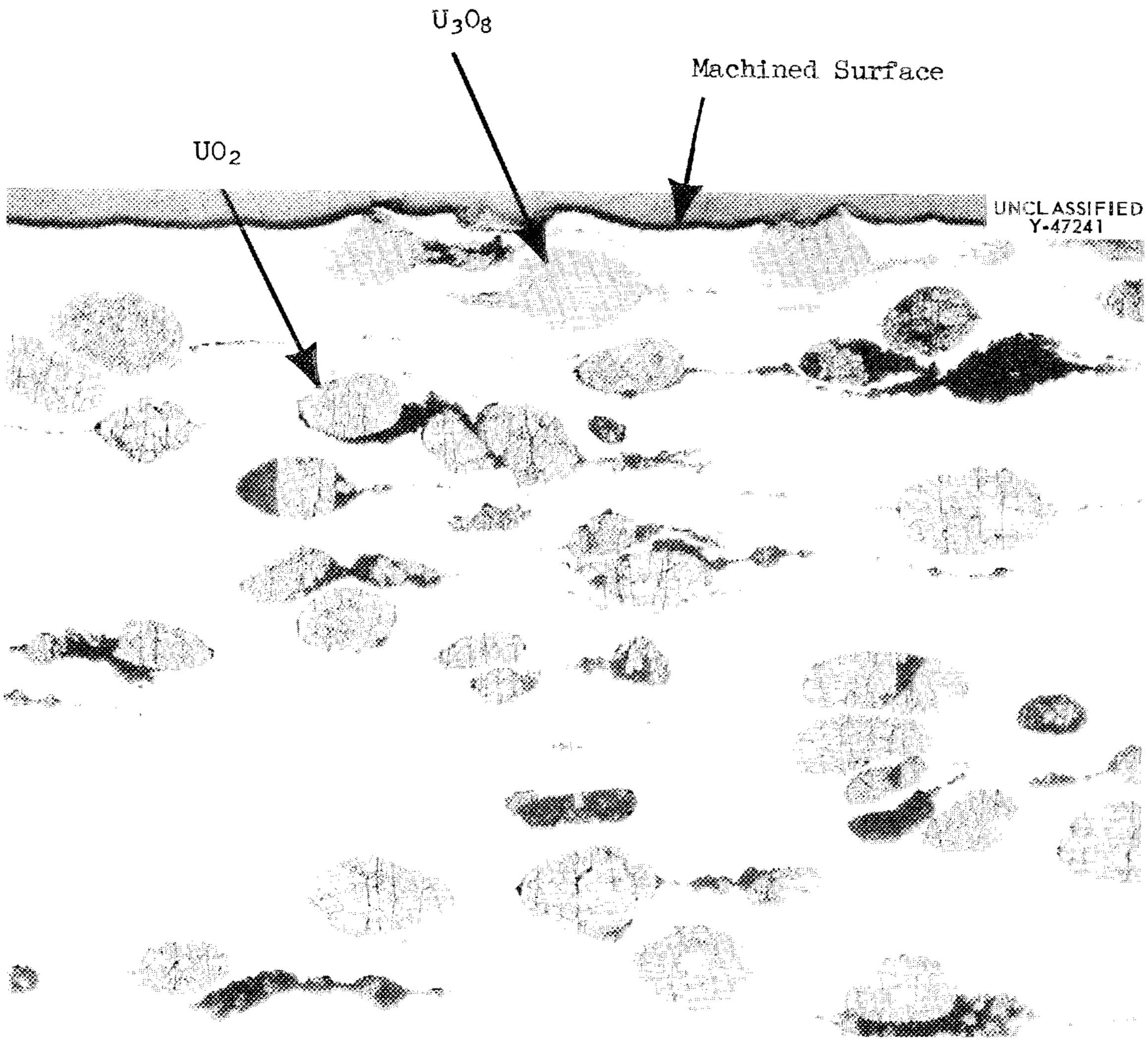
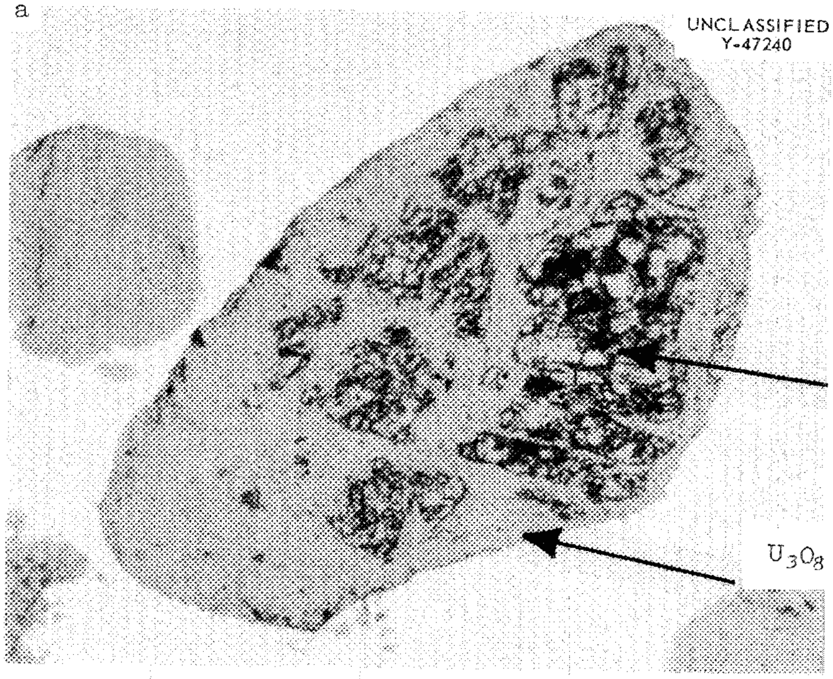


Fig. 9. Type 347 Stainless Steel—36 wt % UO_2 Cermet Tensile Tested at 1000°F in Air; Specimen Cut Parallel to Plate Rolling Direction. Etchant: 70% H_2O, 20% H_2O_2, 10% HNO_3. 100X.



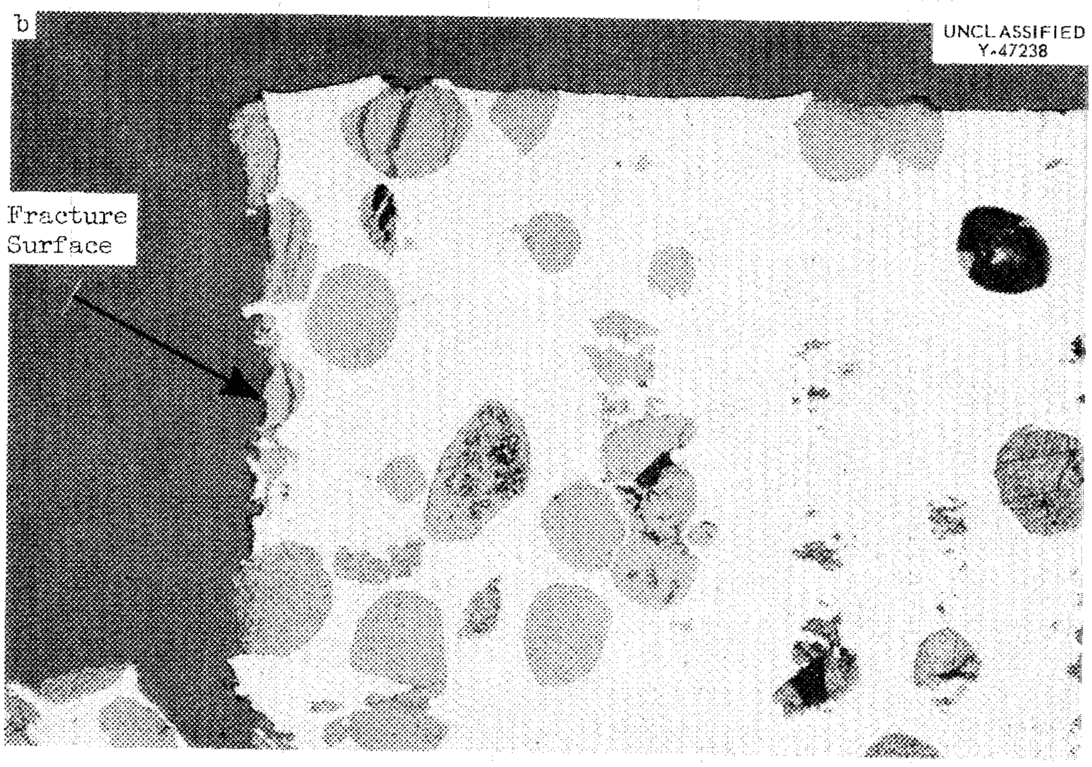


Fig. 10. Type 347 Stainless Steel–36 wt % UO_2 Cermet Tensile Tested at 1000°F in Air; Specimen Cut Transverse to Plate Rolling Direction. Etchant: 70% H_2O, 20% H_2O_2, 10% HNO_3. (a) 500X. (b) 100X. Reduced 6%.

UNCLASSIFIED
ORNL-DWG 63-2313

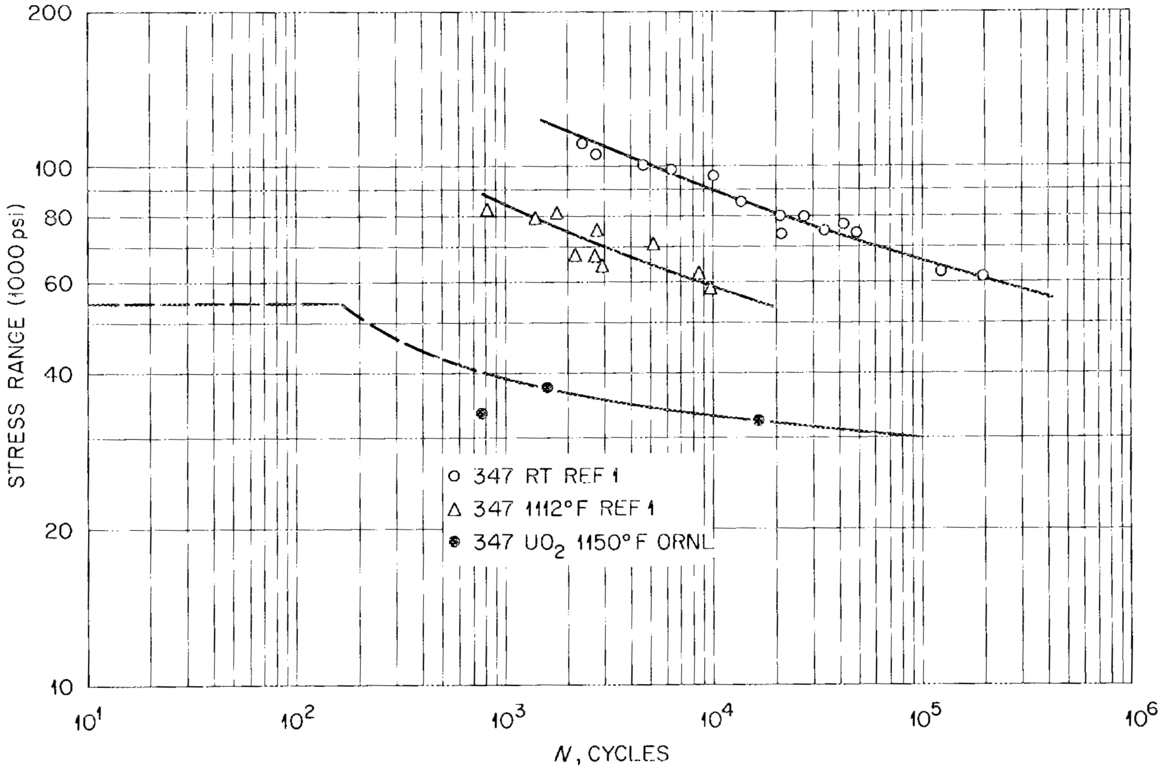


Fig. 11. Stress Range vs Cycles to Failure for Type 347 Stainless Steel—36 wt % UO_2 and Type 347 Stainless Steel.

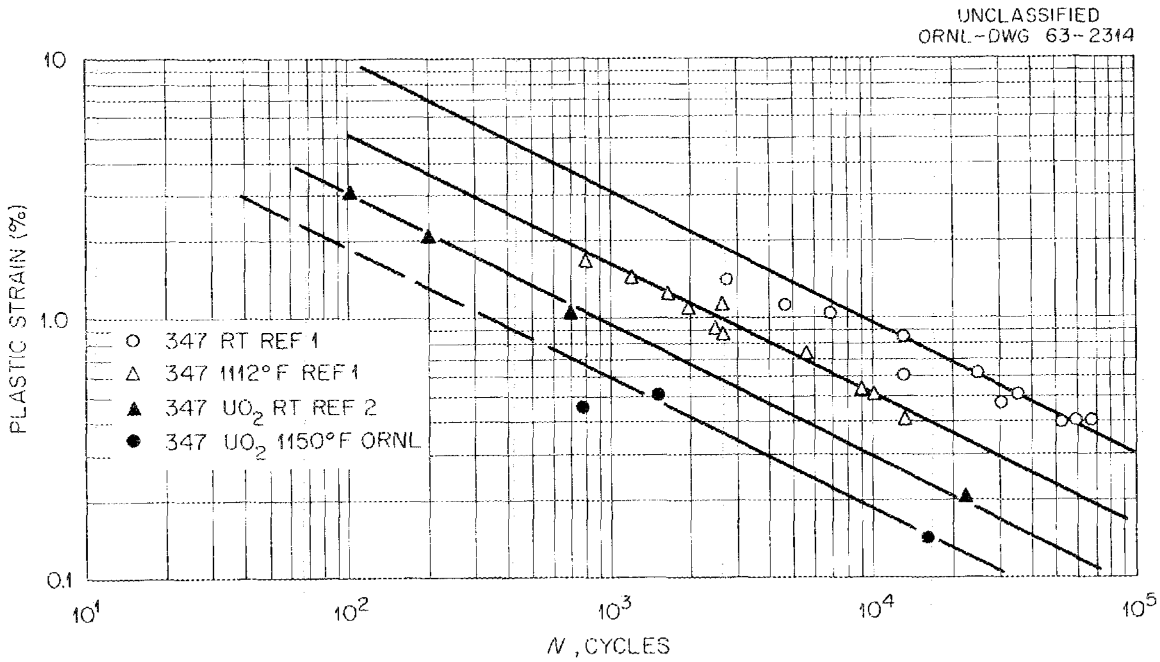


Fig. 12. Plastic Strain Range vs Cycles to Failure for Type 347 Stainless Steel-UO_2 and Type 347 Stainless Steel.

On the basis of rather limited data, it appears that the strain-fatigue behavior of the cermet can be described by:

$$N^{1/2} \epsilon_p = C$$

where N = number of cycles to failure

ϵ_p = plastic strain range

C = a constant ≈ 0.19.

Metallography of a strain-fatigue specimen is shown in Fig. 13. The argon blanket prevented formation of U_3O_8 as is apparent from the etched high magnification photomicrograph of an individual particle located at the fracture.

One strain-fatigue test, also not included in Figs. 8 and 9, was run in air. A composite of photomicrographs taken at various locations in the specimen is given as Fig. 14. Examination of Fig. 14 reveals that conversion of UO_2 to U_3O_8 occurred at locations remote from the surface.

It can be easily shown that, for the size particles under consideration, the increase in volume due to formation of the higher oxide can result in stresses, in the matrix immediately adjacent to the particle, exceeding the strength of the stainless steel. These stresses were probably responsible for the early failure which was observed with this specimen.

All strain-fatigue data are presented in the Appendix.

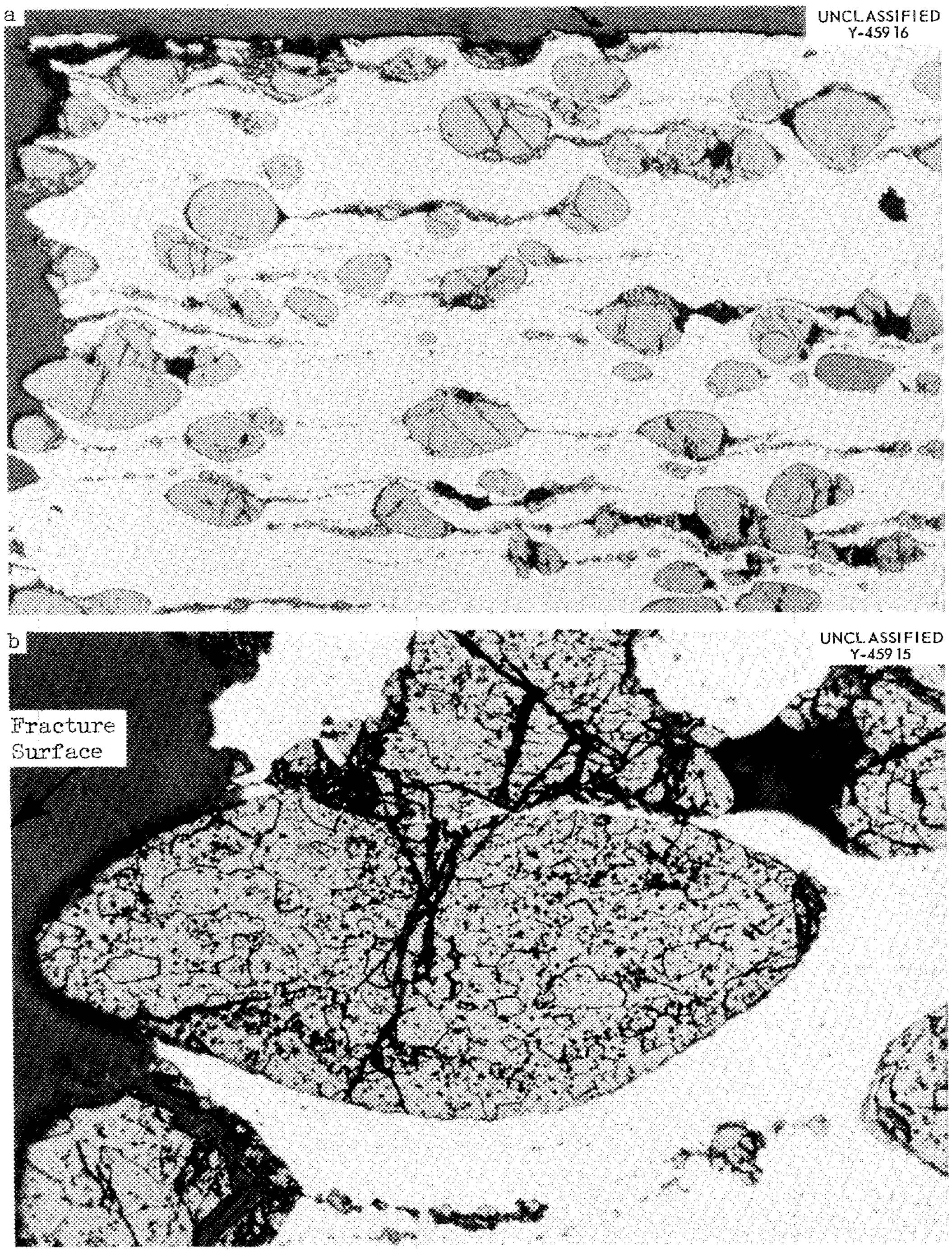


Fig. 13. Type 347 Stainless Steel-UO_2 Cermet Strain Cycled in Argon. Test No. 919: Plastic strain range – 0.0014 in./in.; Stress range – 32,000 psi; Cycles to failure – 15,600. (a) As-polished; 100X. (b) Etchant: 70% H_2O, 20% H_2O_2, 10% HNO_3; 500X. Reduced 10%.

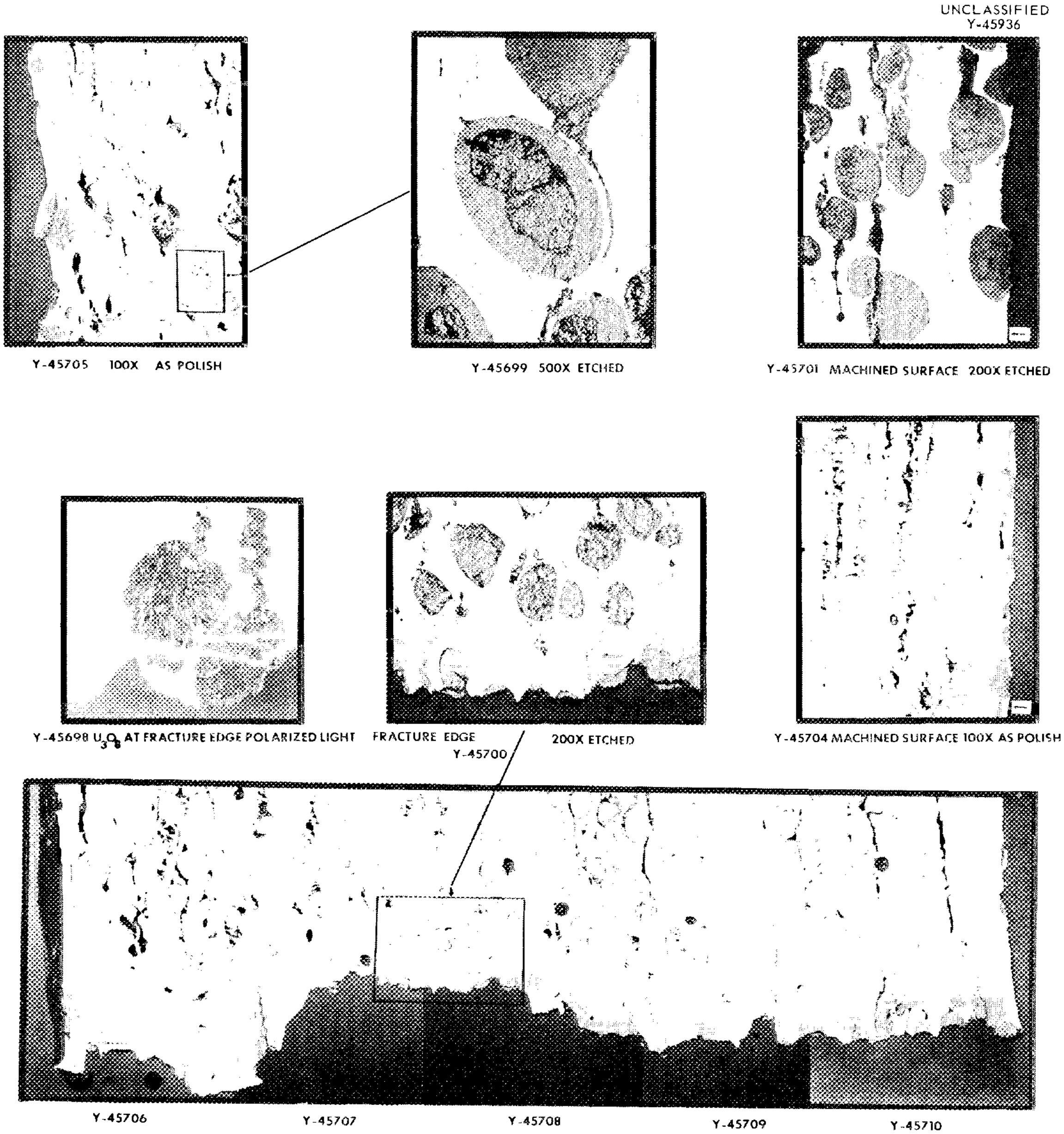


Fig. 14. Type 347 Stainless Steel-UO_2 Cermet Strain Cycled in Air. Test No. 2017: Plastic strain range – 0.0016 in./in.; Stress range – 44,000; Cycles to failure — 795. Reduced 22%.

APPENDIX

Table 1. Tensile Properties of Type 347 Stainless Steel—36 wt % UO_2 Cermet

Geometry	Temp (°F)	Ultimate Tensile Strength (psi)	0.2% Yield Strength	% Elongation
Bare plate, parallel to rolling direction	Room	43,900	27,700	15
	Room	44,100	24,600	13
	Room	44,500	25,300	14
Bare rod, parallel to rolling direction	Room	44,800	25,400	20
	1150	27,300	18,300	9
Clad plate (0.007 in. of clad on each surface), transverse to rolling direction	Room	37,700	25,100	10
	Room	37,200	25,000	10
	Room	39,600	25,200	11
Bare plate, transverse to rolling direction	Room	39,500	25,300	11
	Room	35,400	24,800	10.5
	Room	35,100	24,700	8
	Room	36,800	24,600	11
	Room	36,400	25,500	13
	Room	31,100	23,700	4.1
	Room	31,700	23,500	4.3
	400	24,200	19,300	2.4
	400	23,800	19,900	2.2
	600	21,700	18,300	2.4
	600	23,700	19,900	3.0
	800	22,500	19,400	2.7
	800	21,500	16,400	2.4
	1000	23,000	16,200	8
	1000	23,900	16,150	13
	1000	24,400	16,800	8
	1000	18,400	15,700	1.7
	1000	21,100	16,400	2.2
	1200	22,300	15,600	6
	1200	23,300	15,800	7
	1200	23,100	16,600	7
	1200	21,800	------	4
	1200	16,600	14,400	1.3
	1200	19,000	15,900	1.9

Table 2. Strain-Fatigue Properties of 36 wt % UO_2—Type 347 Stainless Steel at 1150°F in Argon (120 cycles per hour)

Plastic Strain Range (in./in.)	Stress Range (psi)	Cycles to Failure
0.02	50,000	0.25
0.06	50,000	2
0.005	37,500	1,500
0.0014	32,000	15,600
0.0045	32,300	769
0.0016	44,400	795[a]

[a]Tested in air.

INTERNAL DISTRIBUTION

1–2. Central Research Library
3. Reactor Division Library
4. ORNL – Y-12 Technical Library Document Reference Section
5–7. Laboratory Records Department
8. Laboratory Records, ORNL RC
9. ORNL Patent Office
10. G. M. Adamson
11. R. J. Beaver
12. B. S. Borie
13. J. V. Cathcart
14. G. W. Clark
15. R. E. Clausing
16. J. H. Coobs
17. J. E. Cunningham
18. J. H. DeVan
19. D. A. Douglas
20. J. H Frye, Jr.
21. A. E. Goldman
22. R. J. Gray
23. J. P. Hammond
24. W. O. Harms
25–27. M. R. Hill
28. E. E. Hoffman
29. H. Inouye
30. C. F. Leitten, Jr.
31. A. L. Lotts
32. T. S. Lundy
33. H. G. MacPherson
34. W. D. Manly
35. W. R. Martin
36. R. W. McClung
37. D. L. McElroy
38. C. J. McHargue
39. P. Patriarca
40. M. L. Picklesimer
41. J. L. Scott
42. G. M. Slaughter
43–45. R. W. Swindeman
46. A. Taboada
47–49. W. C. Thurber
50–52. J. T. Venard
53. J. R. Weir, Jr.

EXTERNAL DISTRIBUTION

54–56. A. A. Shoudy, APDA
57. W. H. Jens, APDA
58. R. C. Williams, APDA
59–60. D. F. Cope, AEC, ORO
61. J. M. Martin, AEC, ORO
62. G. M. Wensch, AEC, ORO
63. L. A. Redecke, AEC, COO
64. R. R. Rohde, Argonne National Laboratory
65–79. Division of Technical Information Extension (DTIE)
80–81. Research and Development Division (ORO)