CONF-8009179--6

THE INFLUENCE OF IRRADIATION ON THE TENSILE PROPERTIES OF AUSTENITIC STAINLESS STEEL WELDMENTS*

F. W. Wiffen J. A. Horak
D. P. Edmonds J. F. King
Metals and Ceramics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

ADIP Program Review Meeting
DOE — OFE
Materials and Radiation Effects Branch
Germantown, Maryland
September 30—October 1, 1980

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract No. W-7405-eng-26 with Union Carbide Corporation.

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Weldments in the first wall and front sections of the blanket of a fusion reactor will be exposed to approximately the same operating conditions as will the base metal. Thus the irradiation response of weld metal, of the weld heat affected zones in the base metal, and of the base metal are all of equal concern. Austenitic stainless steels will most likely be joined by a gas tungsten arc welding process. Welds have been made by this process between sections of 6-mm-thick (0.25 in.) base plate of type 316 in the 20%-cold-worked condition, with either type 316 or 16-8-2 stainless steel filler metal. Rod tensile specimens were cut through the welds, containing weld metal in the central gage portion.

Weld-containing tensile specimens have been irradiated in HFIR at 55°C and throughout the temperature range 280 to 620°C. The neutron fluences ranged from 0.5 to 1.6 × 10^{26} n/m^2 (> 0.1 MeV). The corresponding displacement damage levels range from 4.5 to 12.1 dpa, and the helium generation from the thermal neutron captures in nickel resulted in 100 to 550 at. ppm He.

Tensile tests at temperatures near the irradiation temperature resulted in fractures in the weldments, not in the weld heat affected zone. These tests showed that for irradiation and test temperatures up to 375°C, irradiated weldments were stronger than unirradiated material from the same weldment. For temperatures of 475 to 620°C the strength of irradiated weldments were equivalent to, or lower than, the strength of control material. After irradiation, and throughout the temperature range, the strength of both weld materials was lower than the strength of irradiated 20%-cold-worked type 316 stainless steel. Total elongation of irradiated weldments showed a broad minimum in the range 300 to 400°C, at approximately 4% elongation. Elongation of the base metal at 350°C is approximately 8% for similar irradiation conditions. (Because the gage length of the specimen contained weldment, weld heat affected material, and base metal, the measured elongation includes contributions from each of these. It is not truly a measure of the weldment ductility.) Fractography showed that all material irradiated and tested at temperatures up to 475°C had failed in a ductile shear mode. For higher temperatures, there was some association of the fracture path with the grain boundaries in the weld deposit structure.

Metallographic examination of cross sections through the welds showed both weldments to contain approximately 4% delta ferrite in the as-deposited condition. The microstructures of samples irradiated at 475°C and lower showed little difference from as-deposited weld metal. At higher irradiation temperatures additional fine-scale precipitation had occurred in zones near the original delta ferrite, and some of the delta ferrite had transformed to sigma phase.

These tensile properties indicate that for operating temperatures below 620°C and operating times of 1 to 2 MW-y/m^2 conventional welding techniques used with 316 stainless steels would impose only modest additional operating limitations on the reactor. While these data will guide material selection for near-term fusion power reactors, higher fluence evaluation will be required for commercial reactor design.

THE INFLUENCE OF IRRADIATION ON THE TENSILE PROPERTIES OF AUSTENITIC STAINLESS STEEL WELDMENTS

Objective

TO SCOPE THE EFFECT OF IRRADIATION SIMULATING ONE TO THREE YEARS OF FUSION REACTOR SERVICE ON THE TENSILE PROPERTIES OF WELDMENTS

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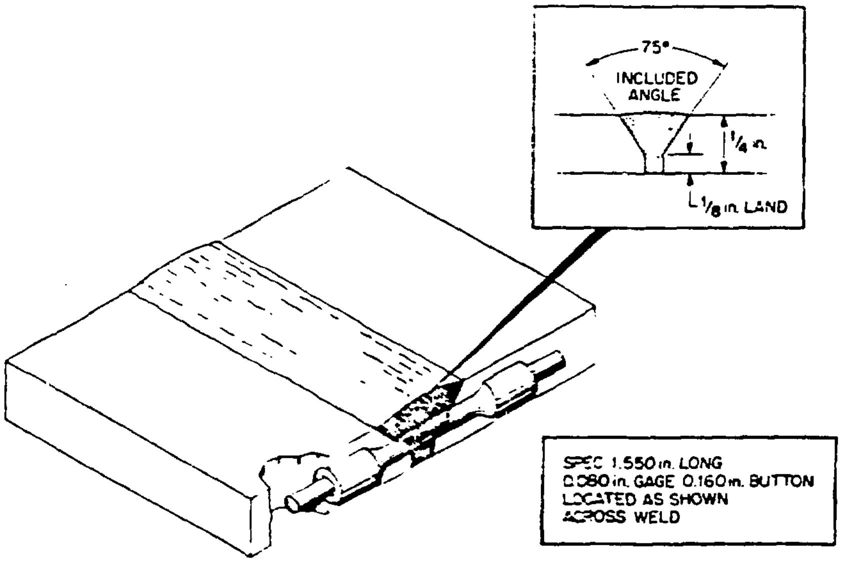

SAMPLE AND WELD ORIENTATION

COMPOSITION OF BASE PLATES AND WELD FILLER METALS

Element	Type 316 Base Plate	Type 316 Filler Metal	16-8-2 Filler Metal
Cr	17.3	19.5	16.4
Ni	13.4	13.4	8.6
Mo	2.3	2.4	1.7
Mn	1.9	1.7	1.3
Si	0.62	0.38	0.29
C	0.060	0.026	0.045

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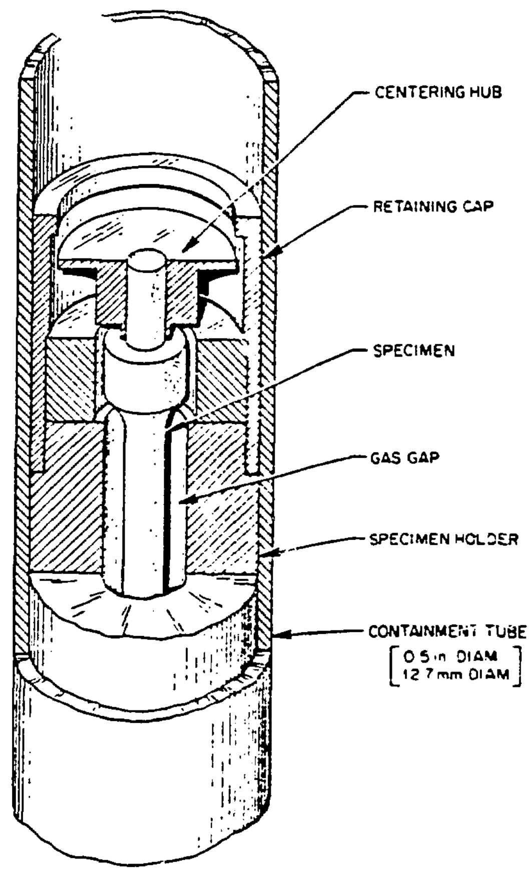


CTR EXPERIMENT FOR HFIR–PTP IRRADIATION

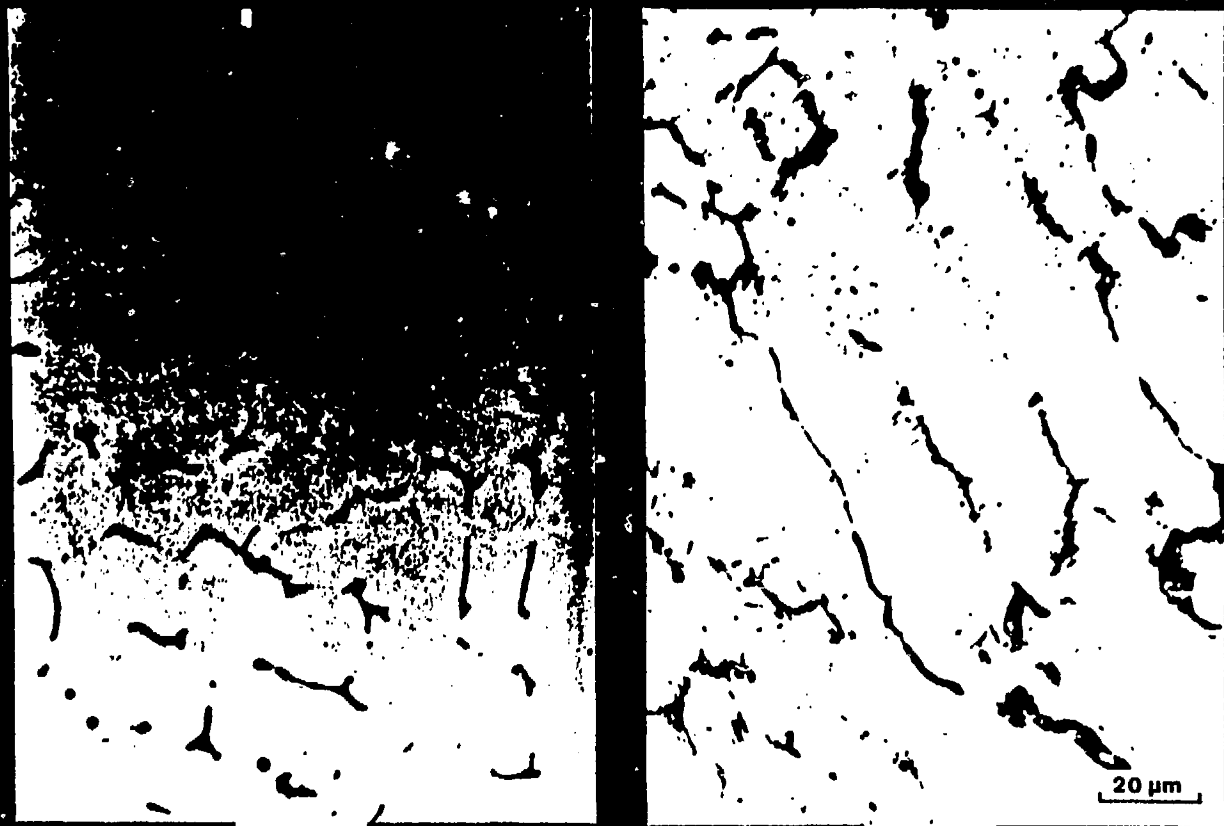
HFIR IRRADIATION OF 316

FAST FLUX	$\leq 1.4 \times 10^{19}$ n/m^2-s
FLUENCE	1.6×10^{26} n/m^2 (> 0.1 MeV)
	TO PRODUCE 12 dpa
TOTAL FLUX	$\leq 5.5 \times 10^{19}$ n/m^2-s
	TO PRODUCE 480 at. ppm He (max)
	From $^{58}Ni\ (n,\gamma)^{59}Ni$
	$^{59}Ni\ (n,\alpha)^{56}Fe$

TEMPERATURE RANGE: 55 to 620°C

IRRADIATION PARAMETERS RELATED TO FUSION REACTOR OPERATION

	These Experiments	Fusion Reactor (1 MW-y/m^2)
dpa	4.5 to 12.1	11.5
He, at. ppm	100 to 480	145
H, at. ppm	54 to 145	530
Temperature, °C	55 to 620	100 to 550



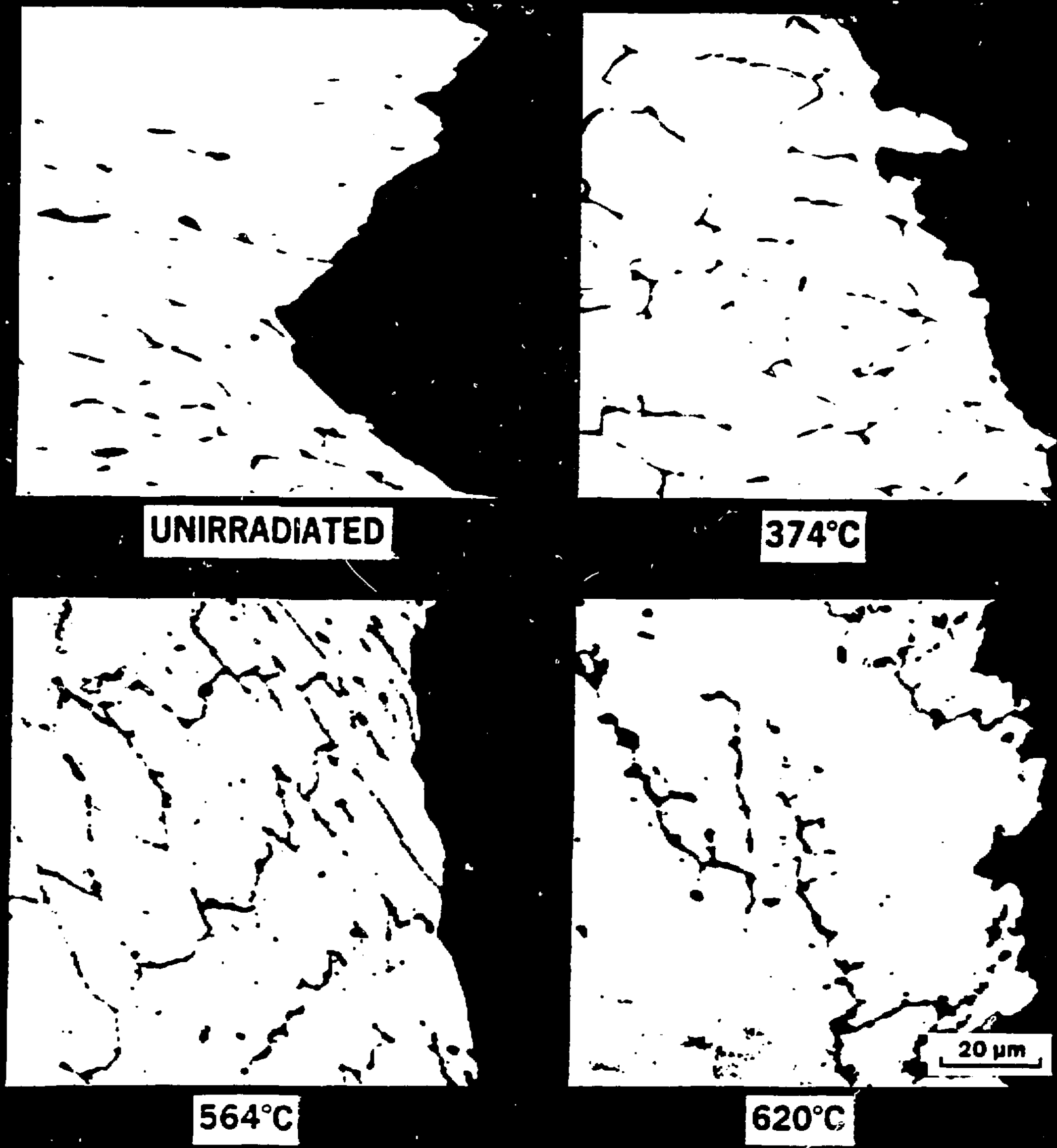
473°C 620°C

316 WELDMENT

IRRADIATED AT INDICATED TEMPERATURE

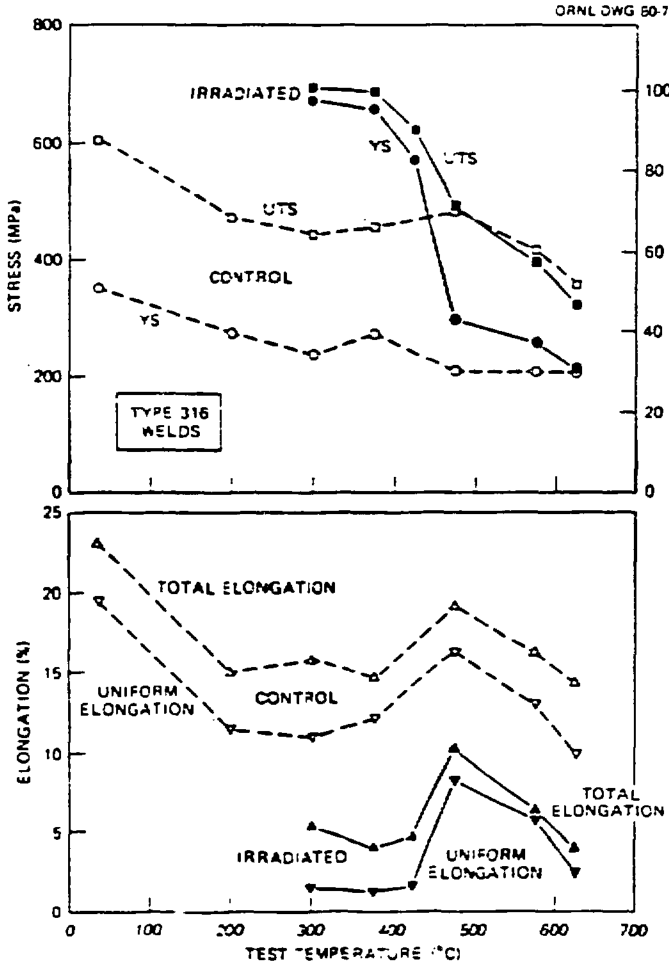
TO 9.7dpa, 470 at. ppm He

TENSILE TESTED NEAR IRRAD. TEMPERATURES.

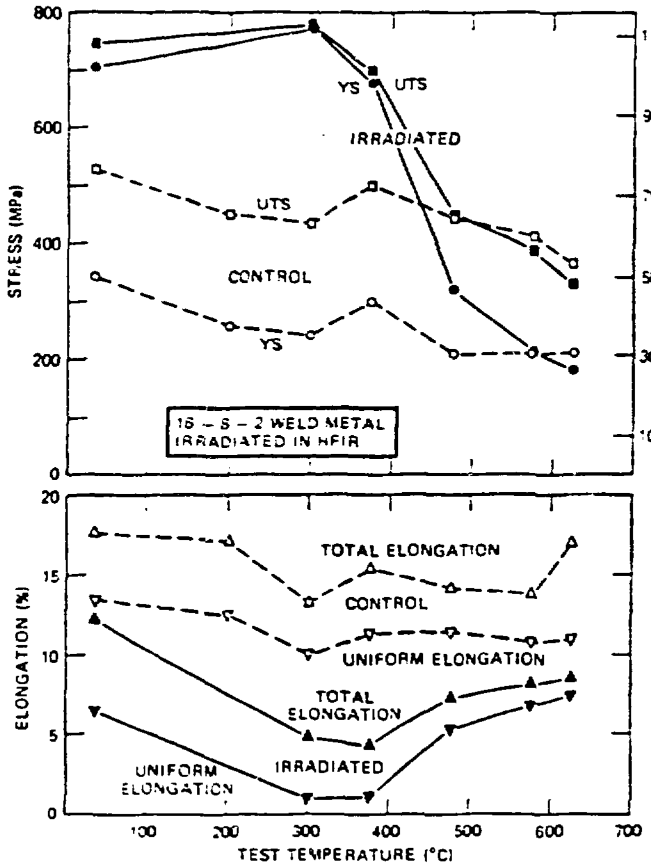


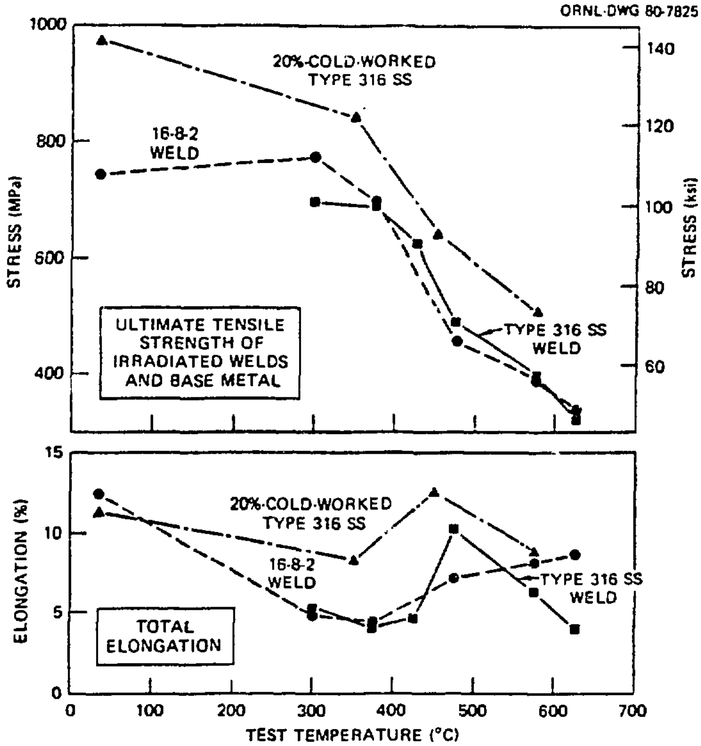
16-8-2 WELDMENT, INCLUDING FRACTURE.

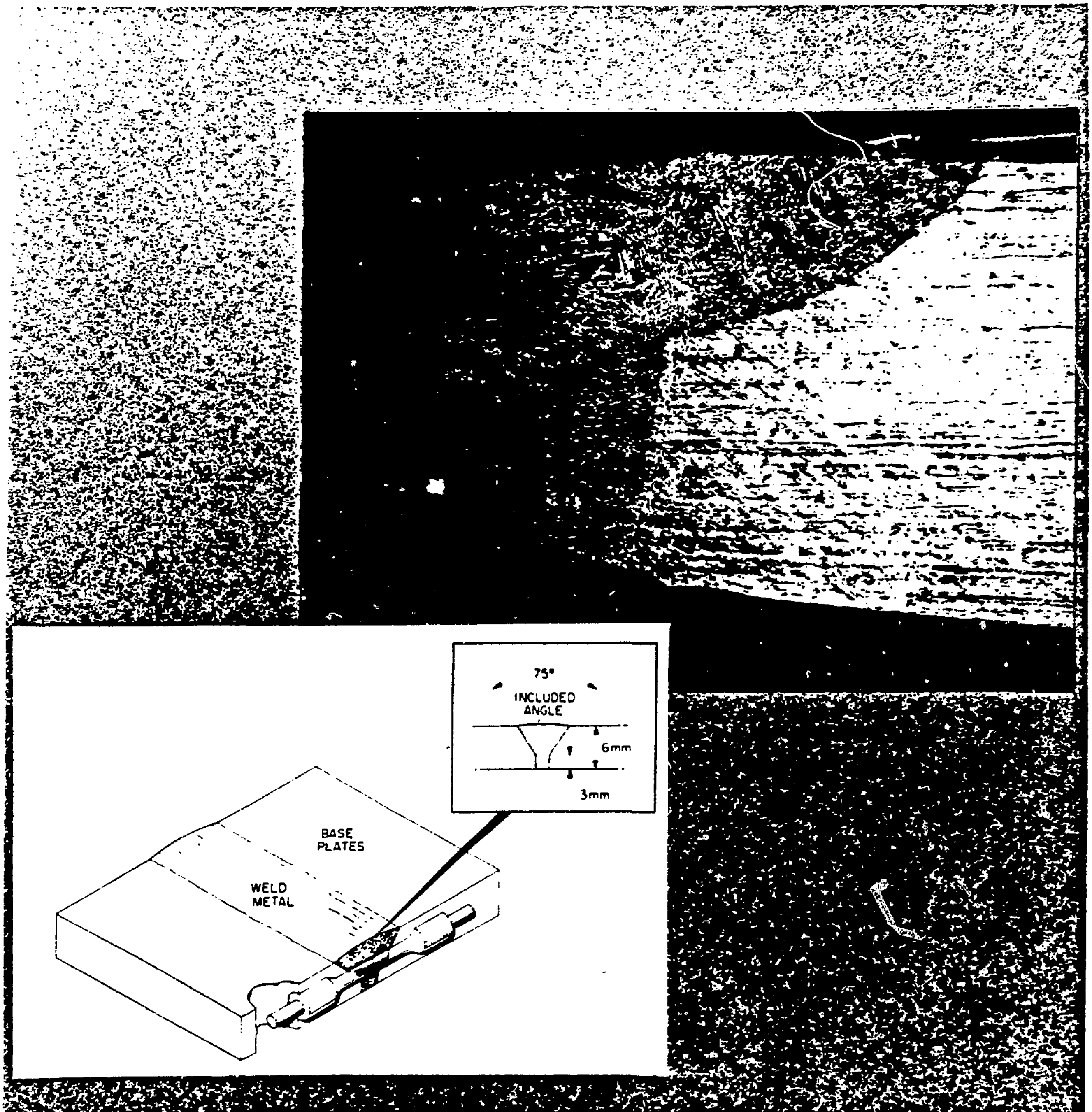
IRRADIATION PRODUCED 9-12 dpa, 300-420 at. ppm He. TENSILE TESTED NEAR IRRADIATION TEMPERATURE.


ORNL DWG 80-7824
IRRADIATED
YS
UTS
CONTROL
TYPE 316
WELDS
STRESS (MPa)
STRESS (ksi)
TOTAL ELONGATION
UNIFORM
ELONGATION
IRRADIATED
ELONGATION (%)
TEST TEMPERATURE (°C)

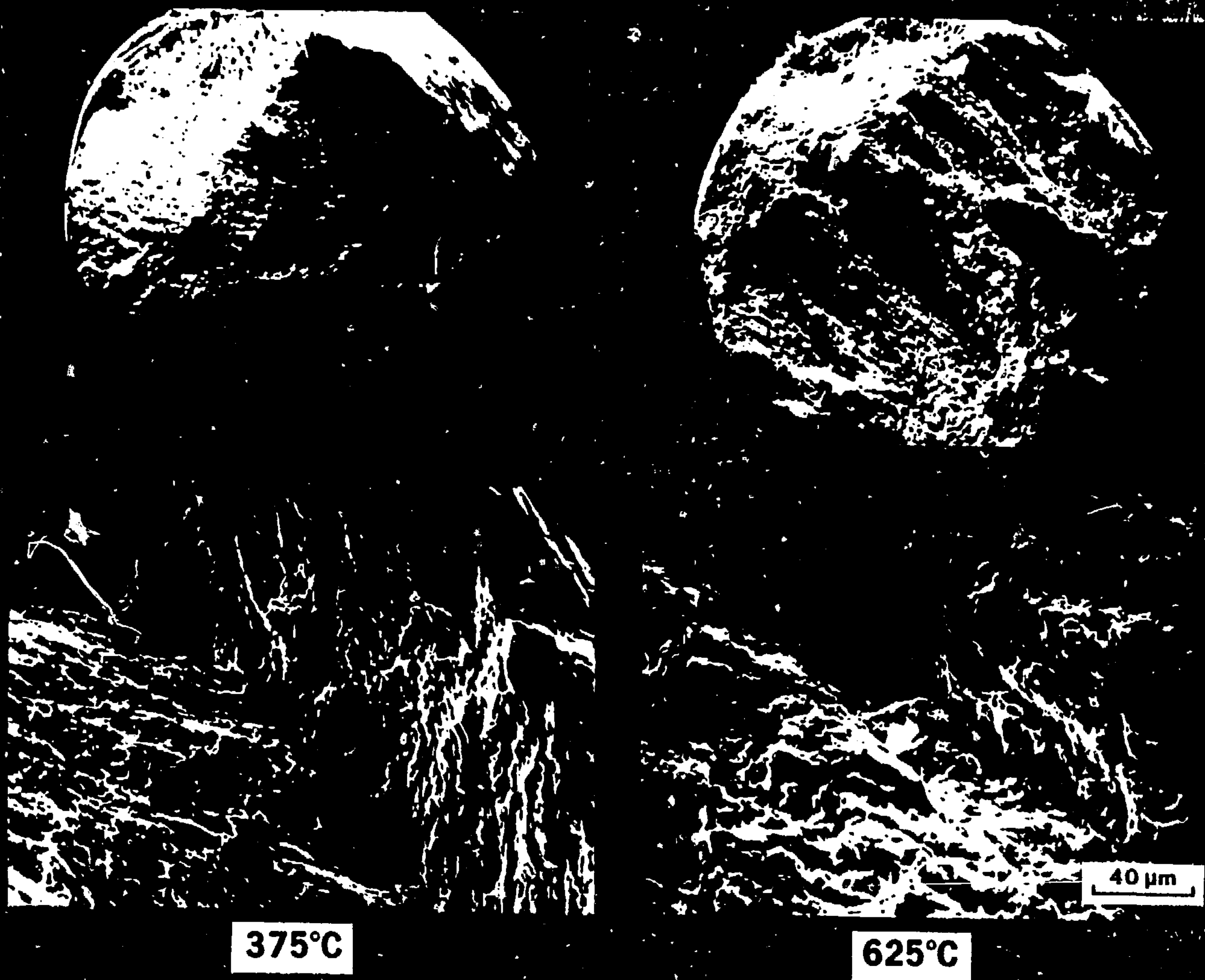
ORNL-DWG 79-18732R




ORNL-DWG 80-7825
20%-COLD-WORKED
TYPE 316 SS
16-8-2
WELD
TYPE 316 SS
WELD
ULTIMATE TENSILE
STRENGTH OF
IRRADIATED WELDS
AND BASE METAL
STRESS (MPa)
STRESS (ksi)
1000
800
600
400
140
120
100
80
60
15
10
5
0
ELONGATION (%)
TOTAL
ELONGATION
0
100
200
300
400
500
600
700
TEST TEMPERATURE (°C)

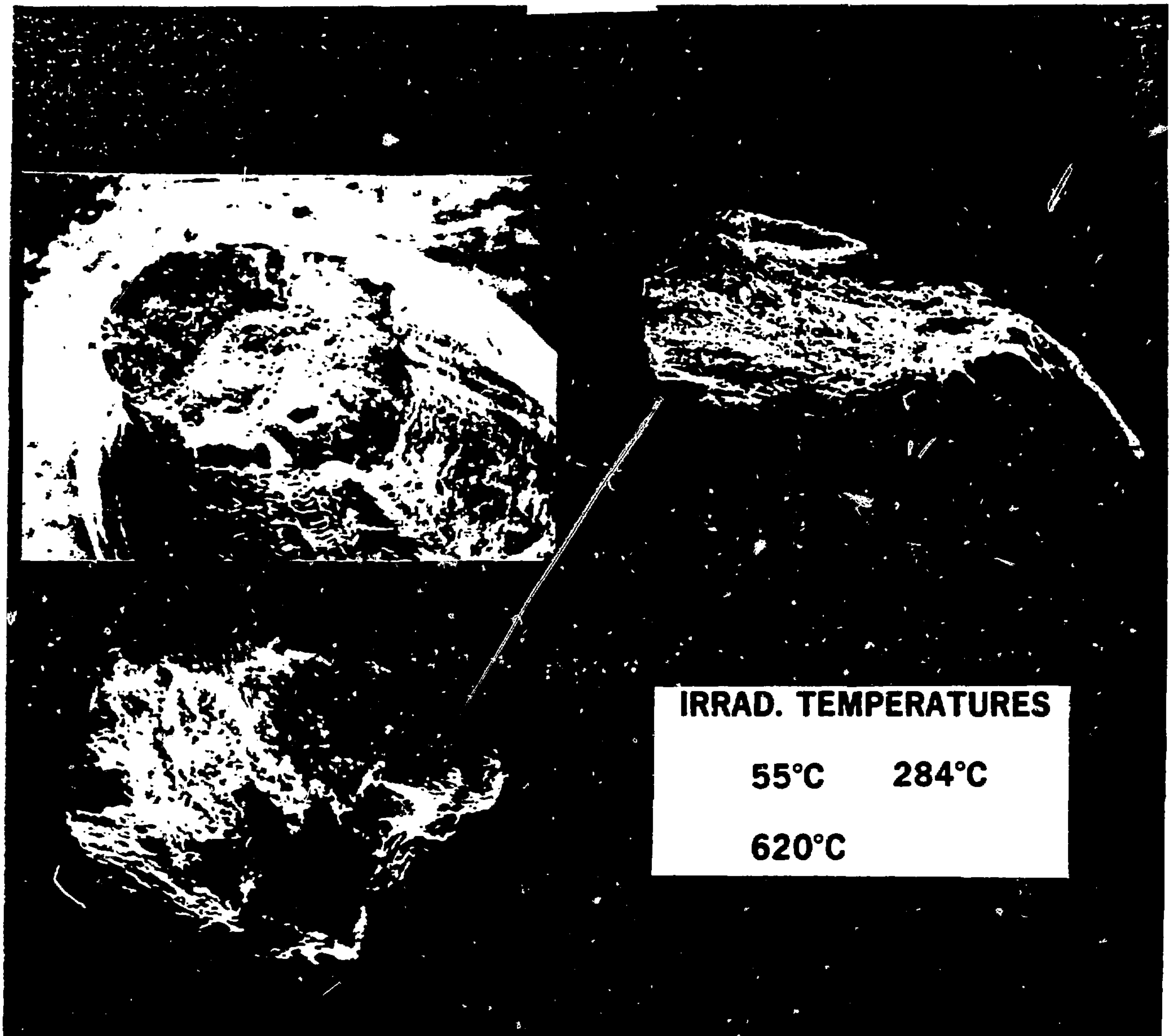


WELD-BASE METAL INTERFACE IN IRRADIATED AND TESTED SPECIMEN



TYPE 316 SS WELDMENT

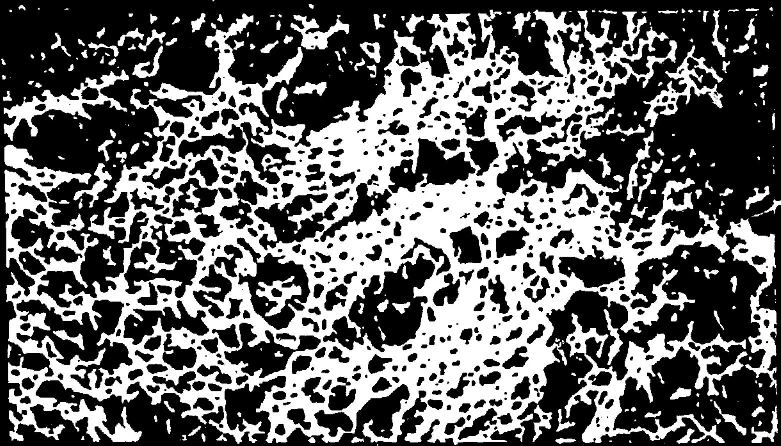
(8-10 dpa; 340-480 at. ppm He)

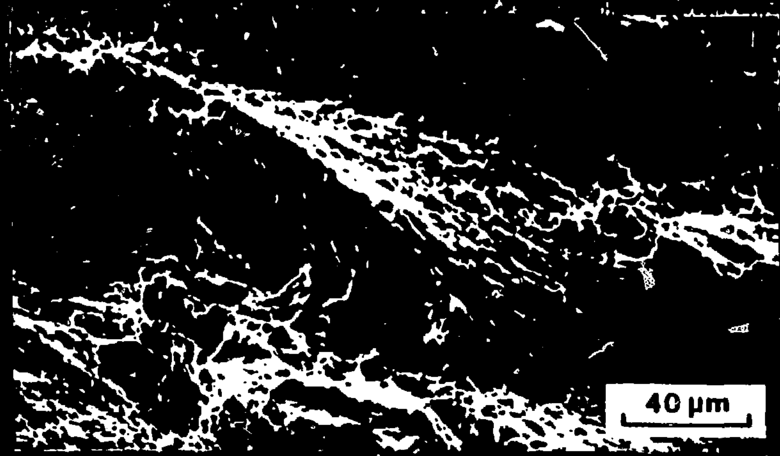


FRACTURE SURFACES IN 16-8-2 WELDMENTS.

IRRADIATED TO PRODUCE 6.5 TO 12 dpa,

160 TO 420 at. ppm He.





IRRADIATION TEMPERATURES

55°C 284°C

620°C

FRACTURE SURFACES IN 16-8-2 WELDMENTS

(6.5-12 dpa; 160-420 at. ppm He)

SUMMARY

1. TYPE 316 AND 16-8-2 WELDMENTS SHOW SIMILAR RESPONSE TO IRRADIATION.
2. THE WELDMENT STRENGTH IS LOWER THAN THAT OF THE 20% CW 316 BASE METAL.
3. THE WELDMENT DUCTILITY IS LOWER THAN THAT OF THE BASE METAL.
4. THE 16-8-2 WELDMENT HAS BETTER DUCTILITY ABOVE 550°C THAN DOES 316 WELDMENT.
5. LARGE-SCALE PRECIPITATION HAS OCCURRED IN BOTH WELDMENTS FOR IRRADIATION AT 575 AND 620°C.
6. FRACTURES AT HIGHER TEMPERATURES FOLLOW THE AS-CAST WELD STRUCTURE.

CONCLUSION

IN FUSION REACTOR STRUCTURES, WELDMENTS WILL IMPOSE ADDITIONAL SERVICE RESTRICTIONS BEYOND THOSE SET BY PROPERTIES OF THE BASE METAL. FOR AUSTENITIC STAINLESS STEELS THE PRESENT RESULTS SHOW THE PROPERTIES OF IRRADIATED WELDMENTS TO BE ONLY MODESTLY INFERIOR TO BASE METAL IRRADIATED TO THE SAME CONDITIONS.