3

DPST-82-128-1

MASTER

DO NOT MICROFILM
COVER

^{238}Pu FUEL-FORM PROCESSES QUARTERLY REPORT

JANUARY - MARCH 1982

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

DISCLAIMER

Printed in the United States of America

Available from

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed Copy A03; Microfiche A01

DPST-82-128-1

^{238}Pu FUEL-FORM PROCESSES QUARTERLY REPORT

JANUARY - MARCH 1982

Approved by:
R. L. Folger, Research Manager
Hydrogen and Ceramic Technology Division

Publication Date: July 1982

Issued by E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, SC 29808

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED page blank

CONTENTS

Analytical Studies of Weld Quench Cracking in DOP-26 Iridium Alloy-Clad Vent Sets

Cracks that occur in the arc quench region of the girth welds on DOP-26 iridium alloy-clad vent sets (CVS) have been a problem in production of general-purpose heat sources (GPHS) in the Savannah River Plant (SRP) Plutonium Fuel Form (PuFF) Facility.[1] Previous analytical work has shown that alloy grain boundaries in cracks have a characteristic ridge network porosity. Such porosity is thought to weaken the grain boundaries and promote cracking. Efforts are being made to identify the mechanism responsible for producing the ridge network porosity.

FOREWORD

This report is one of a series to summarize progress in the Savannah River Laboratory ^{238}Pu Fuel Form Program. This program is supported primarily by the DOE Advanced Nuclear Systems and Projects Division (ANSPD).

Goals of the Savannah River Laboratory (SRL) program include providing technical support for the production of $^{238}PuO_2$ fuel forms in the Savannah River Plant's (SRP) Plutonium Fuel Form (PuFF) Facility. This part of the program includes:

Demonstration of processes and techniques developed by the Los Alamos National Laboratory (LANL) for production at SRP. Information from the demonstration will provide the technical data for technical standards and operating procedures.

Technical Support to assist plant startup and to ensure continuation of safe and efficient production of high-quality heat-source fuel.

Technical Assistance after startup to accommodate changes in product and product specifications, to assist user agencies in improving product performance, to assist SRP in making process improvements that increase efficiency and product reliability, and to adapt plant facilities for new products.

GENERAL PURPOSE HEAT SOURCE (GPHS) PROCESS SUPPORT

ANALYTICAL STUDIES OF WELD QUENCH CRACKING IN DOP-26 IRIDIUM ALLOY-CLAD VENT SETS

Introduction and Summary

Cracks that occur in the arc quench region of the girth welds on DOP-26 iridium alloy clad vent sets (CVS) have been a problem in production of general-purpose heat sources (GPHS) in the Savannah River Plant (SRP) Plutonium Fuel Form (PuFF) Facility.[1] Previous analytical work has shown that alloy grain boundaries in cracks have a characteristic ridge network porosity. Such porosity is thought to weaken the grain boundaries and promote cracking. Efforts are being made to identify the mechanism responsible for producing the ridge network porosity.

Cracks in CVS's welded in the PuFF Facility are detected by an ultrasonic, nondestructive examination (NDE) which also gives a signal proportional to the crack area. SRP analysis of welding results have shown that weld quench cracking severity varies for each batch of DOP-26 iridium alloy.[2] Cracking severity was greatest in alloy batch MER, least in batches L and LR, and intermediate in batches M, N, P, and Q.

Analytical studies of weld quench cracking in DOP-26 iridium alloy continued during this period. Two CVS's welded by the SRP Equipment Engineering Department (EED), using the long quench taper adopted for production welding, were analyzed by scanning electron microscopy (SEM) at SRL and a high-resolution scanning Auger microprobe (SAM) at Oak Ridge National Laboratory (ORNL). Results confirmed that cracking occurs on grain boundaries with extended ridge-network porosity. Two other types of grain boundary porosity, grain-edge porosity and distributed pores, were identified and shown to have features similar to ridge network porosity.

CVS's composed of cups from alloy batches LR and MER were welded by SRP-EED with multiple quench regions to permit a statistical assessment of cracking severity and provide specimens for comparative analyses to identify the specific alloy properties responsible for weld cracking. Analytical results confirmed more severe cracking in weld quenches in MER cups than in LR cups. Cracking severity also varied from quench to quench on each cup suggesting that cracking may be related to alloy inhomogeneity. Specimens from long quenches in both CVS's have been analyzed by ion microscopy to determine whether cracking severity is related to differences in elemental concentrations and/or distributions.

ORNL is developing a weldability test for DOP-26 iridium alloy. The proposed test has shown possible differences in weldability for several alloy batches. However, the weld cracking produced by the weldability test may not be the same as weld quench cracking caused by SRP production welding. Weldability test specimens will be analyzed to resolve this question. ORNL believes more development is needed before the test can be applied to alloy characterization.

Discussion

Analyses of Long Quench Taper Welds

CVS T25

CVS T25 was welded by SRP-EED during an evaluation of welder chucks.[3] The upper chuck was a gripping type with a beryllium-copper insert. The lower chuck was the collet type used in SRP production welding. CVS T25 consisted of two scrap cups. The top cup was identified as L252-6, but the bottom cup was unidentified. CVS T25 was welded using parameters similar to those used in SRP production welding, except the rotation speed was 5 rpm rather than 8 rpm, and the current was reduced from about 80 A to 62.6 A to compensate for this lower speed. The girth weld was terminated with a long quench taper like that adopted for SRP production welding.

Several types of cracks were detected on the interior weld bead. Two large cracks extended from near the weld centerline out to the unwelded alloy in the bottom cup beneath the quench taper as shown in Figure 1. Grain-boundary surfaces in these cracks had extended ridge network porosity (Figures 2 and 3). Smaller cracks were detected in alloy welded on the first pass adjacent to alloy rewelded in the overlap region (Figure 4) and in unwelded alloy adjacent to weld (Figure 5).

The weld was fractured along the centerline through the quench revealing the double-pass weld area (melted twice), the columnar grain region and the heat-affected, single-pass weld area (melted once) as shown in Figure 6. Ridge network porosity on grain faces and another type of porosity along grain edges (Figure 7) were detected only in the heat-affected, single-pass weld area where the large cracks were located.

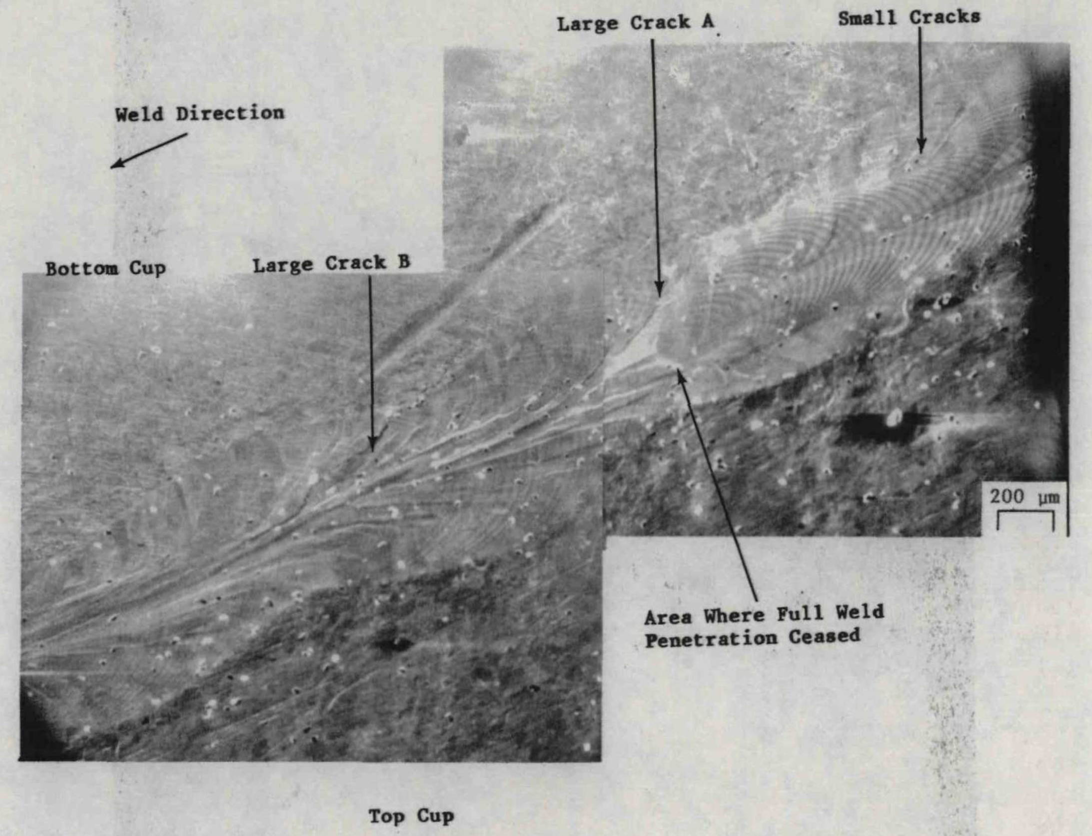
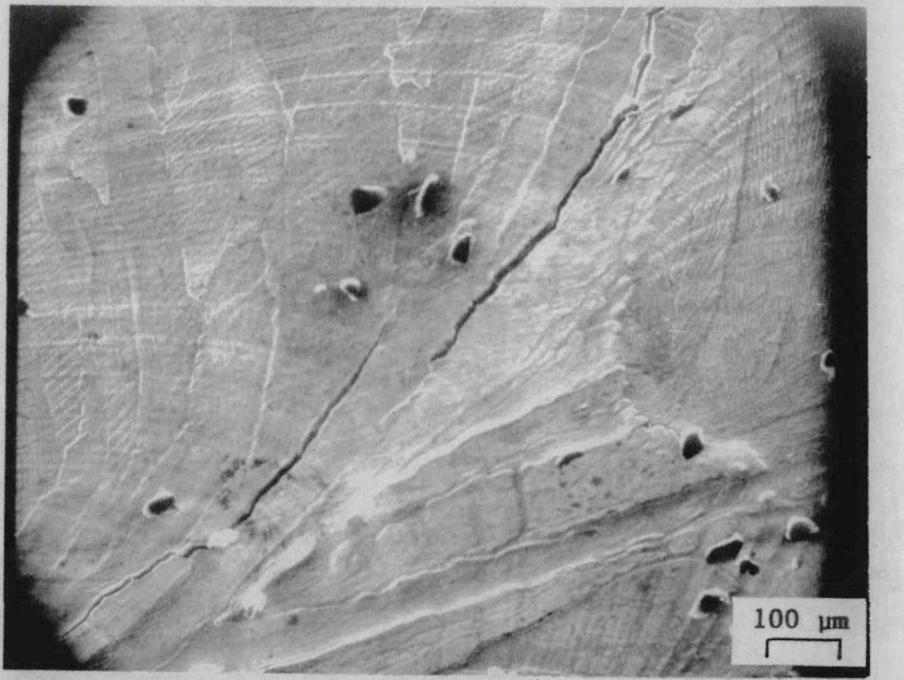


FIGURE 1. Cracks on Interior Weld Bead of CVS T25 at Beginning of the Quench Taper

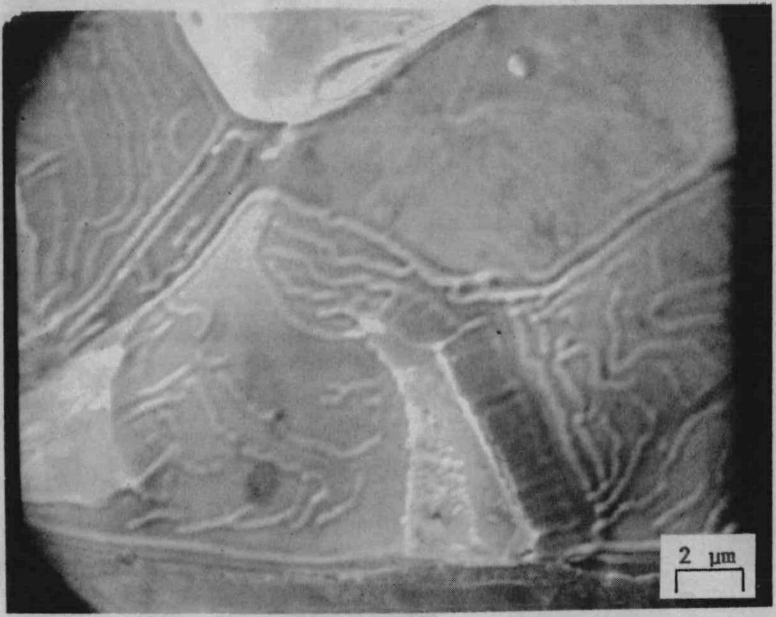


a. Location of Crack A

b. Ridge network porosity on grain boundaries in crack

Figure 2. Large Crack A in CVS T25

a. Location of crack B



b. Ridge network porosity on grain boundaries in crack

Figure 3. Large Crack B in CVS T25

Figure 4. Small Cracks in Single-Pass Weld Adjacent to Double-Pass Weld.

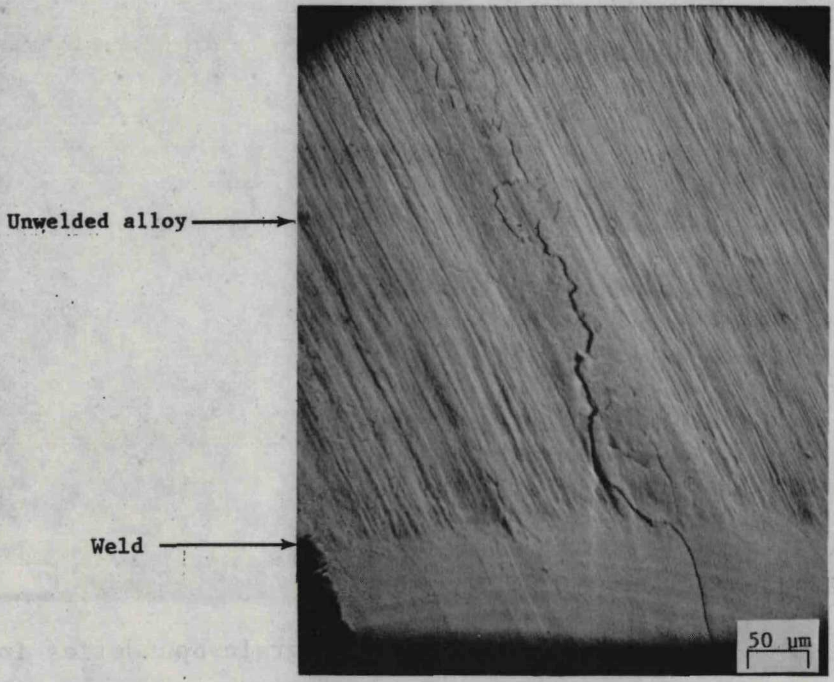


Figure 5. Small Crack at Edge of Weld

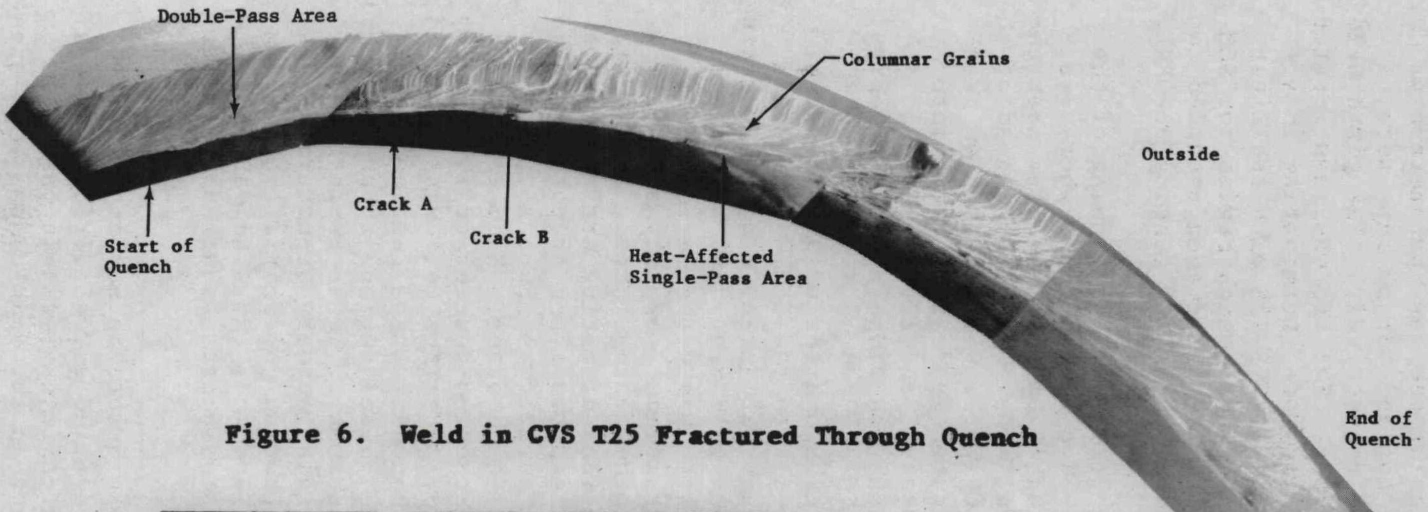


Figure 6. Weld in CVS T25 Fractured Through Quench

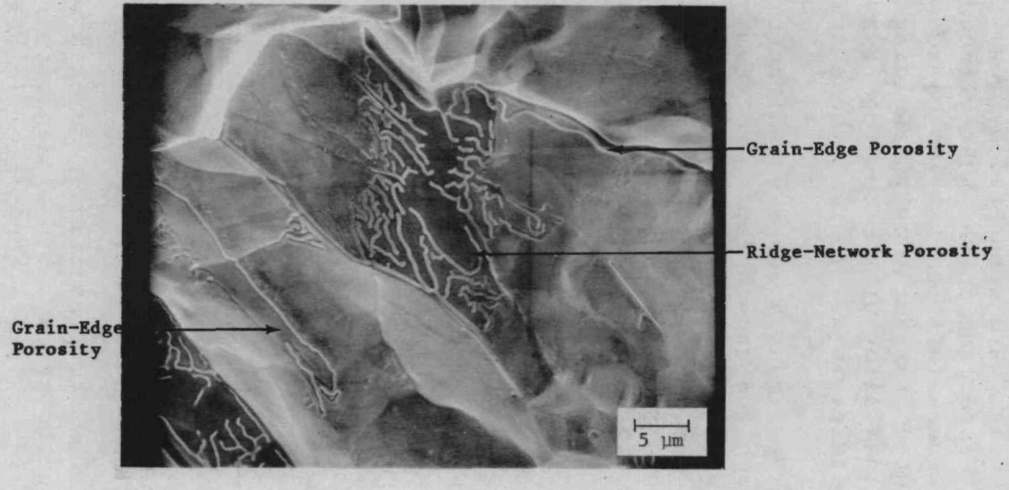


Figure 7. Porosity on Grains Boundaries in Heat-Affected Single-Pass Weld Area Near Cracks A and B

CVS T36

CVS T36 was welded by SRP-EED using the same parameters as used in PuFF Facility welding. The top and bottom cups were identified as MER 17-1 and MER 17-3, respectively. The girth weld was terminated with a long quench taper. The CVS was then rotated about 90°, and a short overlap weld was made, terminating in a second long taper quench. The portion of CVS T36 with the first quench was cut into eight strips across the quench region for SEM and SAM analyses. The portion with the second quench provided two specimens for high-temperature impact ductibility testing at ORNL.

Specimens of the interior weld bead at the beginning of the first quench are shown in Figure 8. Two small cracks where grain boundaries were separated by less than 2 μm were detected near the weld centerline in the heat-affected, single-pass weld ahead of the area where full penetration ceased (Figures 9 and 10). Two cracks oriented transverse to the welding direction extended out into unwelded alloy of the top cup (Figures 11 and 12). Grain boundaries in all four of these cracks had ridge network porosity.

Specimens 5 and 8 were fractured along the weld centerline through the quench taper and examined with the SEM. The quench (Figure 12) consisted of a double-pass weld area, a columnar grain area and a heat-affected, single-pass weld area just as observed for CVS T25. No ridge network porosity was detected in any of these areas. Figure 13 shows the grain-edge porosity and small pores distributed on grain faces in the heat-affected, single-pass weld area. High-resolution examinations of mating grain surfaces (Figures 14 and 15) revealed that these two types of porosity have structures similar to ridge network porosity.[4] Pore shapes on mating surfaces are mirror images of each other. Each region of porosity is surrounded by a rim. A thorium-bearing grain-boundary phase is located outside of this rim. When the weld was fractured, some of this thorium-bearing grain-boundary phase remained with each surface creating patterns where raised regions (phase present) mated with recessed regions (phase absent). These grain-boundary phase patterns are similar to the grain-boundary structures observed by ORNL in weld cracks in thorium-doped iridium alloy and attributed to "eutectic patches."[5] However, the studies at SRL have not confirmed the existence of two phases required to form a eutectic.

The strip containing Crack D was fractured across the weld along the crack. SEM examination revealed extended ridge network porosity on grain boundaries in heat-affected, single-pass weld area where the crack occurred but not in the double-pass weld area (Figure 16).

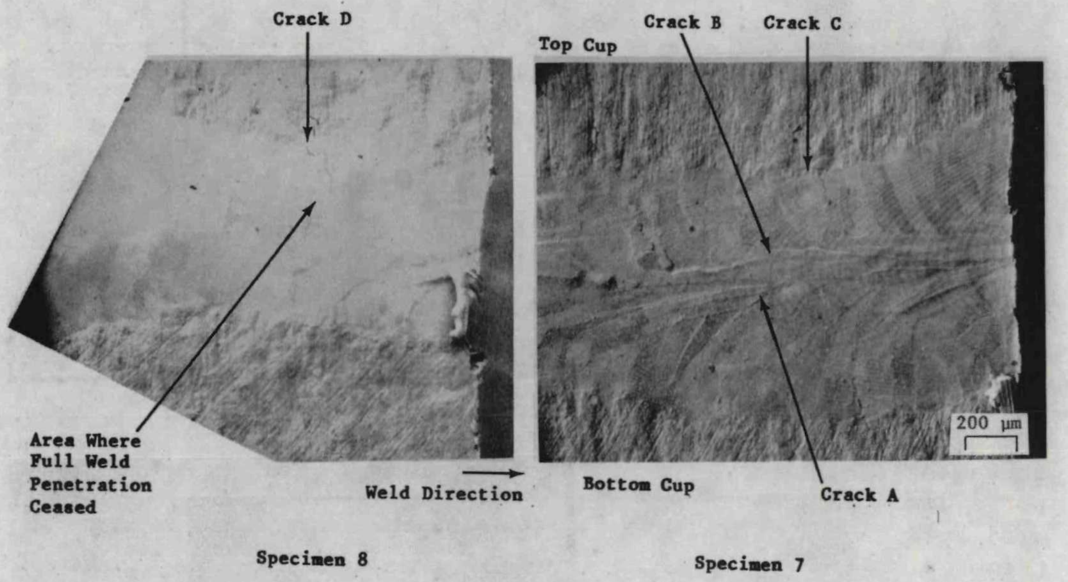


Figure 8. CVS T36 Specimens of Interior Weld Bead at the Beginning of the First Quench

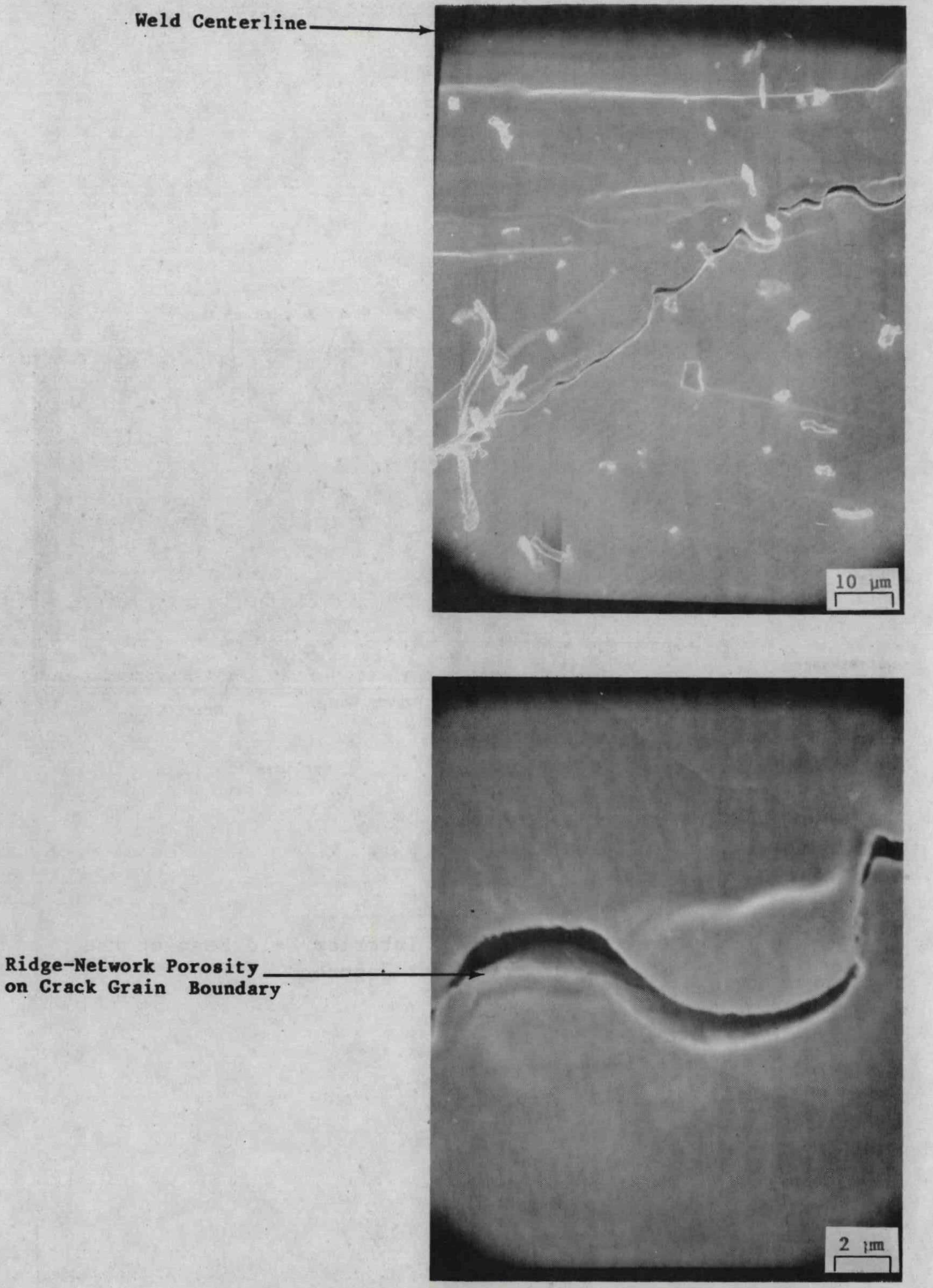


Figure 9. Small Crack A in CVS T36 Specimen 7

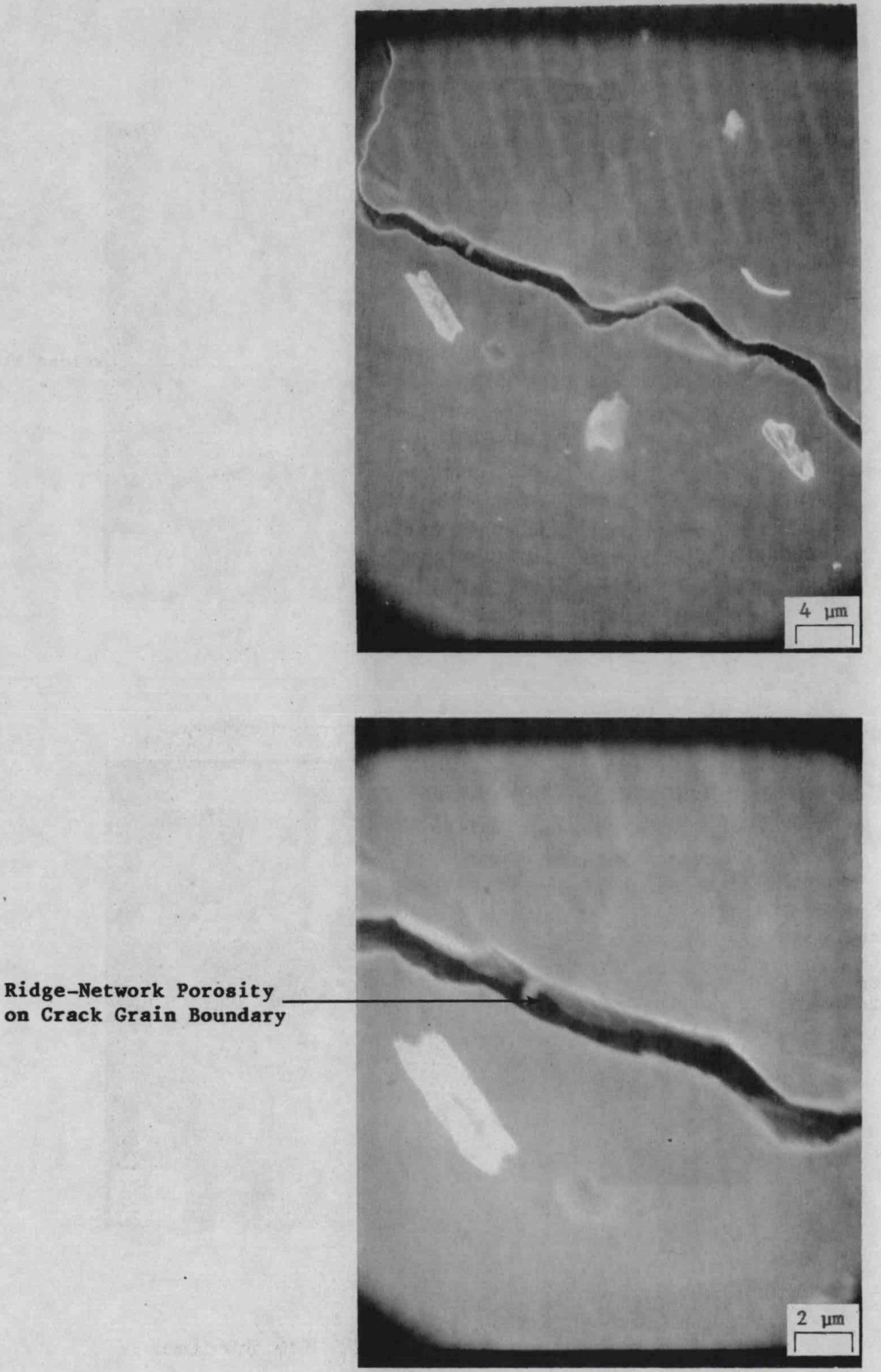


Figure 10. Small Crack B in CVS T36 Specimen 7

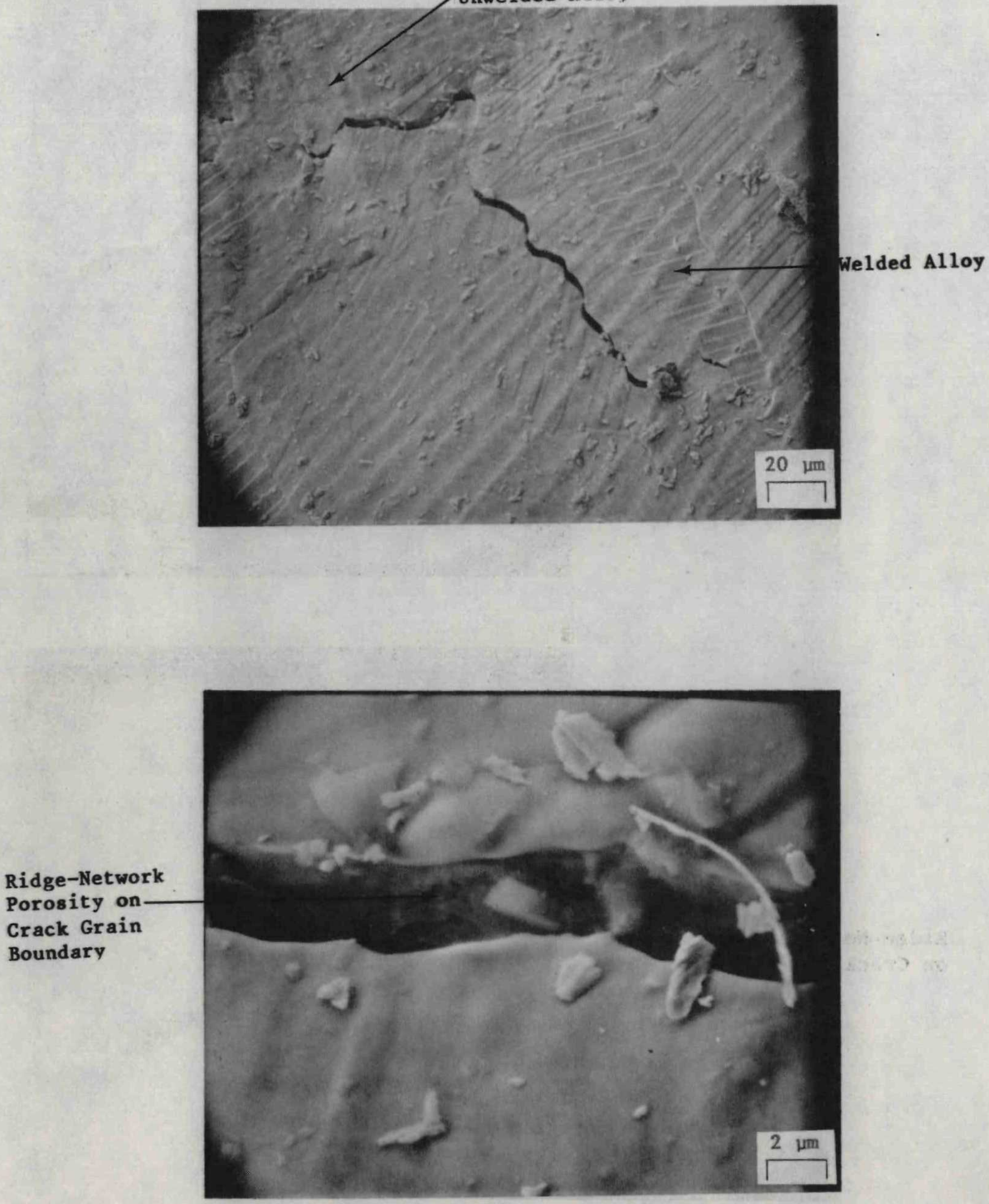


Figure 11. Crack C in CVS T36 Specimen 7

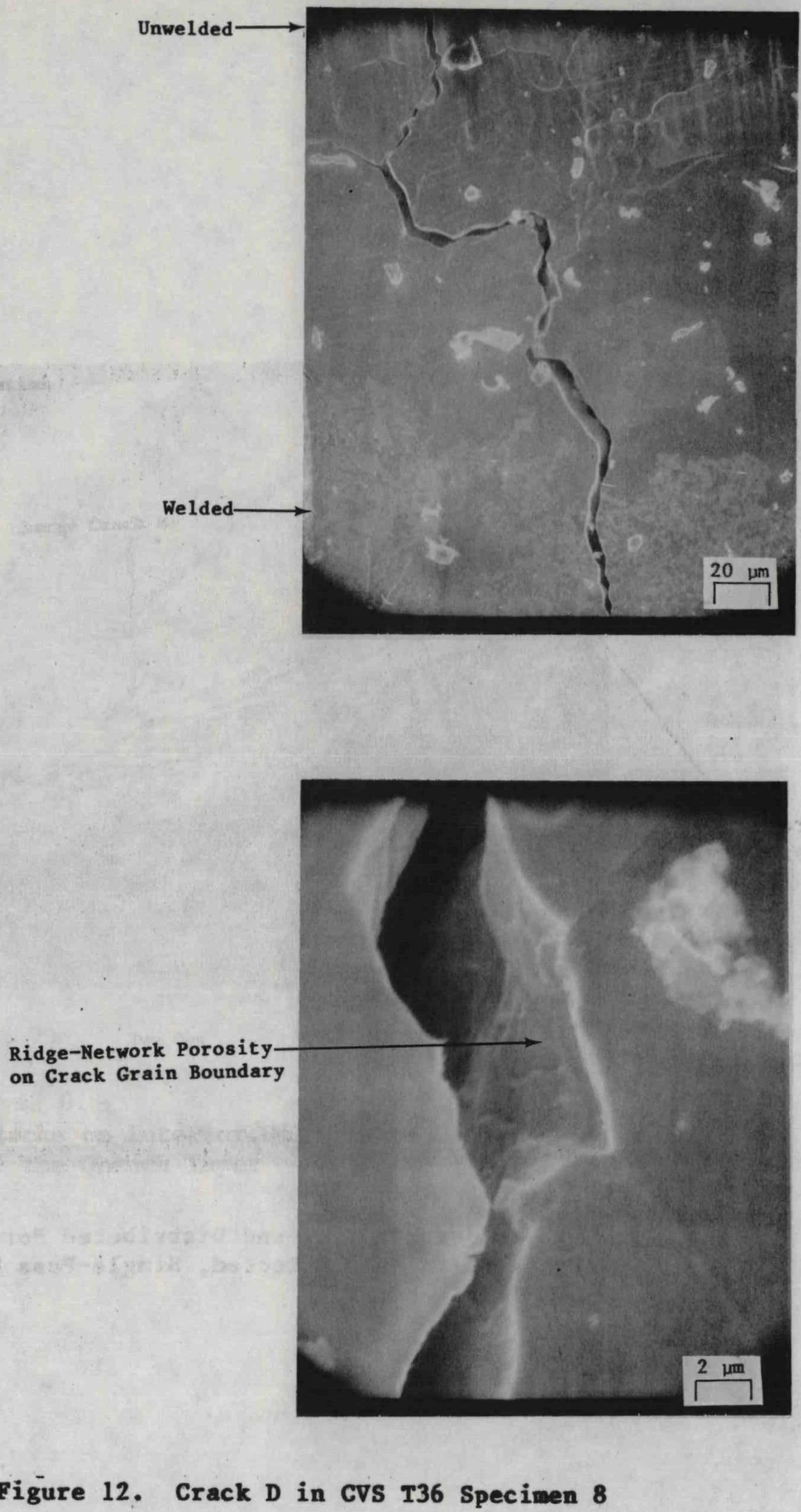


Figure 12. Crack D in CVS T36 Specimen 8

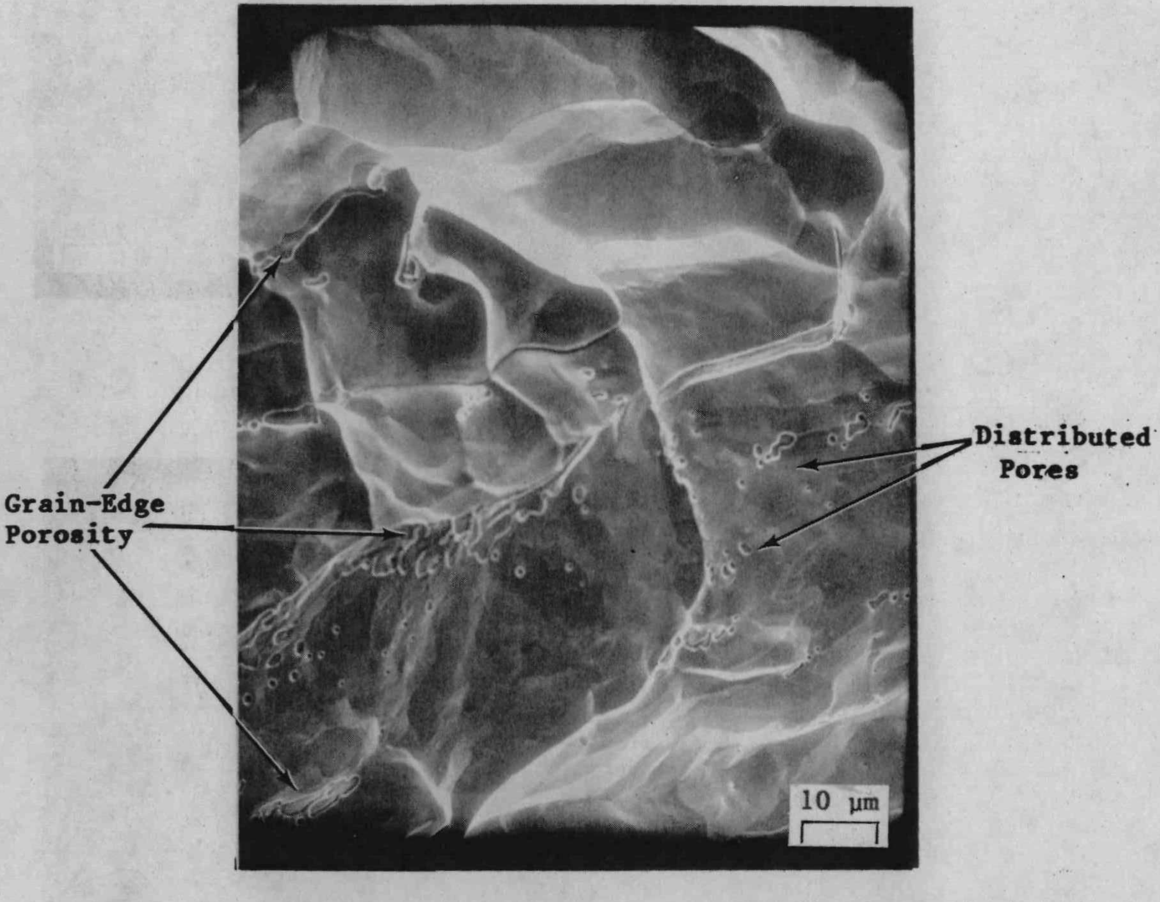


Figure 13. Grain-Edge Porosity and Distributed Pores on Grain Surfaces in Heat-Affected, Single-Pass Weld Area of CVS T36 Specimen 5

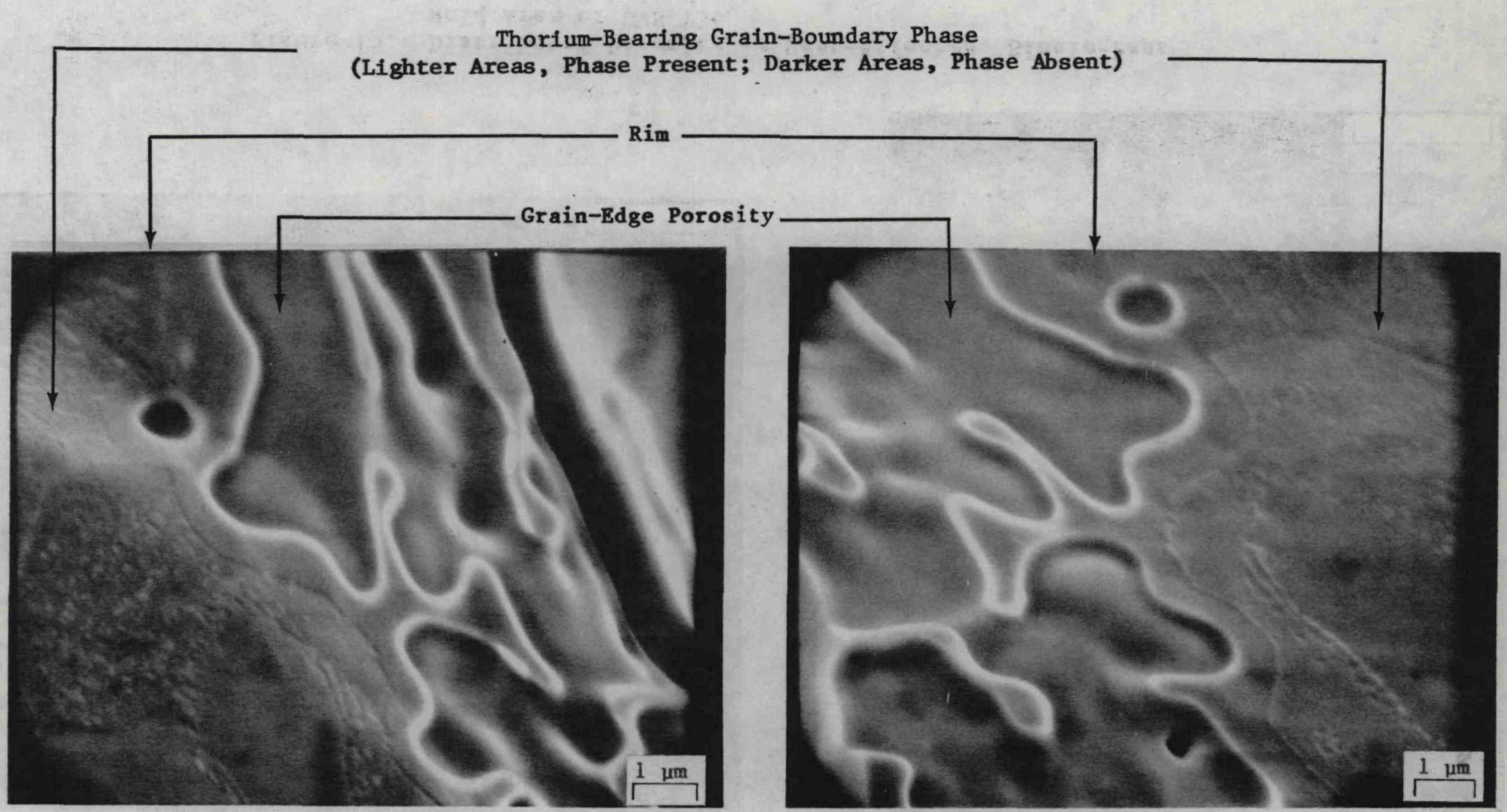


Figure 14. Grain-Edge Porosity in Heated-Affected, Single-Pass Weld Area of CVS T36

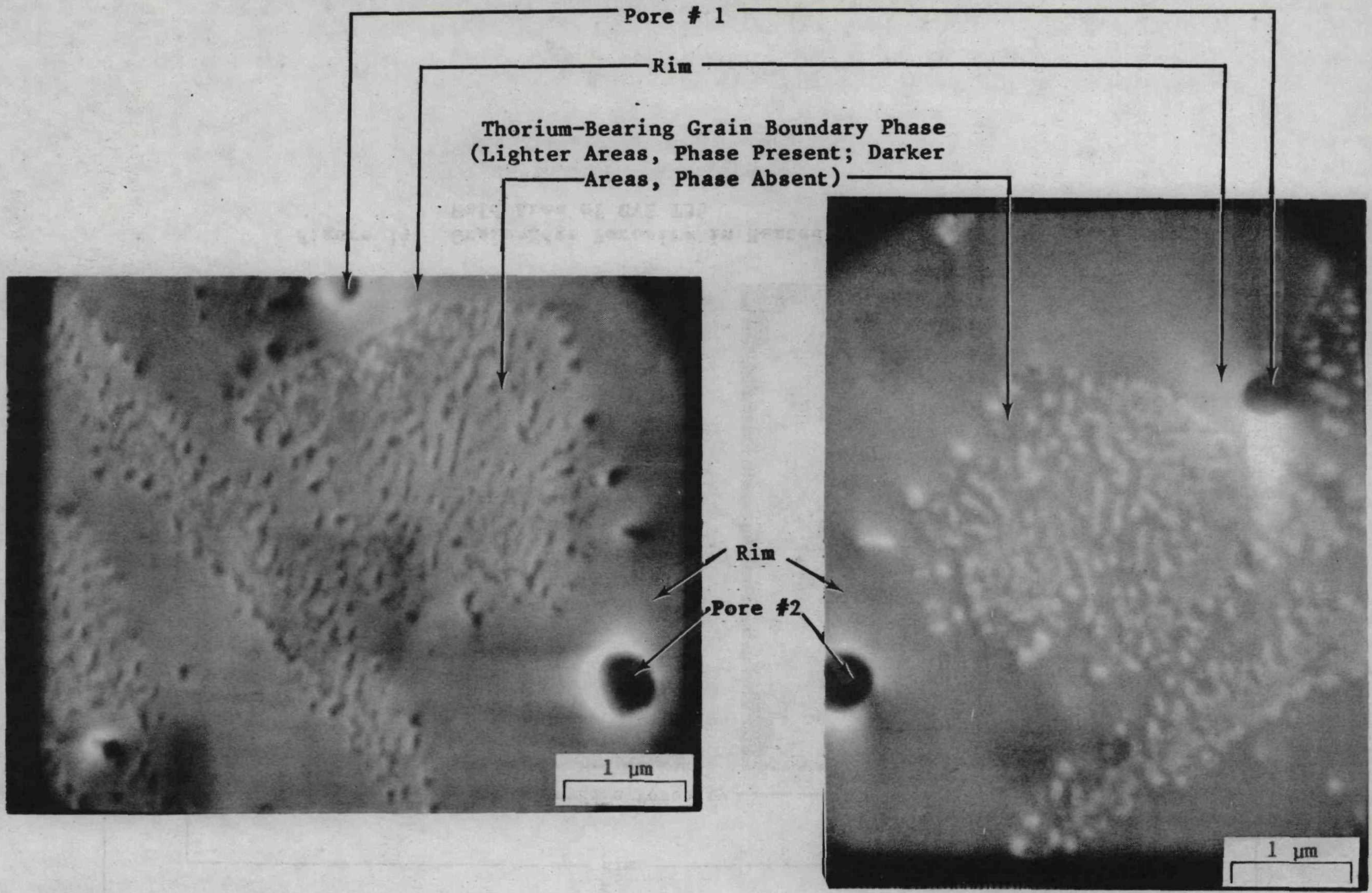


Figure 15. Distributed Porosity in Heat-Affected, Single-Pass Weld Area of CVS T36

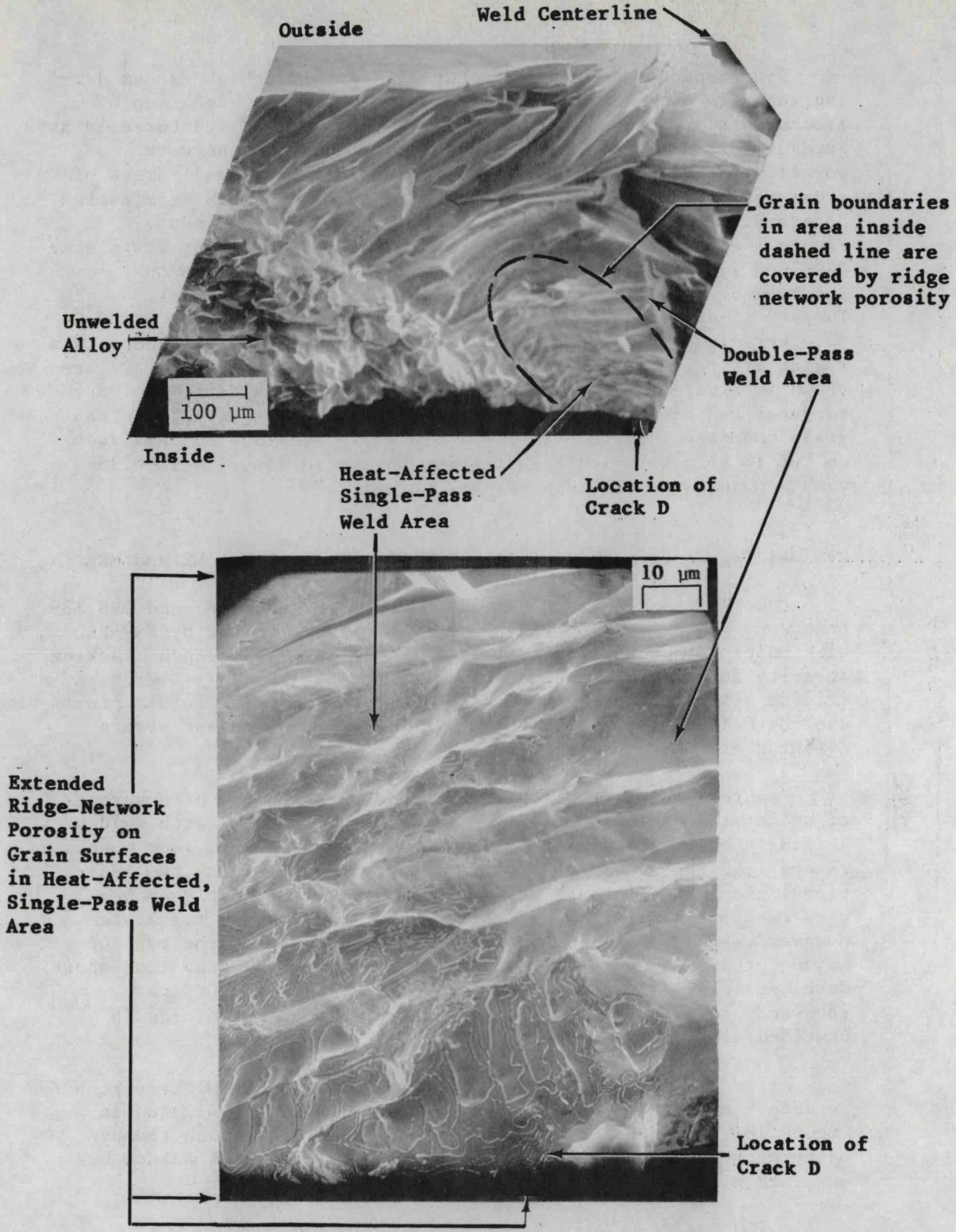


Figure 16. CVS T36 Specimen 8 Fractured Across Weld Along Crack D.

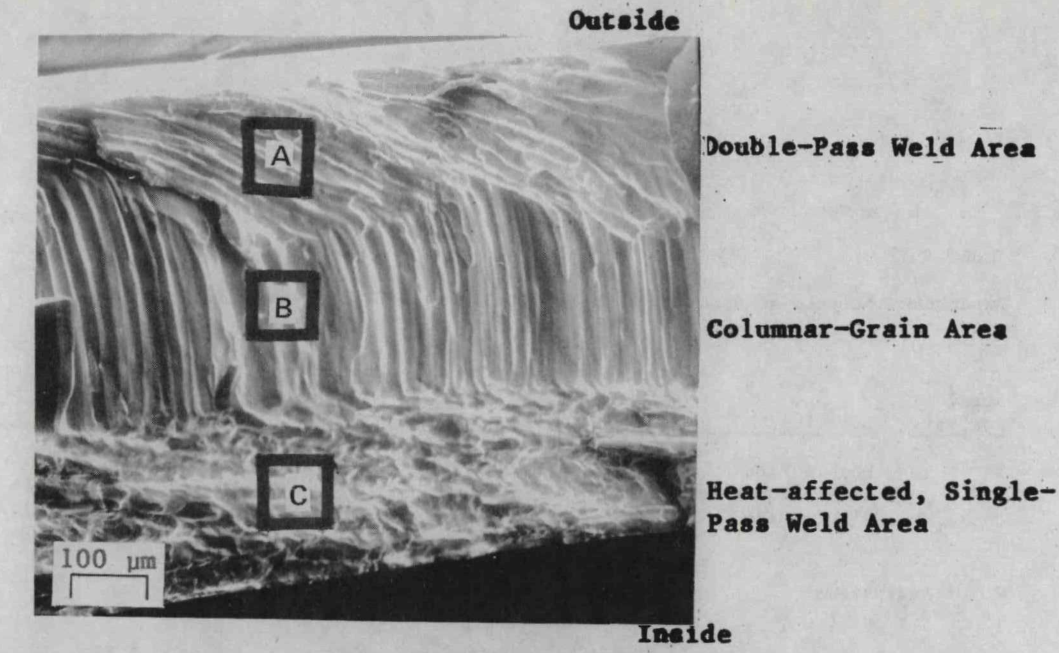
Specimens 6 and 7 were fractured under ultra-high vacuum during analyses with the high-resolution SAM at ORNL. Specimen 6 fractured along the weld centerline, but specimen 7 fractured in an irregular manner off the weld centerline. No ridge network porosity was detected during the SAM analyses, but small areas of ridge network porosity were detected in subsequent SEM examination on grain boundaries near the edge of the weld in Specimen 7. Figure 17a shows the double pass weld area (A), columnar grain area (B), and single-pass weld area (C) analyzed with the SAM on Specimen 6. Results are given in Table 1. In these areas, Th/Ir=0.11-0.16. Traces of carbon were detected in areas B and C. No other elements were detected. Analysis points associated with a region of grain-edge porosity in the single-pass weld area (C) are shown in Figure 17b, and results are also given in Table 1. Pore surfaces had higher thorium concentrations (Th/Ir=0.15-0.24) than grain-boundary surfaces (Th/Ir=0.05-0.13). Previous SAM analyses on CVS T2 also revealed high thorium concentrations (Th/Ir=0.36-0.45) on surfaces of ridge network porosity.[4]

CVS Welding Tests with Cups from DOP-26 Alloy Batches LR and MER

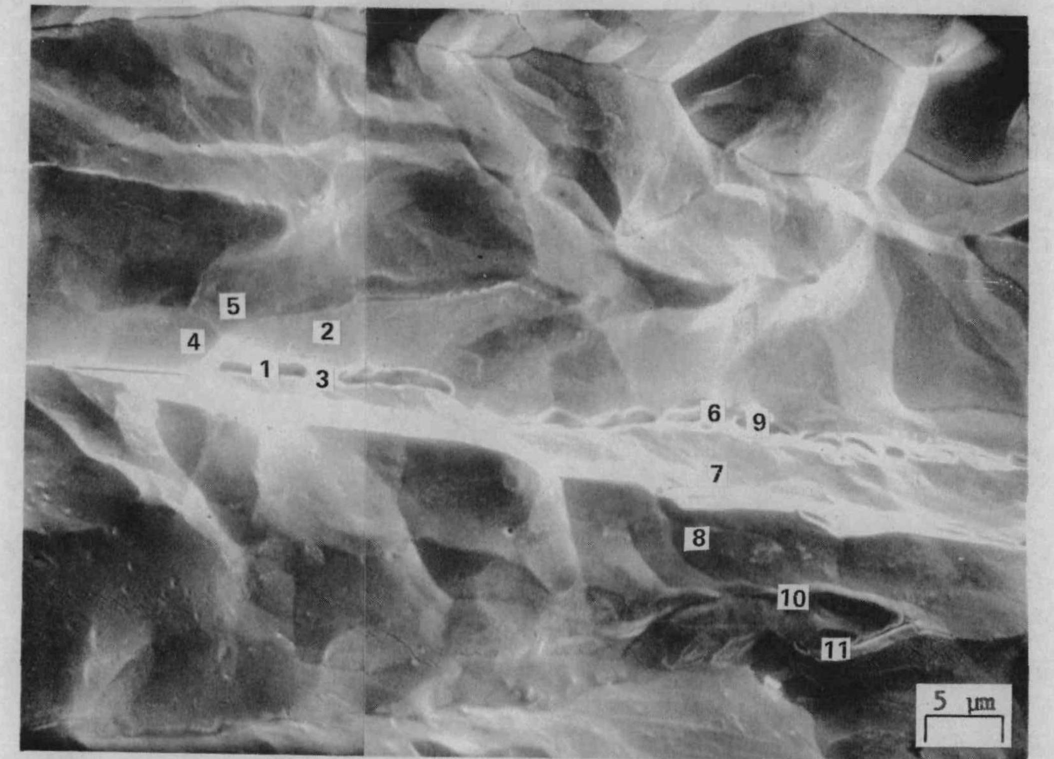
CVS T38 (top cup, LR316-6 and bottom cup, LR314-6) and CVS T39 (top cup, MER 5-7 and bottom cup, MER 5-6) were welded by SRP-EED with multiple quenches to statistically assess weld quench cracking severity and provide specimens for analytical studies. DOP-26 iridium alloy batch MER had caused the worst cracking in SRP production welding while batch LR had resulted in the least severe cracking.[2]

Figure 18 shows the location of the quenches on three series of welds made on the sidewall of each CVS. First, a girth weld joining the two cups was made using parameters (8 rpm, long quench taper) like those used in PuFF Facility welding. Then, two additional short, double-pass welds terminating with short quenches were made over the girth weld. Secondly, the CVS was translated downward, and another full-rotation weld was made in the top cup using production parameters. This weld was followed by four short double-pass welds with short quenches. Thirdly, the CVS was inverted, and six short welds with short quenches were made in unwelded alloy in the bottom cup.

After welding, each quench area was analyzed by ultrasonic NDE to detect cracking. Each CVS was then cut open as indicated in Figure 18, and quench areas were checked for cracks with the dye penetrant technique. Specimens were cleaned, and each quench was examined with the SEM.



a. Areal Analyses



b. Point Analyses in Area C

Figure 17. Locations on CVS T36 Weld Quench Specimen 6 Analyzed with SAM

TABLE 1

Super SAM Analysis of Specimen from Quench Taper of CVS T36 (see Figure 17)

		Auger Peak Intensity Ratios*			Estimated Atom Fractions			
Areal Analysis	Location	Th(67eV)/Ir(54eV)	C(272eV)/Ir(229eV)	O(503eV)/Ir(229eV)	Ir	Th	C	O
A	Double Pass	0.16	<0.29	<0.29	0.86	0.14	0	0
B	Columnar Grains	0.11	0.65	<0.25	0.76	0.08	0.16	0
C	Single Pass	0.15	0.60	<0.53	0.75	0.11	0.14	0
Point Analyses in Area C								
1	Pore	0.24	<0.67	<0.67	0.81	0.19	0	0
2	Grain Surface	0.05	<0.60	<0.60	0.95	0.05	0	0
3	Pore	0.18	<0.36	<0.36	0.85	0.15	0	0
4	Grain Surface	0.13	<0.45	<0.45	0.88	0.12	0	0
5	Grain Surface	0.06	<0.56	<0.56	0.94	0.06	0	0
6	Pore	0.22	<0.60	<0.60	0.82	0.18	0	0
7	Uncertain	0.21	<0.24	0.69	0.65	0.13	0	0.22
8	Grain Surface	0.09	<0.30	<0.30	0.92	0.08	0	0
9	Pore	0.15	<0.39	<0.39	0.87	0.13	0	0
10	Grain Surface	0.12	<0.33	<0.33	0.89	0.11	0	0
11	Grain Surface	0.14	<0.38	<0.38	0.88	0.12	0	0

---

* Peaks reported as < were not detected.

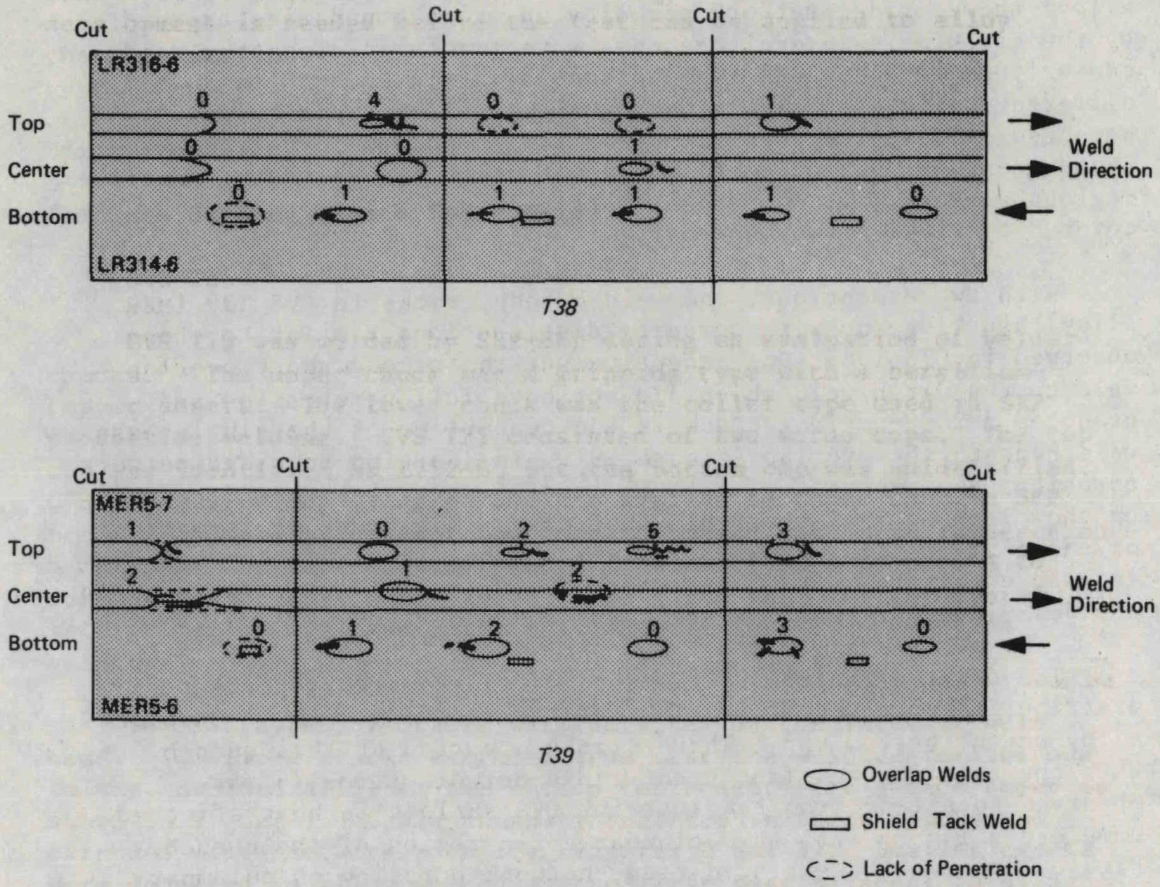


FIGURE 18. **Location of Cracks in Multiple Quench Areas of Welds in CVS T38 (LR-Batch Alloy) and CVS T39 (MER-Batch Alloy). Number of Cracks Shown above Each Weld Area.**

The number and location of cracks detected at each quench are indicated in Figure 18 and in Table 2. The results of this test confirm that weld quench cracking in MER alloy is more severe than that in LR alloy. The test also shows that cracking severity varies from quench-to-quench on each series of welds on both CVS T38 and CVS T39 and, thus, may be related to inhomogeneity of the alloy.

SEM examination of the weld quench cracks in CVS T38 (LR alloy) showed ridge network porosity on grain boundaries exposed by the cracking. Several quenches were fractured along the weld centerlines to allow SEM examinations of grain boundaries in different regions of the quench. Ridge network porosity was detected only in the heat-affected, single-pass weld regions of these quenches. Quenches that did not crack had scattered, small regions of porosity. Quenches that cracked had larger areas covered by ridge network porosity.

With two exceptions, the weld quench cracks in CVS T39 (MER alloy) had ridge network porosity distributions similar to those observed in CVS T38. One exception was the second short overlap weld on the girth weld which did not have full penetration and produced a 2000-µm-long crack in the centerline of the single-pass weld beneath the overlap (Figure 19). In addition to ridge network porosity, agglomerates of 5-10 µm iridium particles were detected on the crack surface near the inner edge. The cause of formation of these small iridium particles and whether they influence cracking are uncertain. ORNL has detected similar iridium structures in cup delaminations that intersect the surface.[6]

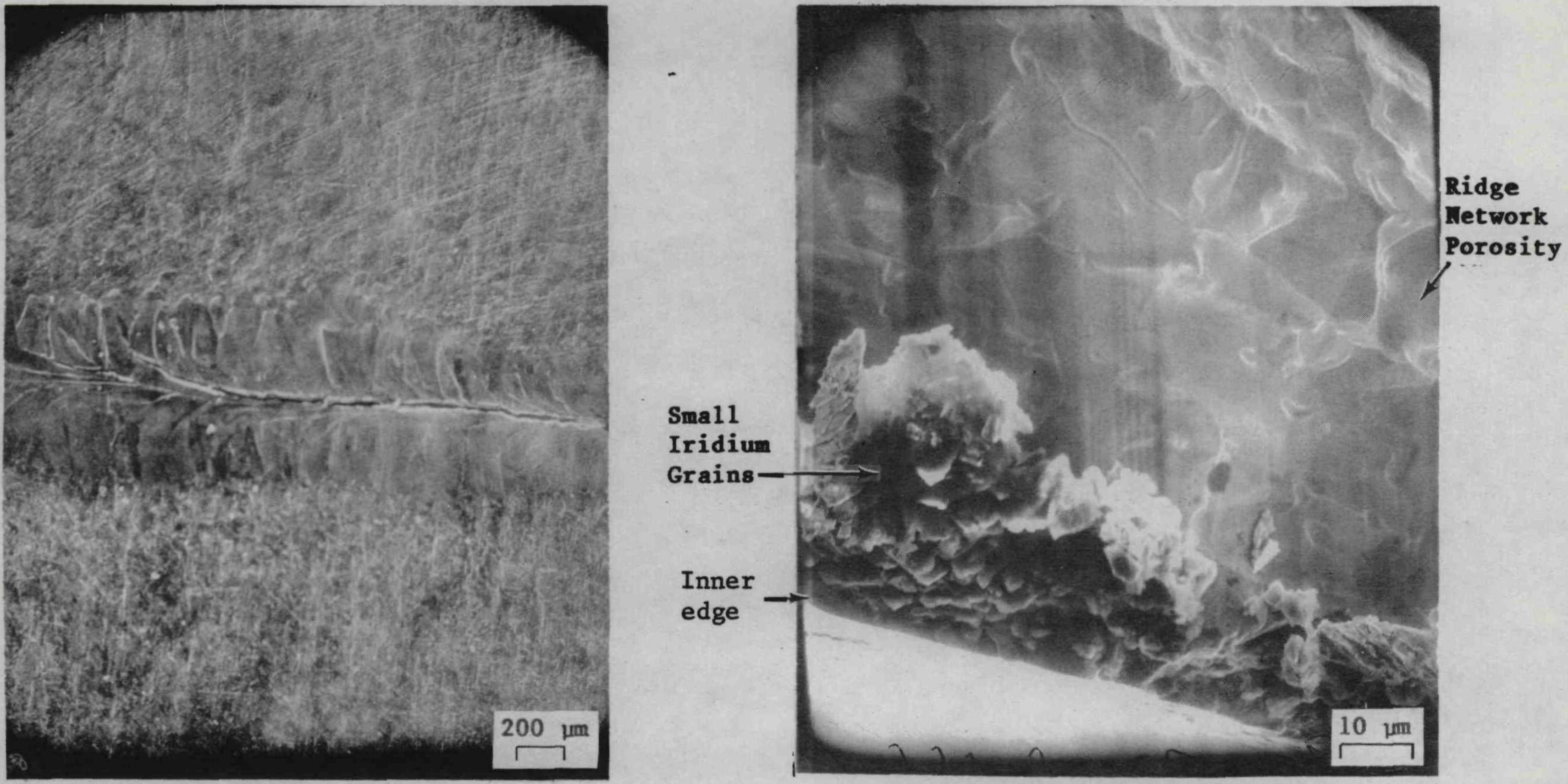
The other exception to the type of ridge-network-porosity distribution observed in CVS T39 was the second quench in unwelded alloy on the bottom cup. Three cracks occurred at this quench. When the specimen was fractured, ridge-network porosity was observed to extend from the interior CVS surface in heat-affected unwelded alloy up into the columnar grain region of the quench. Figure 20 shows the extended ridge-network porosity on columnar grain boundaries. Thorium was detected in micron-size precipitates and scattered patches of a thorium-bearing grain-boundary phase but not on ridges or pore surfaces. This observation that ridge-network porosity can form on the columnar grains explains why the trapezoidal-type cracks identified by SRP metallography extend up into the columnar grain region.[7]

Specimens of the long quench tapers in the top cups of T38 and T39 have been analyzed by secondary ion mass spectrometry (SIMS) using ion microscopes at Charles Evans and Associates in Stanford, California. An effort will be made to correlate differences in elemental concentrations and/or distributions with the differences in weld quench cracking severity of LR and MER alloy. Results are being interpreted and will be discussed in the April-June report.

TABLE 2

Cracks in Quench Regions of CVS Welds

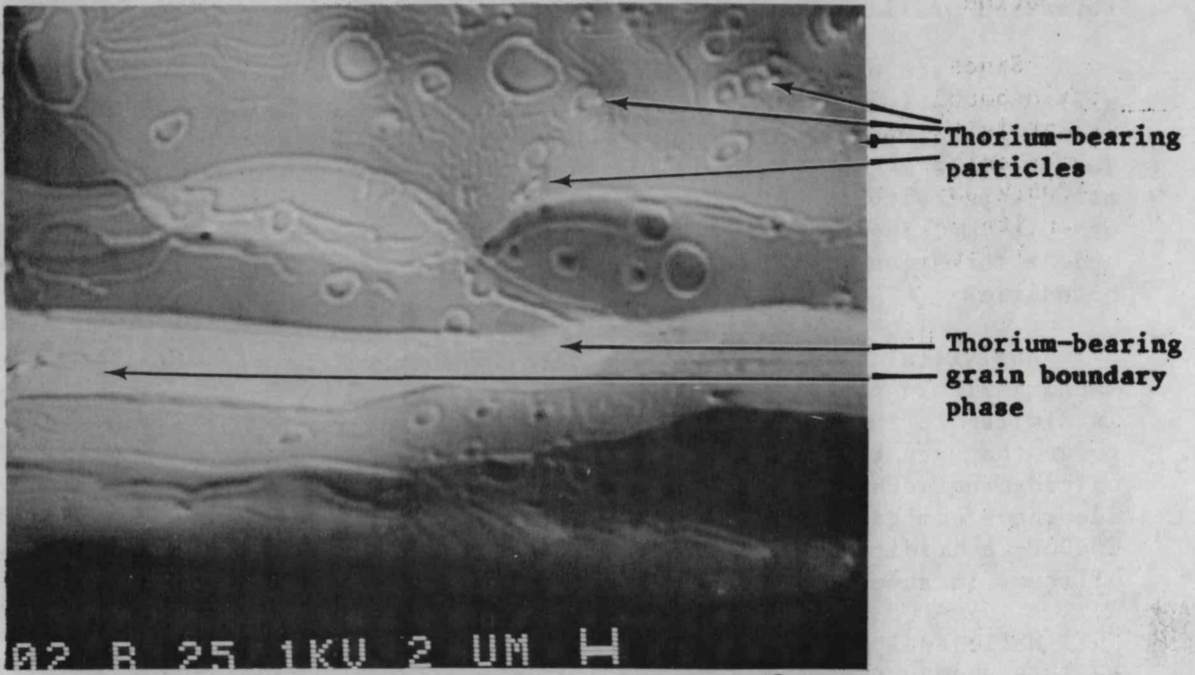
	CVS T38 (LR Alloy)			CVS T39 (MER Alloy)		
Type of Quench	No. of Welds Cracked	No. of Cracks	Max. Length, µm	No. of Welds Cracked	No. of Cracks	Max. Length, µm
Long (2)	0	0	0	2	2	850
Short (6)	3	6	650	5	13	2000
Short (6) (in unwelded alloy)	4	4	500	3	6	350



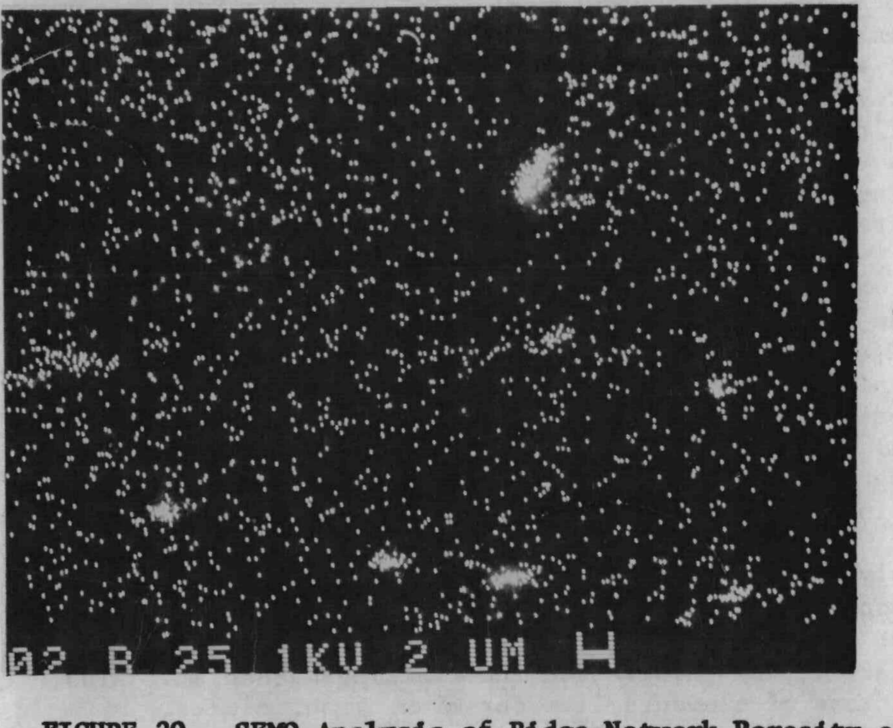
a. Large crack

b. Small iridium grains and ridge network porosity on crack surface

Figure 19. Large Crack Under Short Overlap Weld with Incomplete Penetration on Girth Weld of CVS T39



BSE Image



Thorium Map

FIGURE 20. SEMQ Analysis of Ridge-Network Porosity on Columnar Grains of the Second Weld Quench on the Bottom Cup of CVS T39.

Formation of Ridge-Network Porosity

Since ridge-network porosity is a characteristic feature of grain boundaries in weld quench cracks, efforts are being made to identify the mechanism responsible for producing this porosity. Two possible mechanisms have been identified that could cause ridge network porosity to form when DOP-26 iridium alloy is heated to near its melting point: 1) migration of gas to grain boundaries, and 2) formation of a low-melting phase or eutectic on grain boundaries.

Analytical studies to date generally support the gas porosity mechanism. In particular, the structure of ridge-network porosity is similar to the structures of grain-edge porosity and distributed pores that are typical forms of gas porosity. The carbon detected on ridge network surfaces by SAM analysis could presumably be adsorbed from gas in the porosity. ORNL has also detected porosity in DOP-26 iridium alloy in the forms of gas voids in ingots and blisters in sheets.[8,9]

While analytical studies have been directed at characterizing grain boundary features associated with cracking, analyses with the SEM and scanning electron microprobe quantometer (SEMQ) have indicated that ridges and areas between ridges in ridge networks have the same composition as bulk DOP-26 iridium alloy with thorium concentrations at or below the detectability limit of ~0.03 weight percent. Grain-boundary phases with thorium concentrations up to 8 weight percent are located outside of the ridge networks. However, SAM analyses revealed more thorium in the outer few atomic layers of surfaces of ridge networks (Th/Ir = 0.4 atom ratio) than on grain surfaces outside ridge networks (Th/Ir = 0.2). The presence of a low-melting phase or eutectic in ridge-network porosity cannot be concluded from these analytical results.

The observation that weld-quench cracking for MER alloy is much worst than that caused by other alloy batches suggests that cracking is related to differences in composition. Reported chemical analyses showed that MER cups used in SRP production weld had higher thorium contents (67.2 ±23.6 ppm) than L cups (56 ±24 ppm Th) and LR cups (51.4 ±25.6 ppm Th). Concentrations of chromium, copper, iron, nickel, and rhodium in MER cups were significantly lower than in L and LR cups.

While analyses to date have not succeeded in identifying the mechanism responsible for producing ridge network porosity, results do suggest that elements like thorium and carbon, which segregate to grain boundaries, are involved in the cracking mechanism. Also, some concentrations of elements like chromium, iron, nickel, copper, and rhodium may be beneficial in retarding the cracking mechanism. Efforts are being made to correlate cracking severity with differences in elemental concentrations and/or distributions as determined by secondary ion mass spectroscopy and spark source mass spectrometry.

Improved Spark Source Mass Spectrometric Analyses for Thorium in DOP-26 Iridium Alloy

Efforts to correlate weld-quench cracking with thorium content in DOP-26 iridium alloy cups requires more accurate analyses that are presently available. Recent development at SRL has shown that the new JEOL SSMS equipped for electrical detection of ion beam signals can analyze thorium in DOP-26 alloy with a precision better than 10%. Specimens of archive rings of MER cups that had severe cracking and LR cups that had no cracking as determined by NDE of SRP production welds were analyzed by single SSMS analyses at SRL and with an isotopic dilution method at ORNL. Results are given in Table 3 and presented graphically in Figure 21. Two specimens from CVS cups analyzed many times by SSMS and shown to produce reproducible results are awaiting isotopic dilution analysis to provide calibration of the SSMS technique. Additional archive ring specimens have been identified for SSMS analyses to provide better correlation between thorium concentration and weld quench cracking.

DOP-26 Weldability Test Development at ORNL

ORNL was funded by SRP to develop a discriminatory weldability test for DOP-26-iridium alloy. The test developed by ORNL involves making 7/8-inch and 1-3/8-inch-diameter-circular welds on alloy disks produced at ORNL. Weld cracking showed differences in weldability for several alloy batches. Batches L, S, and T had better weldabilities than batches R and MER. Alloys with thorium contents below the 30-ppm specification limit seemed to have better weldabilities than alloys meeting specifications. ORNL feels that additional development is needed before the weldability tests can be used for product control.

SRL is concerned that the weld cracking produced by the ORNL weldability test is not the same as the weld quench cracking occurring in SRP production welding. The weld quench cracks occur ahead of the weld front, and grain boundaries in cracks have the characteristic ridge network structure. The weldability test produces cracks behind the weld front. Similar cracking in linear bead-on-plate welds was shown to be related to the thorium contents of the iridium alloys, and grain boundary surfaces were characterized by "eutectic patches."[5] At SRL's request, ORNL will send weldability test specimens to SRL for SEM examinations to see if crack grain boundaries have ridge networks. These examinations will confirm that the cracking mechanism in the weldability test is the same as that causing weld quench cracking in SRP production welding.

TABLE 3

Thorium Analyses of DOP-26 Iridium Alloy Archive Ring Specimens

Cup Identification	Isotopic Dilution Analyses Th (ppm)	Isotopic Dilution Analysis of ORNL Archive Samples	ORNL SSMS Th (ppm)	SRL SSMS Q (Th)/Q (Ir)
LR 280-7	41.4	43.1	41.0	5144
LR 295-7	53.4	53.5	47.0	5,895
LR 310-5	17.2	17.0	40.0	2,269, 2,289
LR 310-6	48.9	17.0	40.0	5,557
MER 4-7	73.6	NR	79.0	1,0847
MER 4-4	71.5	NR	79.0	9,839
MER 11-4	67.4	NR	60.0	8,856
MER 11-5	NR	NR	60.0	10,317

Thorium Analyses of DOP-26 Iridium Alloy Specimens for SSMS Calibration

Cup Identification	Isotopic Dilution Analyses Th (ppm)	ORNL SSMS Th (ppm)	SRL SSMS Q (TH)/Q (Ir)
L 246-5	NR	63.0	5500
MER 17-3	NR	80.0	9900

Q - Integrated Ion Beam Current.
NR - Not reported to date.

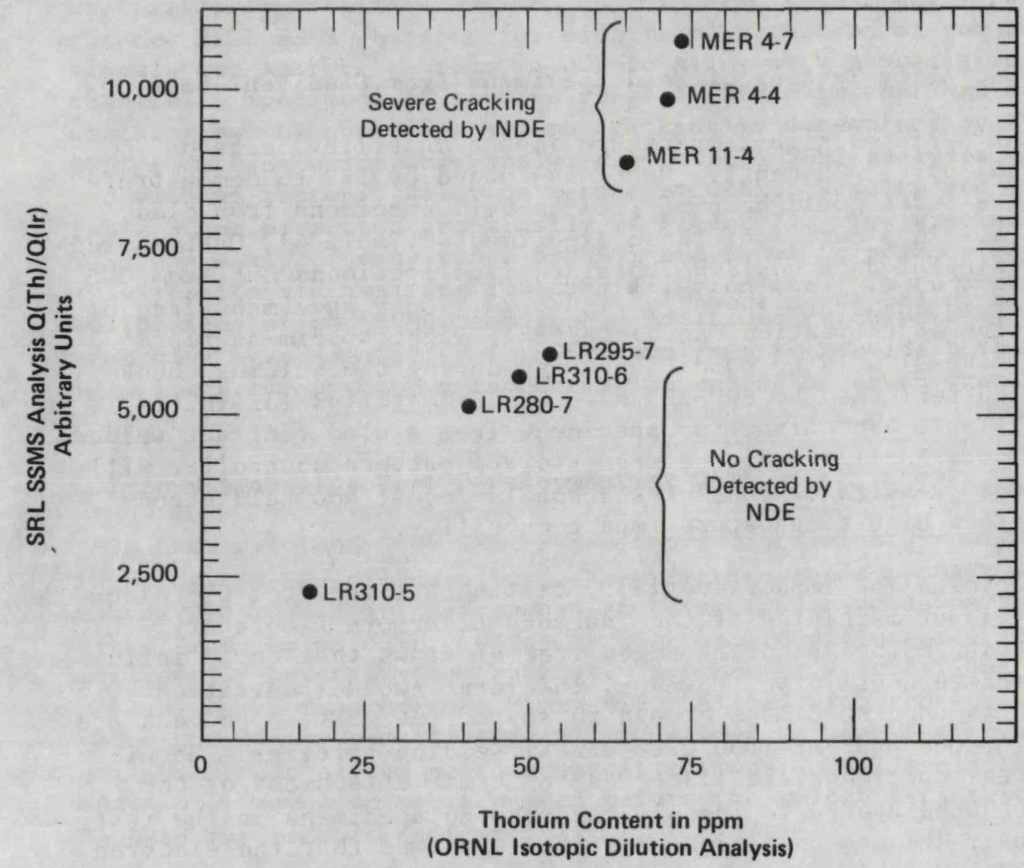


Figure 21. Comparison of SRL SSMS and ORNL Isotopic Dilution Analyses of DOP-26 Iridium Alloy Archive Rings

SRL recommends that an alternative weldability test be considered. In this test, ORNL and Mound Facility would supply cups from new alloy batches to SRP as soon as possible. These cups would be welded by SRP-EED using production welding parameters and multiple quenches to statistically determine weld quench cracking severity. A determination of relative susceptibility for weld quench cracking for new alloy batches would be made by comparing the number and sizes of cracks with results of similar tests on cups from alloy batches for which PuFF Facility production welding results are available. The iridium alloy would not be contaminated with plutonium and could be returned to ORNL for recovery.

Impact Ductility Testing of Weld Specimens from Clad Vent Sets

ORNL performs high-temperature impact ductility tests on iridium alloys.[10] Recently, ORNL was funded by SRP to demonstrate that these tests could be performed on weld specimens from clad vent sets. In a series of three experiments (Table 4), ORNL showed that meaningful data could be obtained from specimens cut from CVS sidewells in the shape shown in Figure 22. Only specimens free of radioactive contamination can be tested. Eight specimens representing several welding conditions used during the welding chuck evaluation performed by SRP-EED have been identified for initial testing (Table 4). Also, two specimens from a clad vent set welded at the Mound Facility using a magnetic arc pattern controller will be tested. Results of these tests should reveal how weld structures affect high-temperature impact ductility.

Specimens for impact ductility testing are cut from CVS sidewalls by laser machining at the Lawrence Livermore Laboratory. This cutting method produces edges free of flaws that could influence specimen ductility. However, the first two demonstration experiments used specimens ground to shape. At ORNL, specimens are heated for one hour at 1500°C to anneal welding stresses. Shoulders of the specimens are flattened to permit attachment of the extension tabs needed to install the subsize specimens in the test apparatus. The demonstration experiments showed that the electron beam welds attaching the extension tabs to the specimens must be very strong to prevent their fracture during testing. Specimens are tested at 980°C at an impact velocity of 200 feet/second (61 m/s). Elongation is determined by measuring changes in distances between hardness indentations on the specimen surfaces.

The specimens listed in Table 5 will be tested using the same conditions used in the third demonstration experiment. It is interesting to note that specimen T29E of a single-pass weld made using SRP production welding parameters was more ductile than the unwelded alloy. The 18.9% elongation measured for this specimen is much higher than the 10% expected for such welds and is the same as the 15-20% measured for base metal.[11]

TABLE 4

ORNL Demonstration of High-Temperature Impact Ductility Testing of Specimens from Clad Vent Sets

		Test Results	
	Specimen Description	Location of Fracture	Elongation, %
Experiment 1	Unwelded alloy from scrap CVS; ground to shape	Tab weld	>9.0
	Single-pass weld from scrap CVS; ground to shape	Tab weld	>7.4
Experiment 2	Single-pass weld from CVS T24; laser cut to shape; ground to 0.100-inch-gauge width; improved tab weld	T24A-weld (tear in pin hole in extension tab)	10.4
		T24B-weld	7.1
Experiment 3	Single-pass welds from CVS's T26 and T29; laser cut to shape; improved tab weld	T26C-weld	10.6
		T29E-unwelded alloy (tab joint also failed)	18.9

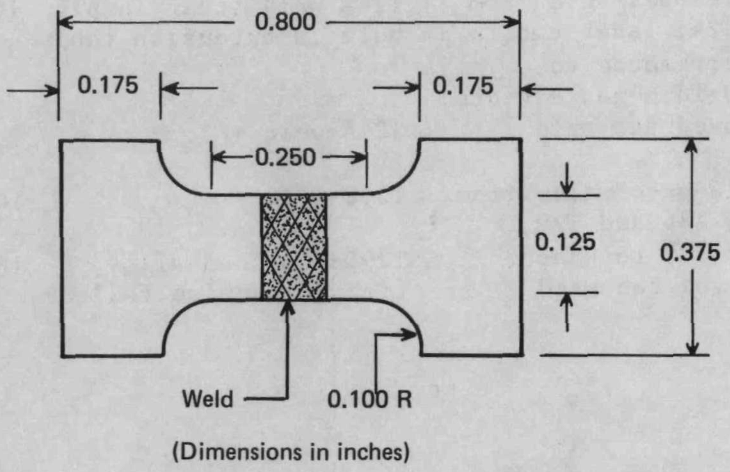


FIGURE 22. Weld Specimen for High-Temperature Impact Ductility Testing as Laser-Machined from a Clad Vent Set

TABLE 5

CVS Weld Specimens for High-Temperature Impact Ductility Testing

Identification		
Choice	Backup	Description
T29B	T29C	Single-pass weld; cups LR291-2 and NR 518R-4; production welding parameters
T26D	None	Single-pass weld; cups LR289-2 and N511-2; matched chucks; 8 rpm
T30B & C	T30E	Single-pass weld; cups M 422-2 and L260-4; minimum chill chucks; 8 rpm
T32B & C	T32A	Single-pass weld; cups MER 4-6 and LR302-6; matched chucks; 5 rpm
T36A & B	T36C	Quench taper; cups MER 17-1 and MER 17-3; production welding parameters
MFA & MFB	MFC	Single-pass weld; welded at Mound Facility using a magnetic arc pattern controller

REFERENCES

1. **^{238}Pu Fuel Form Processes Quarterly Report, April - June 1981.** USDOE Report DPST-81-128-2, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1981).

2. **Pu-238 Fuel Form Activities, January 1-31, 1982.** USDOE Report DPST-82-133-1, E. I. du Pont de Nemours and Co., Savannah River Laboratory and Plant, Aiken, SC (1982).

3. **Pu-238 Fuel Form Activities, September 1-30, 1981.** USDOE Report DPST-81-133-9, E. I. du Pont de Nemours & Co., Savannah River Laboratory and Plant, Aiken, SC (1981).

4. **^{238}Pu Fuel Form Processes Quarterly Report, July - August 1981.** USDOE Report DPST-81-128-3, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (1982).

5. S. A. David and C. T. Liu. "Weldability and Hot Cracking in Thorium-Doped Iridium Alloys," **Metals Technology, 7,** 102 (1980).

6. **Technical Highlights of Space and Terrestrial Systems Programs at Oak Ridge National Laboratory for January 1981.** USDOE Report ORNL/CF-81/55, Oak Ridge National Laboratory, Oak Ridge, TN (1981).

7. **Pu-238 Fuel Form Activities, November 1-30, 1981.** USDOE Report DPST-81-133-11, E. I. du Pont de Nemours & Co., Savannah River Laboratory and Plant, Aiken, SC (1982).

8. **Technical Highlights of Space and Terrestrial Systems Programs at Oak Ridge National Laboratory for December, 1980.** USDOE Report ORNL/CF-81/34, Oak Ridge National Laboratory, Oak Ridge TN (1981).

9. **Technical Highlights of Space and Terrestrial Systems Programs at Oak Ridge National Laboratory for March, 1981.** USDOE Report ORNL/CF-81/84, Oak Ridge National Laboratory, Oak Ridge, TN (1981).

10. C. T. Liu, H. Inoye, and A. C. Schaffhauser. "Effect of Thorium Additions on Metallurgical and Mechanical Properties of Ir-0.3 pct W Alloys." **Met. Trans. A, 12A,** 993 (1981).

11. **Technical Highlights of Isotopic Power Materials Development at ORNL for September 1979.** USDOE Report ORNL/CF-79/329, Oak Ridge National Laboratory, Oak Ridge, TN (1979).

DISTRIBUTION

Copy No.	
1	F. E. Coffman, Acting Director, Office of Coordination and Special Projects, U. S. Department of Energy
2	B. J. Rock, Acting Director, Space Systems, U. S. Department of Energy
3	J. J. Lombardo, Space Systems, U. S. Department of Energy
4	G. Bennett, Space Systems, U. S. Department of Energy
5	H. Roser, Asst. Secretary for Defense Programs, U. S. Department of Energy
6	A. W. Whiteman, Albuquerque Operations Office
7	D. L. Krenz, Albuquerque Operations Office
8	H. N. Hill, Manager, Dayton Area Office
9	R. D. Baker, CMB, DO, Los Alamos National Laboratory
10	S. E. Bronisz, CMB-5, MS-730, Los Alamos National Laboratory
11	R. A. Kent, Los Alamos National Laboratory
12	R. Behrens, Los Alamos National Laboratory
13	W. T. Cave, Monsanto Research Corporation
14	B. R. Kogenge, Monsanto Research Corporation
15	Technical Library, Sandia National Laboratories
16	T. J. Young, Sandia National Laboratories
17	W. Whitmore, General Electric Company
18	R. H. Cooper, Oak Ridge National Laboratory
19	W. Pardue, Battelle Memorial Institute
20	G. Linkous, Teledyne Energy Systems
21	R. W. Englehart, NUS Corporation
22-27	Savannah River Operations Office, DOE
28-63	Savannah River Laboratory, TIS Files
64-65	Technical Information Center, Oak Ridge, TN