March 25, 2002

TO: NRC Document Control Desk

Re: Vepco to NRC Letter dated 3/22/02; Serial No. 02-130

Please be advised that the attachment to the above letter, "Metallurgical Investigation of Cracking of the Alloy 82/182 J-Groove Weld of the Reactor Vessel Head Penetration Joint at North Anna Unit 2 Station" (WCAP-15777) is NOT a proprietary document even though the document is marked as Westinghouse Proprietary Class 3. Westinghouse has advised us that this document is not proprietary and may be released to the public.

Maggie McClure
Corporate Nuclear Licensing
(804) 273-2200

VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

March 22, 2002

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No. 02-130
NL&OS/ETS R0
Docket No. 50-339
License No. NPF-7

Gentlemen:

VIRGINIA ELECTRIC AND POWER COMPANY
NORTH ANNA POWER STATION UNIT 2
SUPPLEMENTAL INFORMATION - NRC BULLETIN 2001-01 CIRCUMFERENTIAL CRACKING OF REACTOR VESSEL HEAD PENETRATION NOZZLES
RESULTS OF METALLURGICAL INVESTIGATION OF ALLOY 82/182 CRACKING

In a letter dated January 11, 2002 (Serial No. 01-490E), Virginia Electric and Power Company (Dominion) provided the results of the reactor vessel head penetration nozzle inspections and associated repair activities for North Anna Unit 2. As part of the repair effort, a material sample was removed from penetration 62 for metallurgical examination by Westinghouse. WCAP-15777, "Metallurgical Investigation of Cracking of the Alloy 82/182 J-Groove Weld of the Reactor Vessel Head Penetration Joint at North Anna Unit 2 Station," contains the metallurgical results of the boat sample analysis taken from the North Anna 2 head during the Fall 2001 outage and is attached for your review.

If you have any questions or require additional information, please contact us.

Very truly yours,

Leslie N. Hartz
Vice President – Nuclear Engineering

Attachment

Commitments made in this letter: None

A088

cc: U.S. Nuclear Regulatory Commission
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SN: 02-130
Docket No.: 50-339
Subject: Supplemental Information – NRC Bulletin 01-01

COMMONWEALTH OF VIRGINIA)
)
COUNTY OF HENRICO)

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Leslie N. Hartz, who is Vice President - Nuclear Engineering, of Virginia Electric and Power Company. She has affirmed before me that she is duly authorized to execute and file the foregoing document in behalf of that Company, and that the statements in the document are true to the best of her knowledge and belief.

Acknowledged before me this 22nd day of March, 2002.

My Commission Expires: March 31, 2004.

Maggie McClure
Notary Public

(SEAL)

Attachment

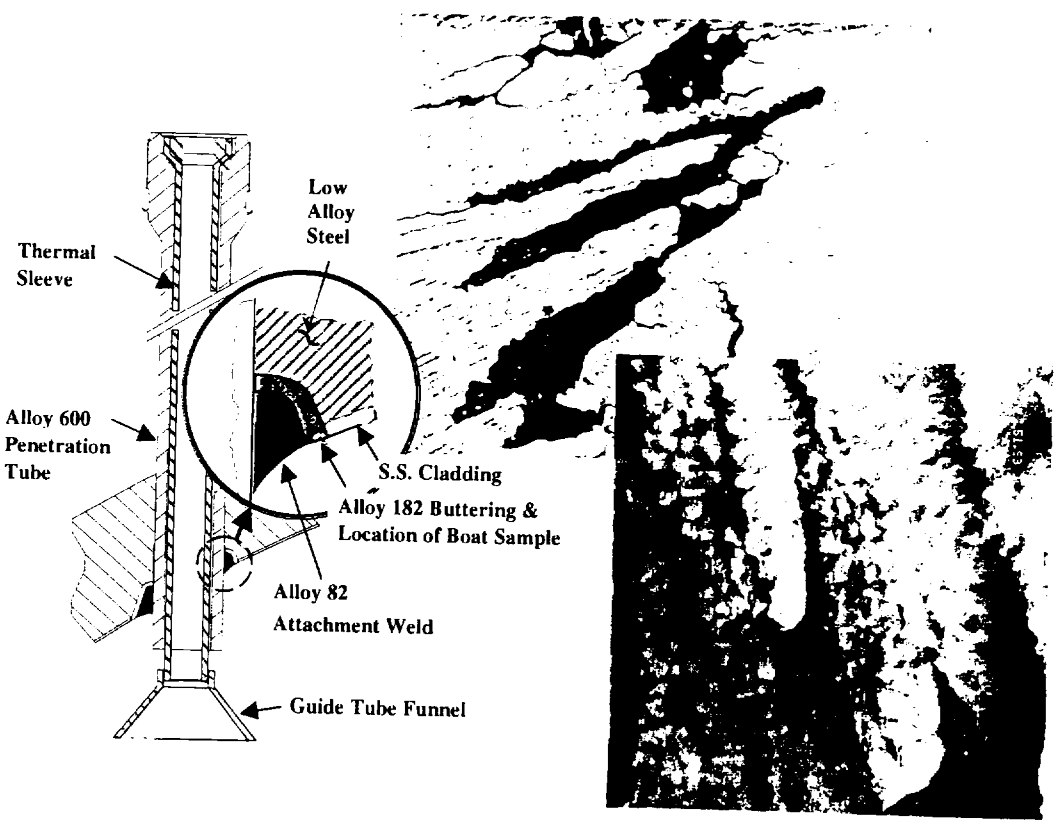
WCAP-15777, "Metallurgical Investigation of Cracking of the Alloy 82/182 J-Groove Weld of the Reactor Vessel Head Penetration Joint at North Anna Unit 2 Station"

Virginia Electric and Power Company
(Dominion)
North Anna Unit 2

Westinghouse Proprietary Class 3

WCAP-15777

Metallurgical Investigation of Cracking of the Alloy 82/182 J-Groove Weld of the Reactor Vessel Head Penetration Joint at North Anna Unit 2 Station



Westinghouse Electric Company LLC

WESTINGHOUSE PROPRIETARY CLASS 3

WCAP-15777

Metallurgical Investigation of Cracking of the Alloy 82/182 J-Groove Weld of the Reactor Vessel Head Penetration Joint at North Anna Unit 2 Station

Summary of Findings of the Boat Sample Investigation

Gutti V. Rao
Westinghouse Materials Center of Excellence

J. Bennetch
Dominion Generation

January 2002

Reviewer: ____________________
J. F. Hall
Component Integrity

Approved: ____________________
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ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of R. A. Reese and C. M. McGuire of Westinghouse in conducting hot cell examinations. The assistance of A. Byers in conducting Auger analysis is appreciated. J. A. Hoffman was helpful in co-ordinating the illustrations in the report.

The authors further acknowledge the following personnel who took time to review the draft report and provided helpful comments.

Robert Gold (Westinghouse)
Robert Phillips (TVA)
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Bob Hardies (BG&E)
Les Spain (Dominion)
Warren Bamford (Westinghouse)
John F. Hall (Westinghouse)

1 INTRODUCTION

In October 2001, while conducting Generic Bulletin 2001-01 visual inspections of the reactor vessel head top surface, Dominion inspectors observed evidence of small boric acid deposits near the CRDM penetration numbers 51, 62 and 63 at North Anna Unit 2 Station. In order to disposition these three penetrations, non-destructive examination (NDE) of the J-groove partial penetration welds on the inside diameter surface of the vessel head were performed. The NDE inspections conducted by Westinghouse revealed reportable dye penetrant (PT) indications in the J-groove weld near the cladding interface of the three penetrations. In addition, surface etching was also performed on the attachment weld/butter/ cladding transition region of Penetration 62 to assess the width of the buttering layer and the relative position of the reportable indications. The results showed that the width of the buttering ranged from approximately 0.5 in. to 0.75 in. which is wider than the specified (6 mm or 0.24 in.) minimum width (see Appendix A and B). The PT examination results of the Penetrations 51, 62 and 63 are illustrated in Figure 1. In order to carry out a detailed metallurgical investigation, a 'boat' sample was removed from penetration no. 62 by Electric Discharge Machining (EDM) and shipped to Westinghouse hot cell facilities for analysis. The 'boat' sample was positioned circumferentially along the weld clad interface region and contained reportable PT indications on the uphill side but away from the previously etched region, for metallurgical investigation. Figures 1(b) and 2 illustrate the location of the boat sample relative to the penetration attachment weld, butter and clad positions. The PT indications captured in the boat sample were representative of these indications observed in penetration nos. 51 and 63. This report summarizes the findings of the hot cell examination of the boat sample from the penetration no. 62 J-groove weld.

2 EXAMINATIONS AND TESTS

The Westinghouse evaluations were centered on an approximately 2.5 inch long, 0.5 inch wide and 0.4 inch deep 'boat' sample oriented circumferentially along the weld-clad interface and removed by electric discharge machining (EDM) from the 'butter' region of the J-groove weld. The investigation included the following major tasks:

2.1 SURFACE EXAMINATIONS

Surface examination of the boat sample were conducted in the as-received condition by light optical and scanning electron microscopy techniques for evidence of cracking, surface deposits, corrosion, pitting or mechanical distress. The results of the surface examinations are illustrated in Figures 3 through 5. The results are discussed in Section 3.

2.2 SECTIONING PLAN

Based on the results of the surface examinations, a plan for destructive examination of the boat was developed. Figure 6 illustrates the sectioning lay out of the boat to obtain specimens employed in various examinations conducted during the investigation.

2.3 METALLOGRAPHIC EXAMINATIONS

Metallographic examinations were conducted on axial and transverse sections of the boat sample by employing light optical and scanning electron microscopy techniques. The purpose of the metallographic examinations was to establish the depth and distribution of cracking, crack initiation locations and propagation directions, the cracking morphology and its relation to the local microstructure. The metallographic examinations were carried out both in the 'as-polished' and 'polished and etched' condition of the sections. The results of the metallographic examinations are illustrated in Figures 7 through 15. The results are discussed in Section 3.

2.4 FRACTOGRAPHIC EXAMINATIONS

Fractographic examinations were conducted on freshly opened cracks in the boat by light optical and scanning electron microscopy techniques to establish the origin and depth of cracking, the fracture morphology, and the mechanism of crack progression. The results of the fractographic examinations are illustrated in Figures 16 through 18.

2.5 CHEMISTRY EVALUATIONS

Chemistry evaluations were conducted by quantitative Energy Dispersive X-ray analysis (EDAX) technique by spot elemental analysis. The EDAX analysis was conducted at various locations of the polished boat sections to establish Alloy 82 weld, Alloy 182 butter, low alloy steel base metal, and stainless steel clad regions in the boat and further to identify the crack initiation and crack progression locations in relation to the buttering and filler metal regions of the J-groove weld. The results are illustrated in Figures 19 through 22.

Limited thin film surface chemistry analysis of the freshly opened fracture faces was conducted by Auger Electron Spectroscopy (AES) to establish surface chemistry, identify the presence of boron from primary water and establish the presence of any low melting and/or detrimental elements present, to aid in the mechanistic assessments. Locations analysed are illustrated in Figure 23. The results are illustrated in Figures 24 and 25.

3 RESULTS AND DISCUSSION

The results of the surface examination of the boat sample in the as-received condition are illustrated in Figures 3 through 5. The surface examination resulted in several significant findings. First the boat contained several transverse and longitudinal (axial) cracks which were open on the 'back side' (EDM surface)[1]. Some of these cracks seemed to have narrowed as they approached the ID surface and appeared as tight cracks on the ID surface while several other cracks did not extend to the ID surface. The ID face contained surface grinding and machining marks, presumably representing the original fabrication condition of the weld. No evidence of surface attack, deposits or pitting was seen on the surfaces exposed to primary water. The cracks observed at the surface likely started in the internal region of hot cracking, extending to the surface over several cycles of operation.

The results of the metallographic examinations conducted on sections taken both transverse and longitudinal (axial) to the boat are illustrated in Figures 6 through 14. The metallography results of the transverse section illustrated in Figures 7 through 14 revealed that the weld metal suffered significant cracking close to the base metal interface in the buttering layer of the J-weld away from the ID surface. The cracking followed interdendritic morphology with significant evidence of interconnected microfissuring and voids. Although the transverse cracking appeared concentrated in the butter close to the EDM face near the base metal, as illustrated in Figure 8, in a few instances narrow, isolated single cracks extended into the boat (ID) face. Figure 15 illustrates the metallography results of an axial section of the boat. The presence of an axial crack progressing from the EDM face towards the ID face can be seen. The axial cracking is interdendritic, branched and followed serrated morphology. A clear distinction can be made between the behavior of this axial crack (near the ID wetted surface) and the cracking seen (near EDM face) on the transverse section (Figure 9). A discussion of the mechanistic assessments of the cracks seen in the transverse and longitudinal (axial) sections is included later in Section 4.

The fractographic examination results of a freshly opened crack are illustrated in Figures 16, 17 and 18. Figure 16 is a montage of scanning electron fractographs illustrating the fracture morphology of a transverse crack through the thickness of the boat. The cracking morphology of selected areas of the fracture is shown at higher magnification in Figure 17. The fractographs illustrates oxide covered interdendritic morphology. Presence of interdendritic gaps and occasional voids are also apparent. The morphology of laboratory induced overload dimpled rupture is illustrated in Figure 18.

The results of the semi-quantitative chemical analyses by Energy Dispersive X-ray (EDAX) technique tend to confirm the fractographic conclusions. EDAX chemistry analyses of a freshly opened fracture face are illustrated in Figure 22 and in Table 2. The elemental spectrum from the fracture clearly shows a significant oxygen peak indicating that the cracking occurred at elevated temperature during fabrication, a condition that is favorable to oxidation of the fracture face. Because of the presence of the significant oxygen peak the semi-quantitative results of the chemistry in Table 2 should be considered approximate.

[1] The transverse boat cracks were actually circumferential flaws with respect to the J-groove weld whereas the longitutinal (axial) boat cracks were radial weld flaws.

In addition, the results indicate that the fracture occurred in the Alloy 182 butter material. The Rotterdam chemistry specification requirements of Alloy 182 buttering and Alloy 82 weld deposit are provided in Table 1 for reference.

As shown, the EDAX results also confirm that the boat sample was machined primarily from the butter region. Elemental EDAX values are shown in Figure 19 for the transverse section, in Figure 21 for the axial section. No evidence of stainless steel cladding (at the ID face) or low alloy steel base material (at the top EDM face) was identified in the boat sample. Only a portion of the top region of the boat (Figure 20) contained Alloy 82 weld deposit (see Figures 20 & 21). Note that virtually all cracking seen here was confined to the Alloy 182 butter layer. Very little cracking was observed to extend into the Alloy 82 weld deposit.

The transverse section of the boat illustrated in Figure 20 showed that a portion of Alloy 82 weld deposit was trapped at the top of the boat bounded by Alloy 182 butter on either side. This configuration of the butter and weld materials is not normally expected and it is inconsistent with the specified weld fabrication procedures. This observation suggests that some type of a weld repair may have been involved at the buttering during the original fabrication of the weld. This is discussed further below.

The North Anna Unit 2 reactor vessel was fabricated by the Rotterdam Dockyard Company, Netherlands. A detailed review of the vendor fabrication records was conducted to examine the weld procedures and any repair histories associated with the penetration 62 J-weld. The review could not identify penetration-specific weld repair histories. However, general procedures employed in the repair of Alloy 182 buttering and Alloy 82 overlay weld deposits were identified. Copies of the original fabrication drawings and weld procedures including the general repair procedures of the weld are included under Appendices 'A' and 'B' of this report for reference.

There are potentially two postulated weld repair scenarios that can produce the weld configuration shown in Figure 20:

- A weld repair involving cutting into the Alloy 182 butter layer at the Alloy 82 weld interface near the ID face and back filling with Alloy 82 weld metal.
- An ID Alloy 82 weld repair at the butter interface employing an Alloy 182 electrode.

It may be of some interest to note that while the fabrication records (Appendix 'A') specified a minimum buttering width of 6 mm (0.24 in.), the entire boat width measuring approximately 0.5 in. consisted of Alloy 182 butter at the ID surface. This is also consistent with the surface etching results of the weld by Dominion during PT examinations (discussed in Section 1). The surface etching revealed that the width of the buttering layer ranged from 0.5 in. to 0.75 in.

The surface examination results of the boat sample in the as-received condition (Figures 3.b and 4.a) showed evidence of surface grinding and cold work on the wetted ID face.

The above sequence of observations suggests that a weld repair of the butter/weld region at the ID surface was most likely involved during fabrication of the penetration 62 J-weld. They also suggest that a surface grinding of the repaired region may have been conducted to disposition a recorded PT indication.

The results of the surface chemistry analysis of a freshly opened fracture face by Auger Electron Spectroscopy (AES) is presented in Figures 23 through 25. The specimen employed (Figure 23) for AES analysis is taken from the bottom right corner of the mating face with the freshly opened fracture face illustrated in Figure 16. The AES analysis is a very useful technique in detecting the presence of low concentrations of detrimental elements on the surface such as grain boundary segregations or presence of low melting constituents so that their role in promoting embrittlement or failure can be assessed. The technique analyzes an approximately 20 Angstrom (Å) thick surface layer to establish the composition of a surface film on the fracture face. The results illustrated in electron energy spectra from the fracture face are summarized in Figures 24 and 25. Note the presence of boron, sulfur, zinc, copper and titanium at several locations of the fracture face including near the ID wetted face. In addition boron was detected at isolated locations on the fracture. It should be emphasized that the AES analysis effort made here was very limited, aimed only at giving a rough indication of the presence of detrimental elements. The results showed that the fracture surface contained several low melting constituents. Their significance is discussed in Section 4.

4 MECHANISTIC ASSESSMENTS

The results of the investigation showed that:

- The entire ID face of the boat sample consisted of Alloy 182 butter material suggesting that the boat was located within the butter layer adjacent to the cladding.

- The cracking observed in the boat was restricted to the Alloy 182 buttering. The majority of the crack population was situated near the EDM face, away from the ID surface exposed to the primary water. The cracking extended into (or connected to) a few isolated tight cracks at the ID face.

- Two categories of cracks were identified, based on location and appearance. The majority of cracks fell into the first category. These cracks never extended to the ID wetted surface of the boat sample but were observed near the opposing EDM face away from the ID. They can be described as broad interconnected microfissures and cracks following adjacent parallel interdendritic paths, accompanied frequently by voids. This type of cracking substructure closely resembles 'Solidification Cracking' or 'Hot Cracking' generated to accommodate excessive strains or displacements induced during the solidification of the weld metal. The movement of supports (or interfaces) or thermal strains at bimetallic interfaces can induce excessive strains depending on the weld procedures followed. In addition, presence of low melting constituents in the weld metal can increase the solidification range beyond the critical solidification range and thus increases its susceptibility to hot cracking.

- A second less frequent type of crack extended towards the ID wetted surface of the boat sample, apparently originating from some of the hot cracking seen near the EDM face (Figures 15 and 21). The latter cracks progressed along a single interdendritic path exhibiting a narrow tight branching and serrated morphology, as opposed to the appearance of the network of interconnected hot cracks. This morphology is consistent with the cracking behavior seen in Alloy 182 under exposure to primary water (Reference 1) which is commonly known as Primary Water Stress Corrosion Cracking (PWSCC). However, since not all of these narrow cracks extended to the ID surface, PWSCC did not appear to play a primary role in crack initiation and growth. PWSCC likely contributed to crack growth once flaws broke the ID surface and became exposed to the PW environment.

- There were at least two broad hot cracks found wide open at the rear EDM face that were connected to the ID wetted surface of the boat sample via narrow ID cracks. Fractographic examination of one crack face in a freshly opened condition at/near the ID surface showed evidence of heavily oxidized and widely separated dendrites (Figure 17). The presence of high temperature oxides indicated the crack had been open to the surface for an extended time period. Auger Electron Spectroscopy of the fracture surface confirmed the presence of contaminants including zinc, sulfur, boron, copper and titanium (Figure 23). The evidence of boron, presumably from boric acid, seen in the AES spectra indicated the intrusion of primary water (PW). This observation backes up the conclusions reached by fractography that PWSCC played a secondary role in crack growth once cracks extended to the ID wetted surface of the weld. Sulfur and low melting point elements such as copper and zinc have been implicated in hot cracking in

nickel-base alloys. Although the source of these elements needs to be further identified, their presence here suggest that the broad open cracks seen at the EDM face most likely occurred by a hot cracking mechanism during fabrication due to contamination of the butter weld. It is conceivable that the hot cracking was not detected at the time of fabrication because no cracks had yet extended out to the ID weld surface, resulting in no reportable linear indications. Then, during subsequent cycles of operation, ID cracks finally surfaced, only then introducing an environment conducive for PWSCC.

- The hot cracking is seen extending through several passes of weld metal as it approached the ID (Figure 8). This is not considered an uncommon occurrence. Depending on the magnitude of strains developed during solidification, the stress (strain) concentration at the tip of initial crack in the proceeding weld layer provides a driving force for extension into the succeeding layer. Another important contribution can come from the residual stresses from multiple repairs on the ID surface.

- The observed cracking behavior of the buttering or weld in the North Anna boat is similar to the hot cracking reported in the penetration 62 J-weld buttering at Ringhals Unit 2 in 1992 (Reference 2). In the case of Ringhals 2, however, there was also decohesion (lack of fusion) observed at the base metal interface. The North Anna Unit 2 boat sample did not exhibit evidence of interface decohesion. However, the boat sample did not contain any base metal.

- In summary,

  - The large gaps or "open cracks" seen in the boat sample are the result of hot cracking in the Alloy 182 buttering deposit.

  - The observation of (elevated temperature) oxides on the interdendritic surfaces indicate that, these regions were exposed to the air at solidification temperatures during fabrication.

  - The hot cracks were not detected during manufacture and subsequent PT inspection since they apparently did not intersect the free surface at the weld stage where PTs were performed (The Rotterdam specification called for PTs every half inch after the first weld layer).

  - There is very little evidence that cracking occurred in Alloy 82 – if at all, it appears that the open (hot) cracks may have been blunted when they reached the Alloy 82 weld region.

  - Most of the cracking/degradation was the direct or indirect result of manufacturing. PWSCC played a minor, secondary role.

  - The presence of grinding marks on the boat ID wetted surface plus the odd juxtaposition of 82 and 182 welds in the transverse and longitudinal metallographic boat sections suggest that repairs may have been performed on the J-groove weld during fabrication.

5 CONCLUSIONS

- The results of this investigation indicate that the cracking in the J-groove weld or buttering of the North Anna Unit 2 reactor vessel head penetration 62 most likely originated from solidification (hot) cracking of the buttering adjacent to the low alloy steel base metal. The results also showed that, once hot cracking extended to the ID surface, further crack extension most likely occurred by primary water stress corrosion cracking.

- No significant cracking was detected in the Alloy 82 weld deposit.

- No evidence of surface attack, deposits or pitting was seen on the wetted boat surface, implying that cracks did not originate at the weld surface. Rather, these cracks observed at the surface likely started internally in the region of hot cracking, extending to the surface over cycles of operation.

- Hot cracking that extended to the ID facilitated the access of primary water and additional crack extension by PWSCC in the butter.

- Repairs may have been made to the J-groove weld during fabrication.

- Although it is plausible that the interconnected hot cracking and extension by PWSCC in the butter or weld layer could contribute to leakage through the head-to-penetration annulus, this could not be conclusively established based on the results of the current investigation.

- The overall results of this investigation strongly suggested that the North Anna Unit 2 reactor vessel head penetration J-groove weld cracking originated from the original fabrication of the weld.

6 LIST OF REFERENCES

1. G. V. Rao " Metallurgical Investigation of cracking in the Reactor Vessel Alpha Loop Hot Leg Nozzle to Pipe Weld at the V. C. Summer Station" Westinghouse non-proprietary class 3 report, WCAP-15616, January 2001.

2. B. A. Bishop, G. V. Rao, W. H. Bamford and S. L. Abbot " R V Closure Head Penetration Supplemental Assessment of NRC SER Issues" Westinghouse Proprietary Class 2 Report, WCAP-14219, Rev.1, October 1995.

Table 1 Summary of Rotterdam Chemistry Specifications for Alloy 182 Welding Electrode (Butter) and and Alloy 82 Filler Note that the cited ASME sections have been discontinued.

	Ni (Min.)	C (Max.)	Mn	Fe (Max.)	S (Max.)	Si (Max.)	Cu (Max.)	Cr	Ti (Max.)	Nb	P (Max.)	Others
Inconel 182 Electrode ASME SB-295 EMoCRFe-3 (SFA-5.11)	balance	0.11	5.0 – 9.5	15.0 (max)	0.015	1.0	0.50	12.5 – 17.0	1.0	1.0 – 2.50 Nb + Ta	0.12	0.5 (max)
Inconel 82 Filler Rod ASME SB-304 ERNiCR-3 (SFA-5.14)	balance	0.07	3.0 – 5.0	2.0 – 5.0	0.015	0.75	0.50	13.0 – 17.0	1.0	2.0 – 3.0 Nb only	0.1	1.0 – 2.5 Mo

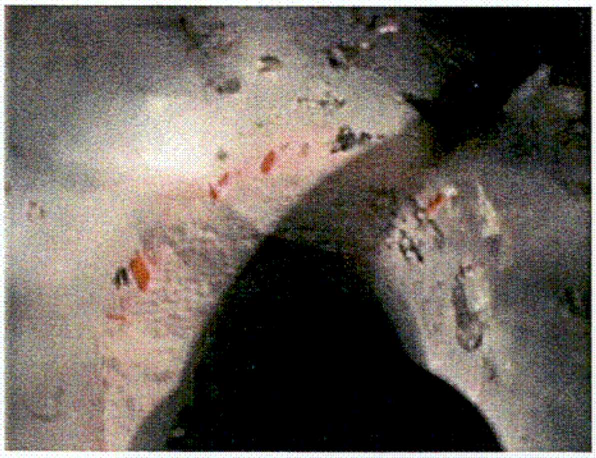
Reference: Rotterdam specifications (see appendix)

Table 2 Summary of Semi-Quantitative EDAX Chemistry Analysis Results of the Freshly Opened Fracture Face (Figure 22) (The results were corrected for oxygen peak) The high Mn and Fe peaks show that the crack propogated in 182 weld

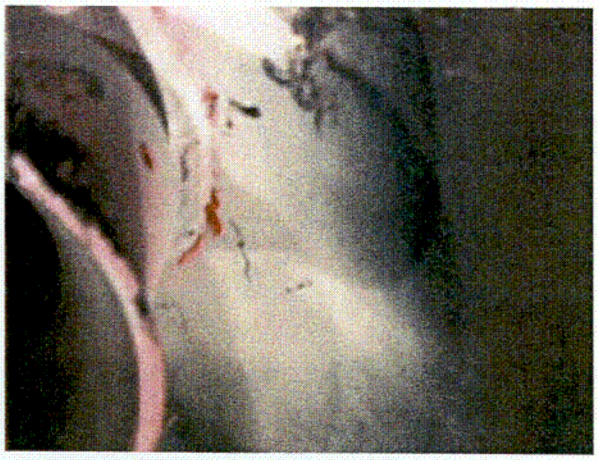
	Ni	Mn	Fe	Si	Cr	Ti	Nb	Total
Area 1 Figure 22(a)	67.22	9.06	7.16	0.60	12.54	1.26	2.16	100.00
Area 2 Figure 22(b)	57.53	10.79	7.05	1.56	16.40	3.29	3.38	100.00

(i)

(ii)

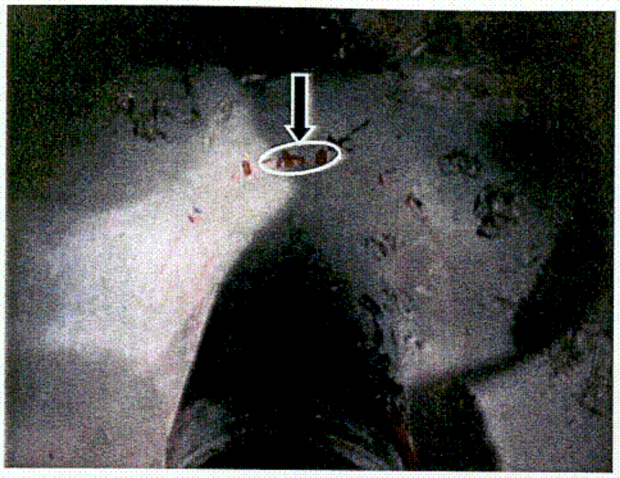


(iii)



(iv)

Figure 1(a) Photomacrographs illustrating Dye Penetrant Examination results of Penetration No. 51

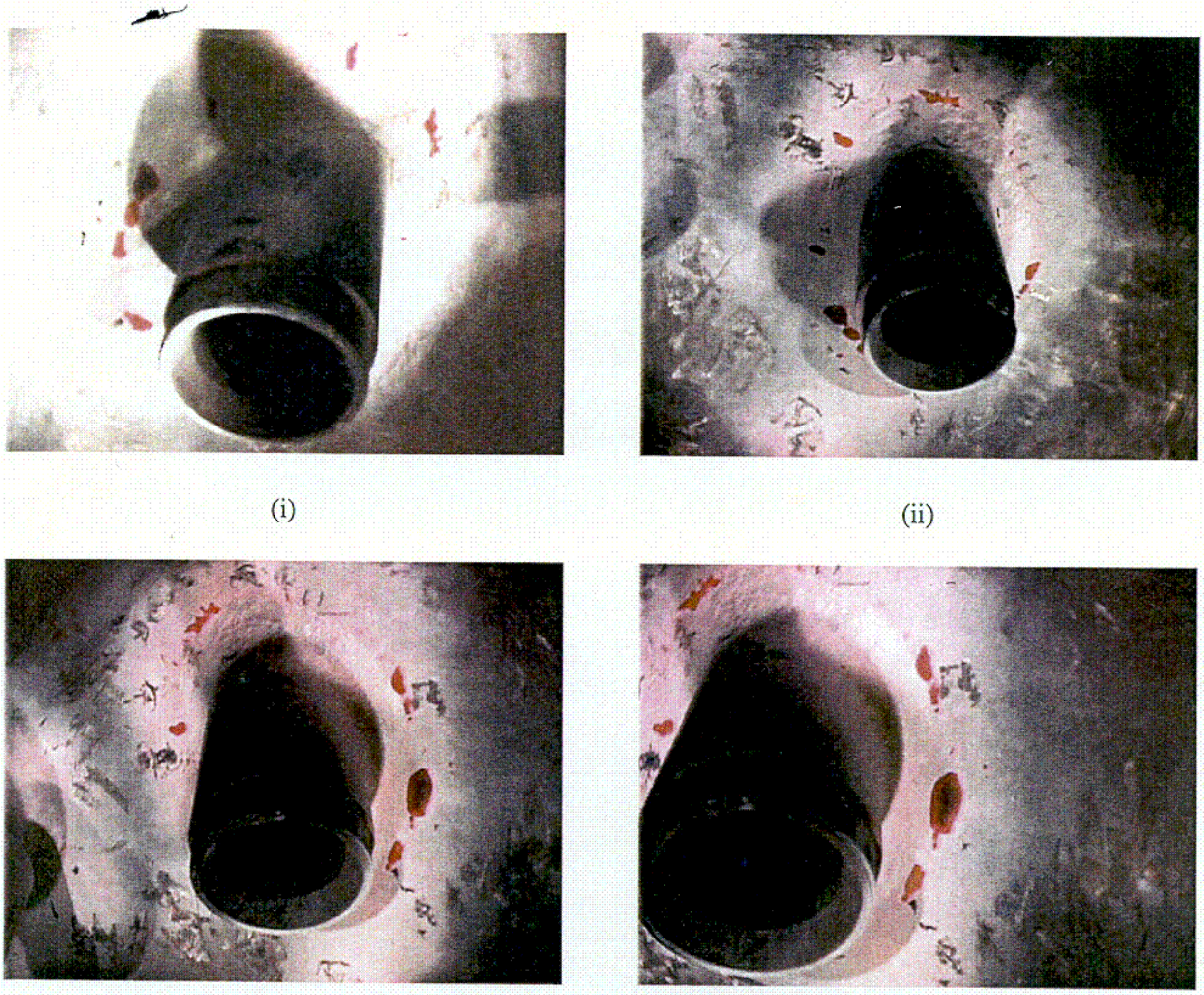


(i)

(ii)

(iii)

Figure 1(b) **Photomacrographs illustrating Dye Penetrant Examination results of Penetration No. 62 (arrow indicates boat sample location)**



(i) (ii) (iii) (iv)

Figure 1(c) Photomacrographs illustrating Dye Penetrant Examination results of Penetration No. 63

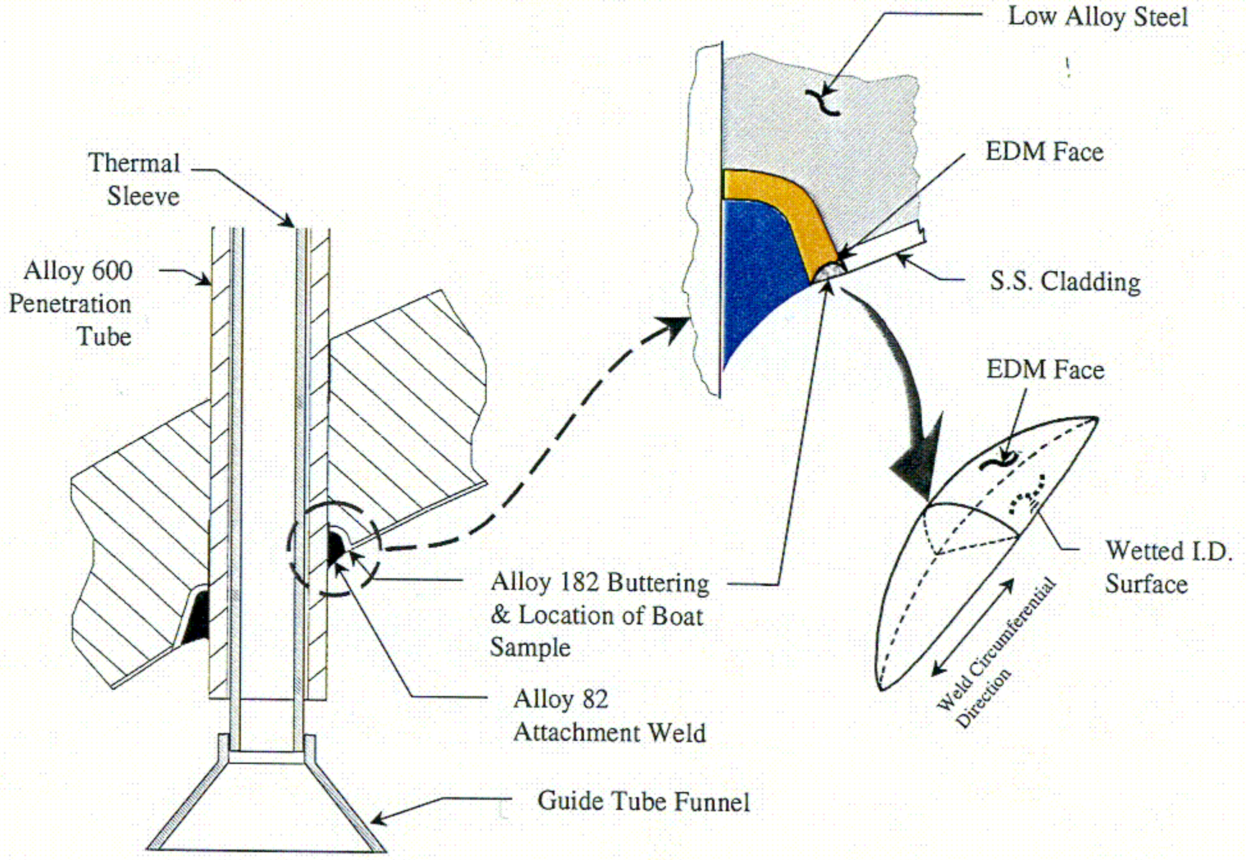


Figure 2 **Schematic representation of the reactor vessel head penetration J-groove weld geometry illustrating the boat sample location at the low alloy steel to butter/clad interface. Note that the long transeverse axis of the boat is oriented parallel to the 182/S.S. cladding interface, whereas the short longitudinal axis is in the radial direction with respect to the J-groove weld**

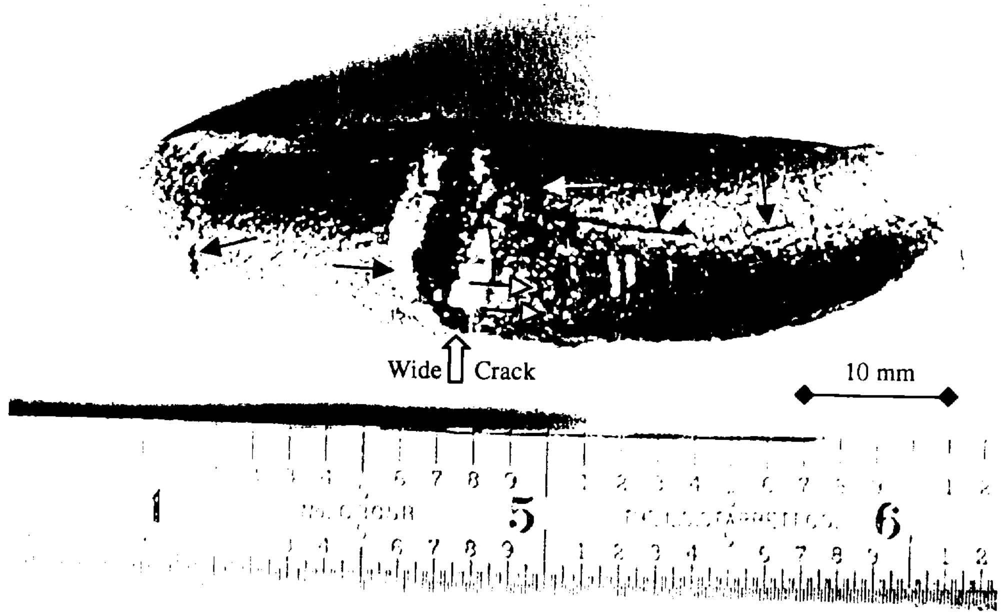


Figure 3(a) **Surface Appearance of Boat EDM Face Showing the Presence of Axial and Transverse Cracks (Arrows) Note that the long axis of the boat is oriented parallel to the Alloy 182 butter/stainless steel cladding interface**

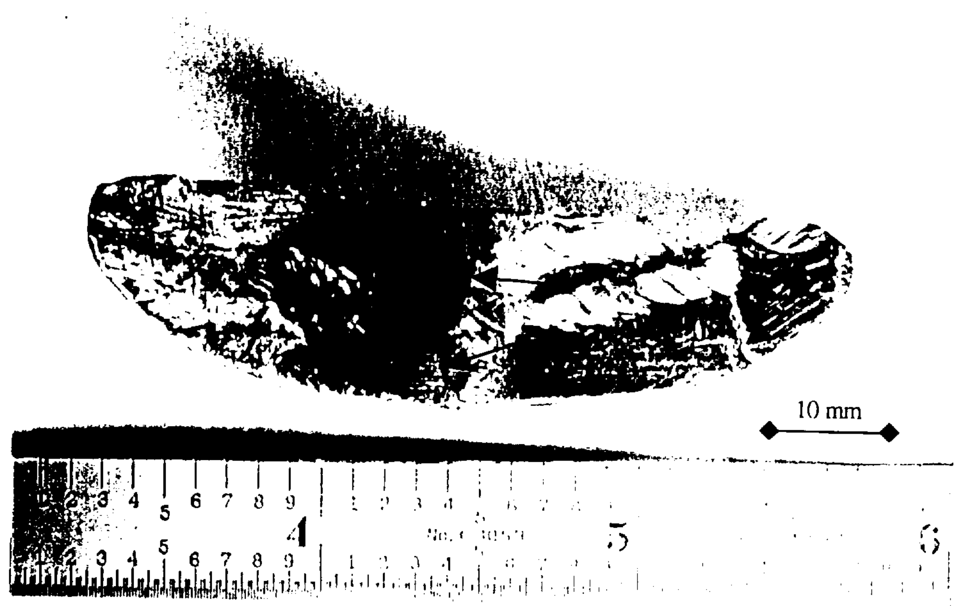


Figure 3(b) **Surface Appearance of Boat ID (Wetted) Face Illustrating the Presence of Grinding Marks and Cracks (Arrows). Note that the long axis of the boat is oriented parallel to the Alloy 182 butter/stainless steel cladding interface**

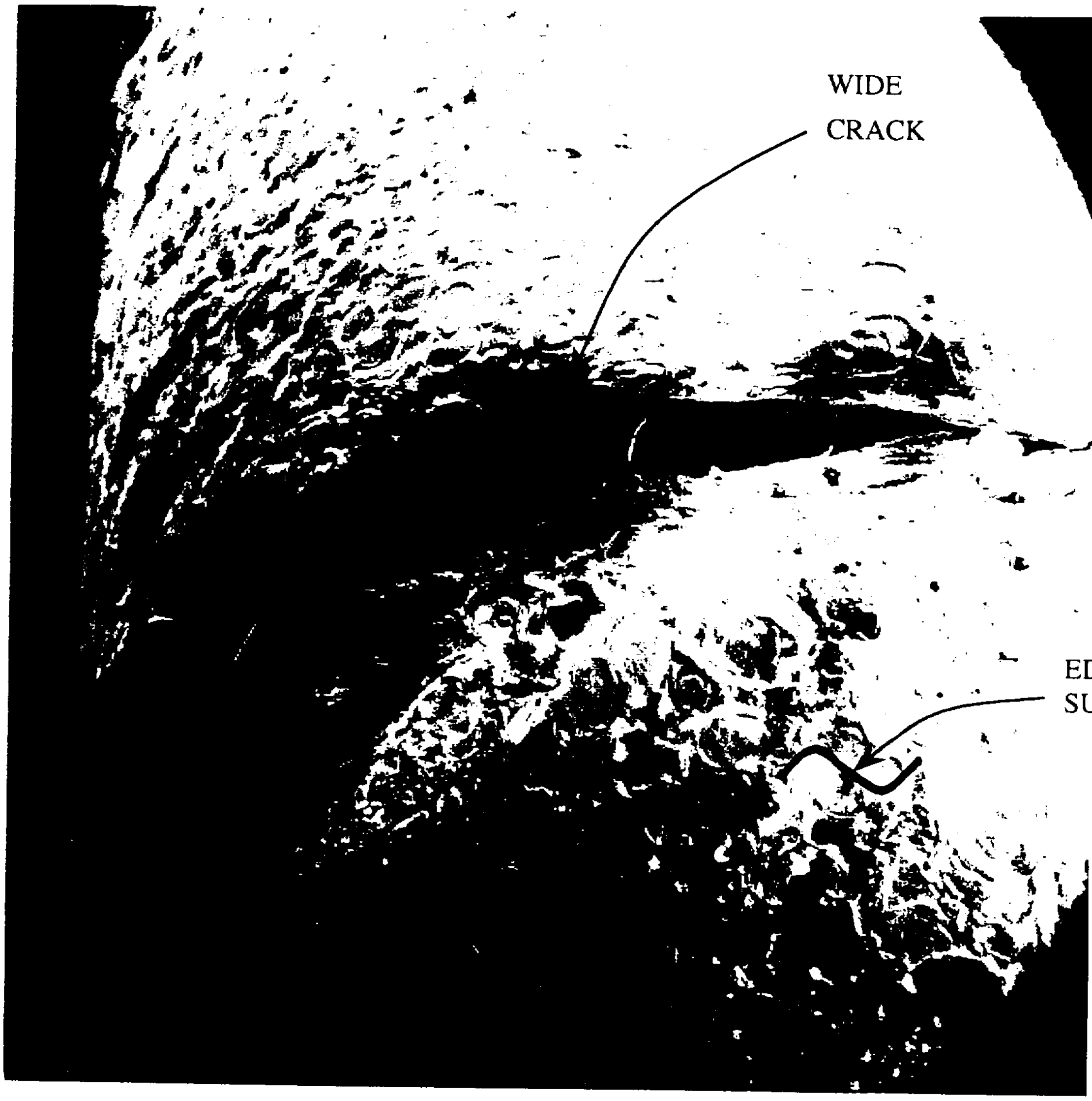


Figure 4 **Appearance of Wide Crack (Figure 3a) on the EDM Surface of the Boat in the As-received Condition**

(7X)

(a)

(13X)

(b)

Figure 5 Close-up View of the Boat ID Surface Illustrating the Appearance of Transverse Cracking

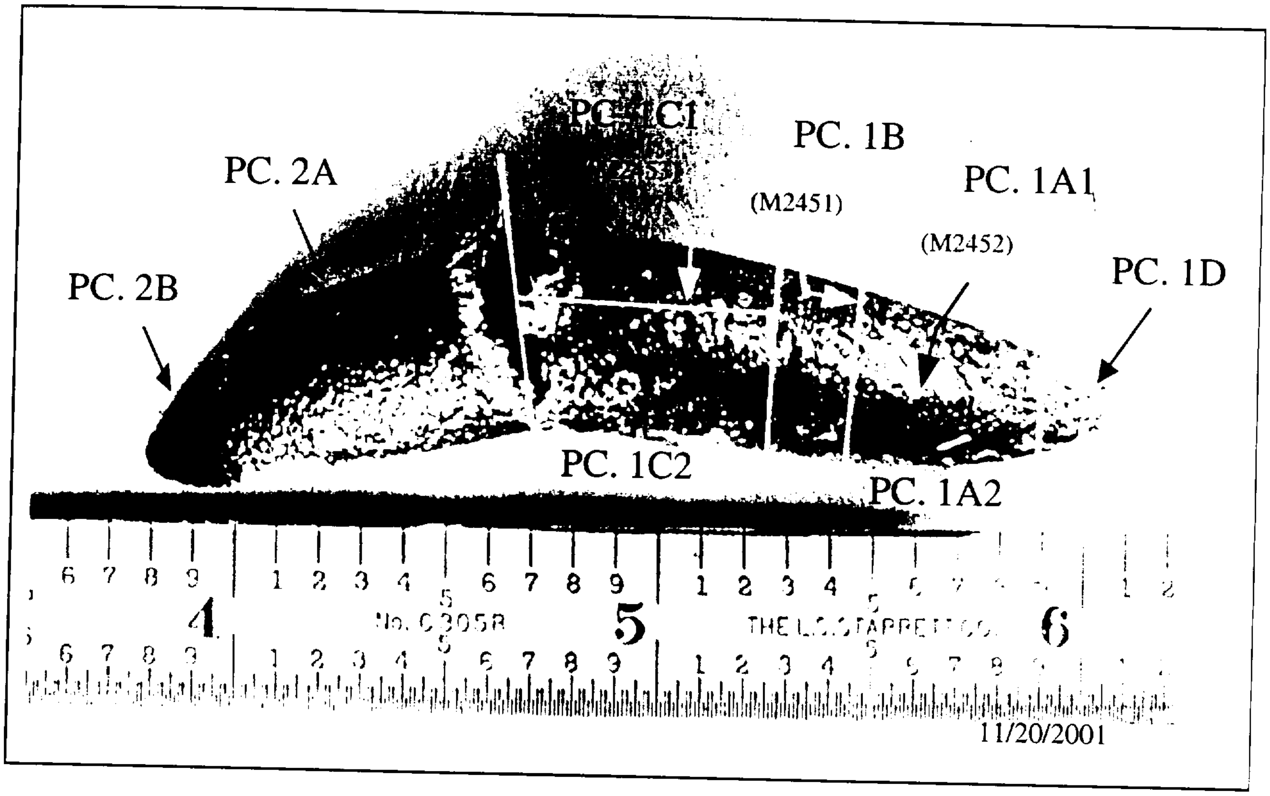
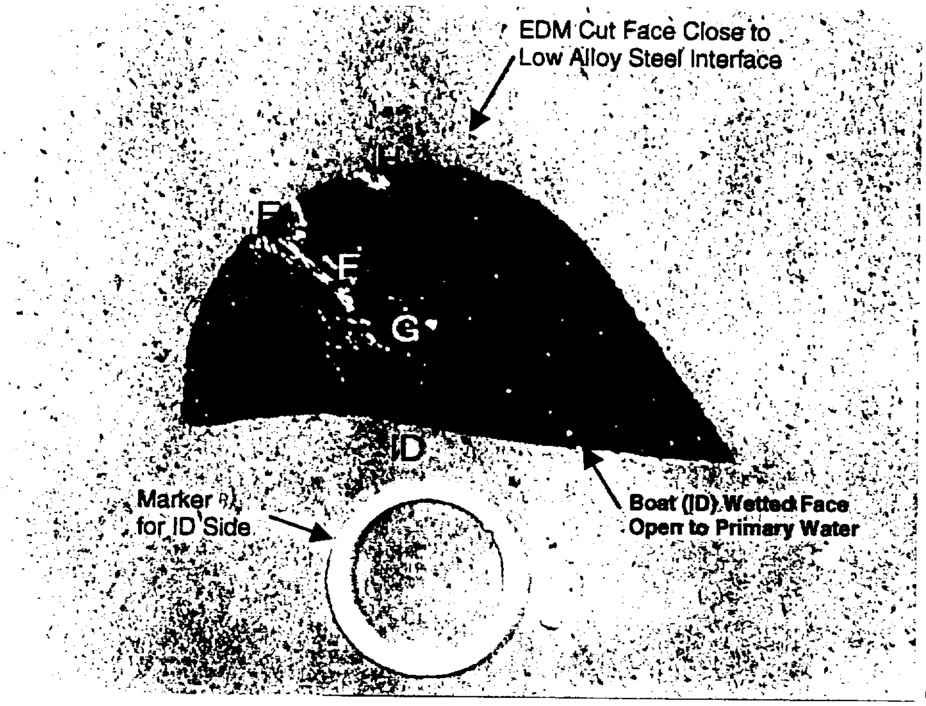
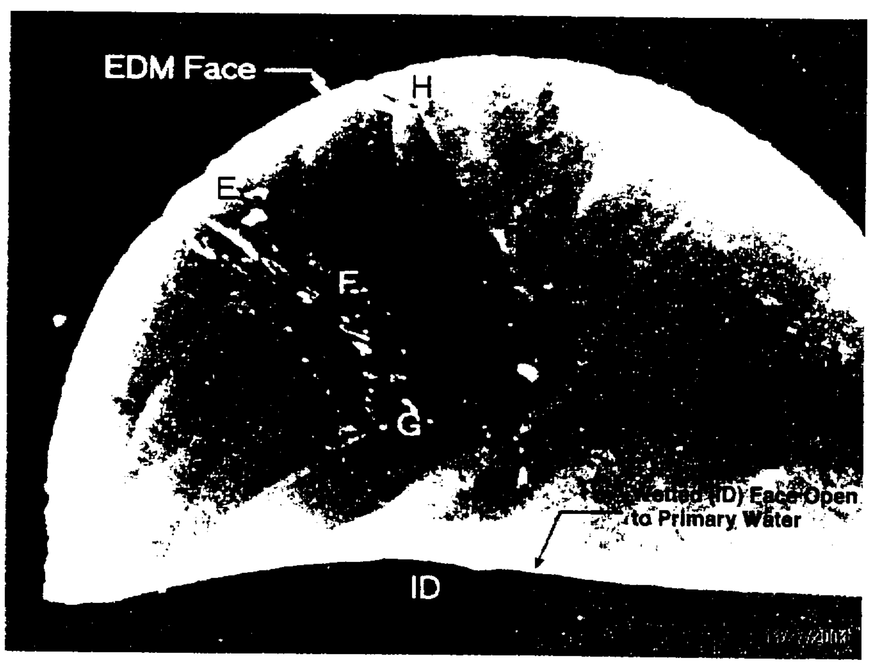


Figure 6 **Sectioning plan of the boat illustrating the identification of various specimens employed in the examination**



(5x)

(a) Polished Condition (reversed light)



(10x)

(b) Polished and Etched Condition

Figure 7 **Metallographic Examination results of the transverse section of the boat identifying the cracking locations. (M2451) Details at areas E, F, G and H are illustrated by the higher Magnification micrographs in Figures 9 through 14.**

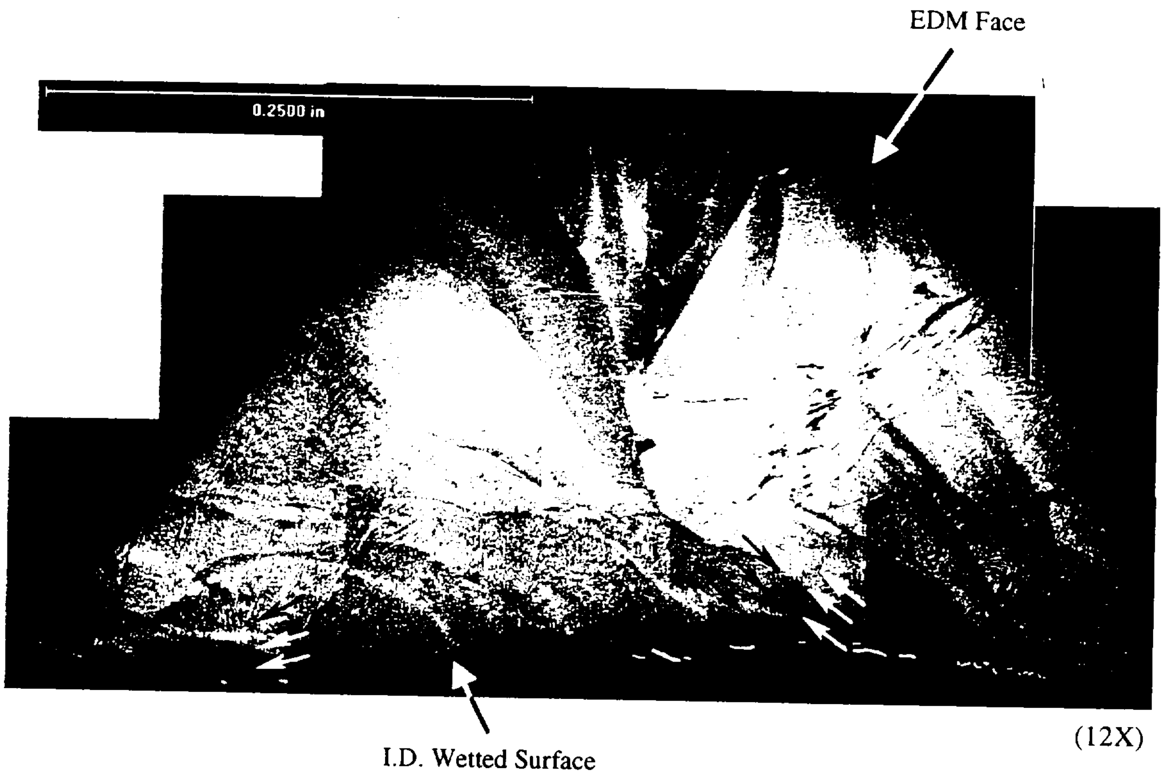
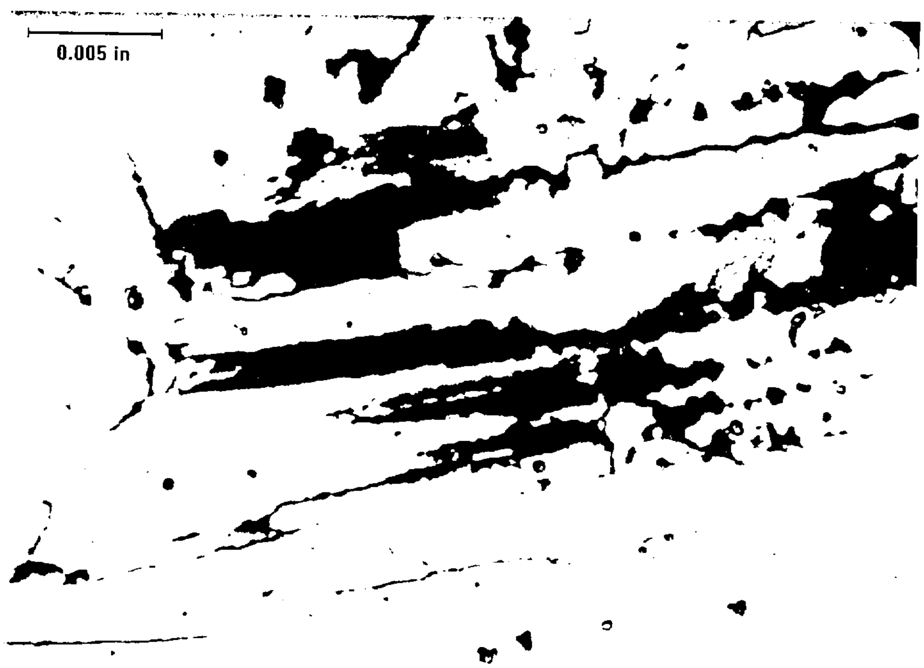


Figure 8 **Metallographic Examination results of the transverse section of the boat illustrating the distribution of cracking. Arrows indicate locations of crack extension to the I.D. wetted surface of the boat. (Mirror image of Figure 7)**

(a)



(b)
Higher Magnification of (a)

Figure 9 **Metallographic Examination results of the transverse section (M2451) of the boat in the 'as-polished' condition illustrating the cracking morphology at Area 'H', Figure 7.**

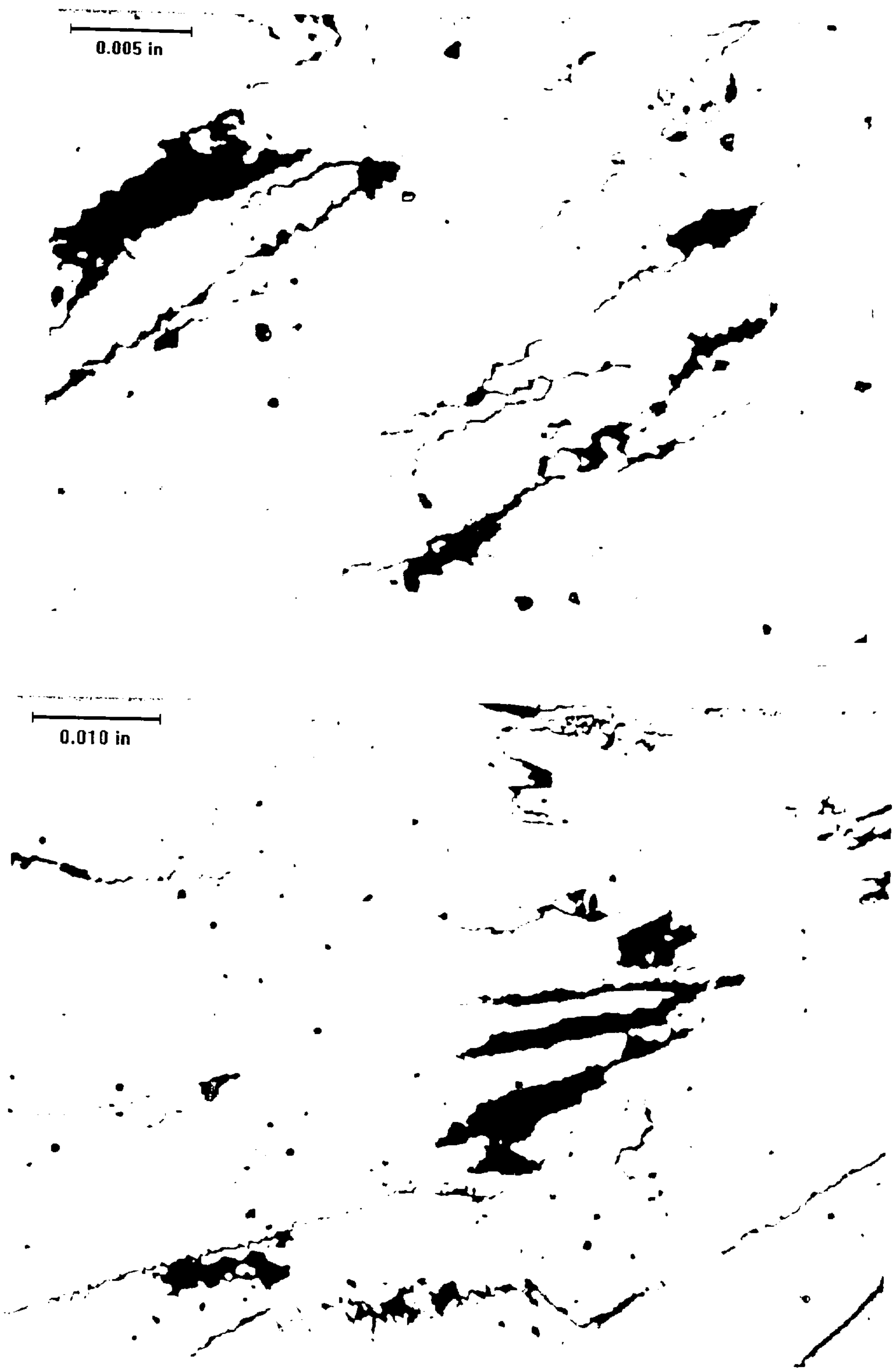
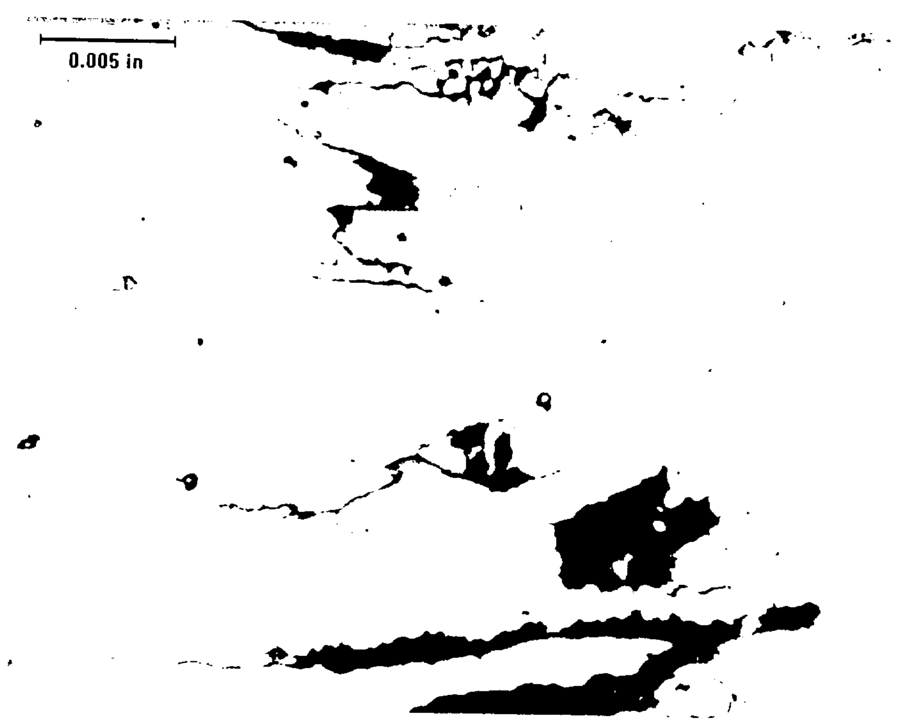
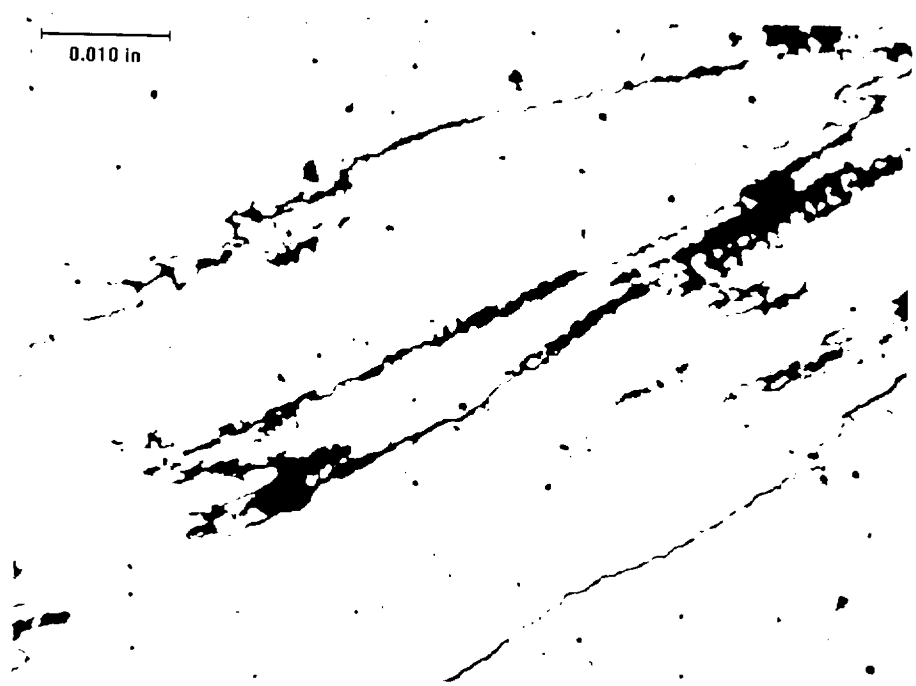


Figure 10 **Metallographic Examination results of the transverse section of the boat identifying the cracking locations. (Area 'F' in Figure 7)**

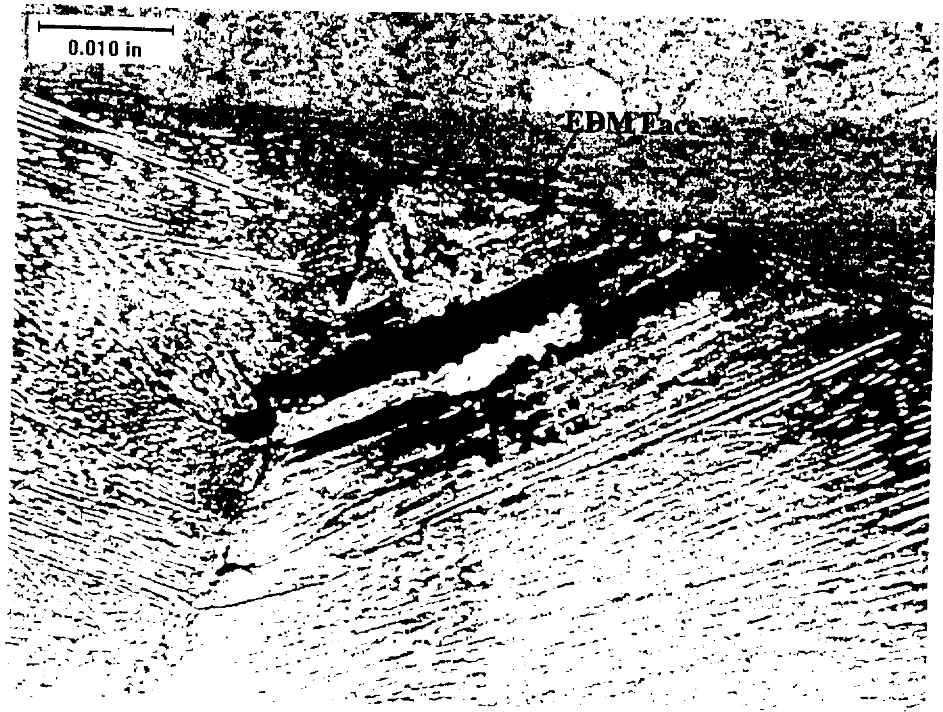


Area 'F' in Figure 7

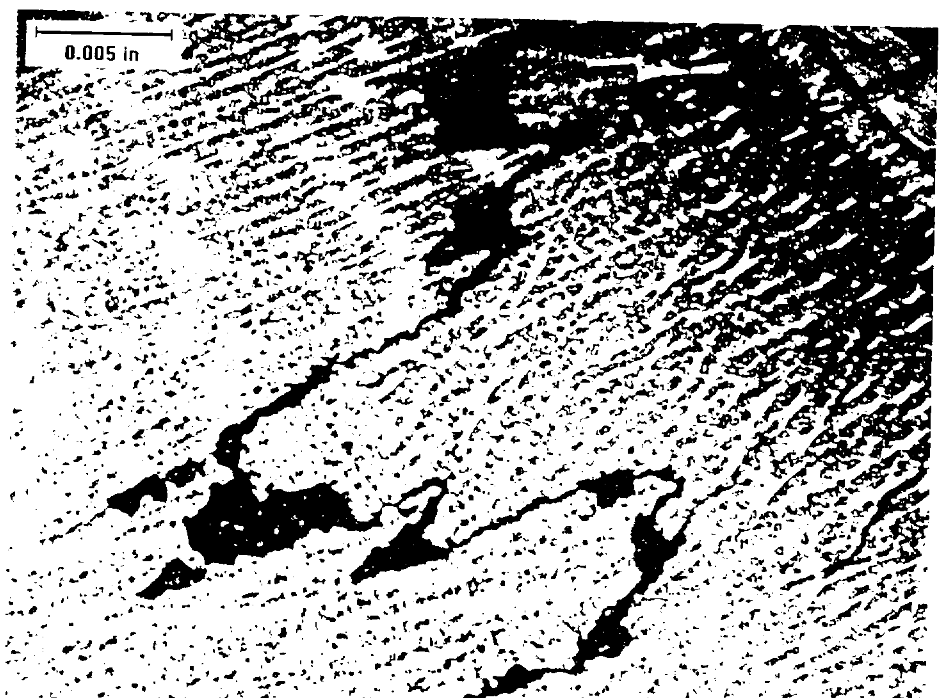


Area 'G' in Figure 7

Figure 11 **Metallographic Examination results of the transverse section of the boat identifying the cracking locations.**



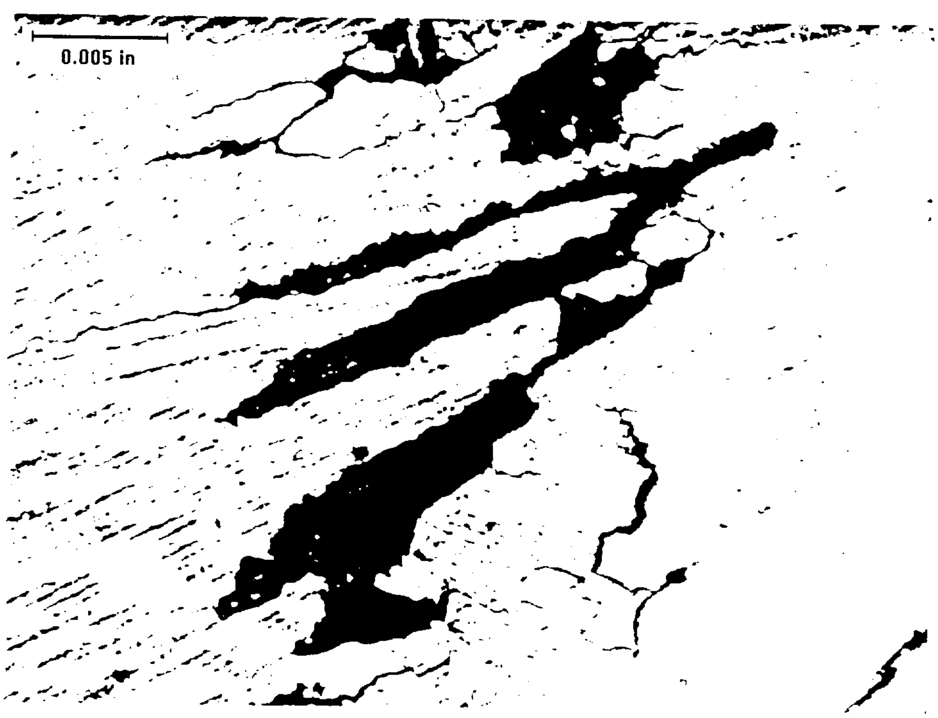
Area 'H' in Figure 7



Area 'E' in Figure 7

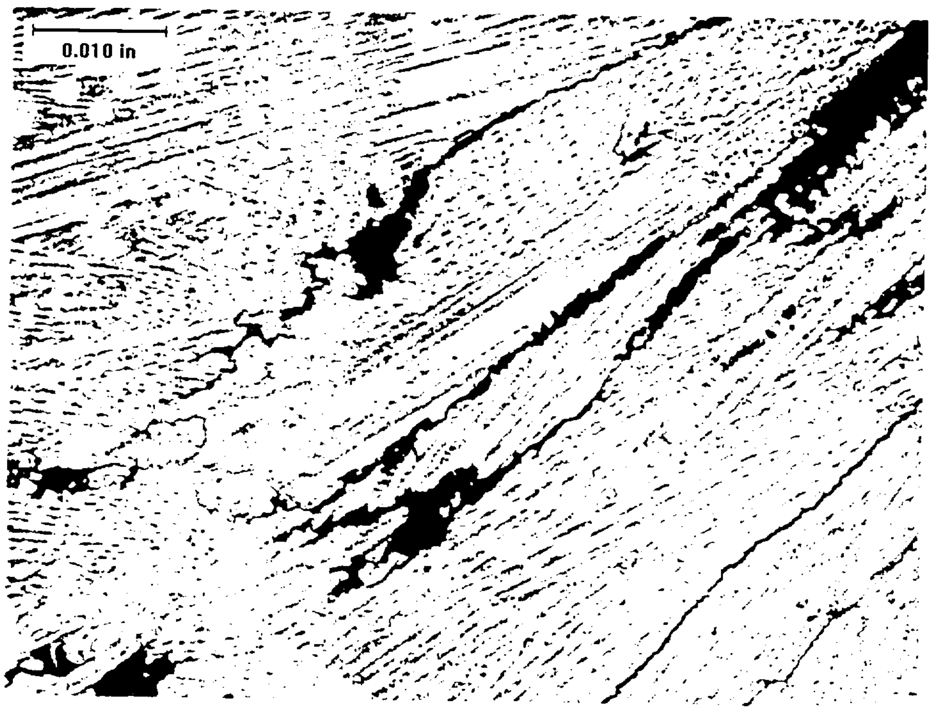
Figure 12 **Metallographic Examination results of the transverse section of the boat in the polished and etched condition identifying the cracking locations. (Nital etch)**

Area 'H' in Figure 7

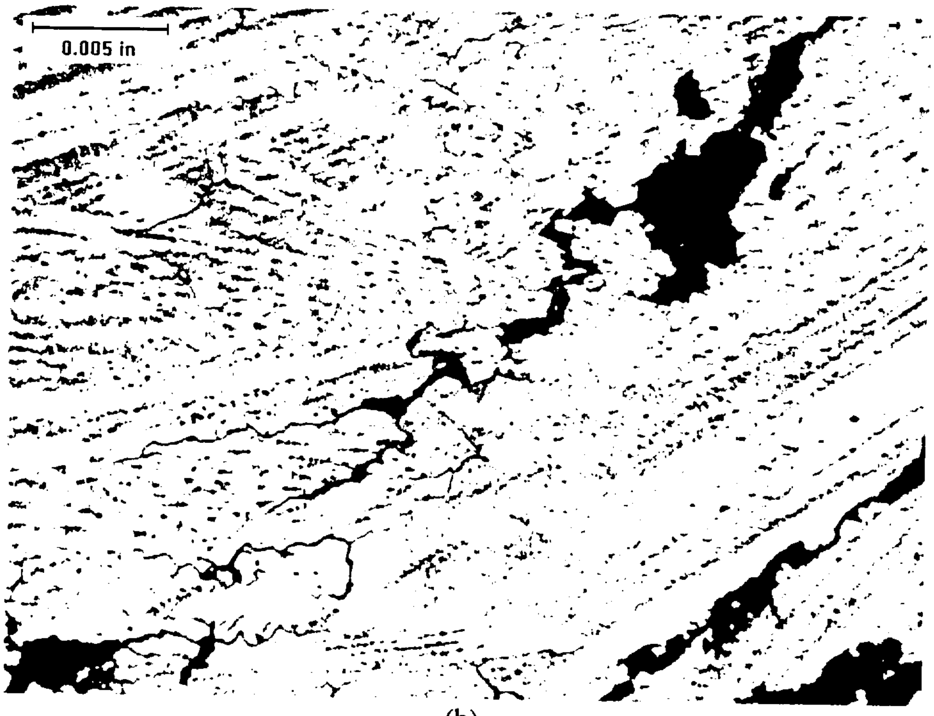


Area 'F' in Figure 7

Figure 13 **Metallographic Examination results of the transverse section of the boat identifying the cracking locations in the polished and etched condition. (Nital etch)**



(a)



(b)

Figure 14 **Metallographic Examination results of the transverse section of the boat identifying the cracking locations in the polished and etched condition. (Area 'H' in Figure 7, Nital etch)**

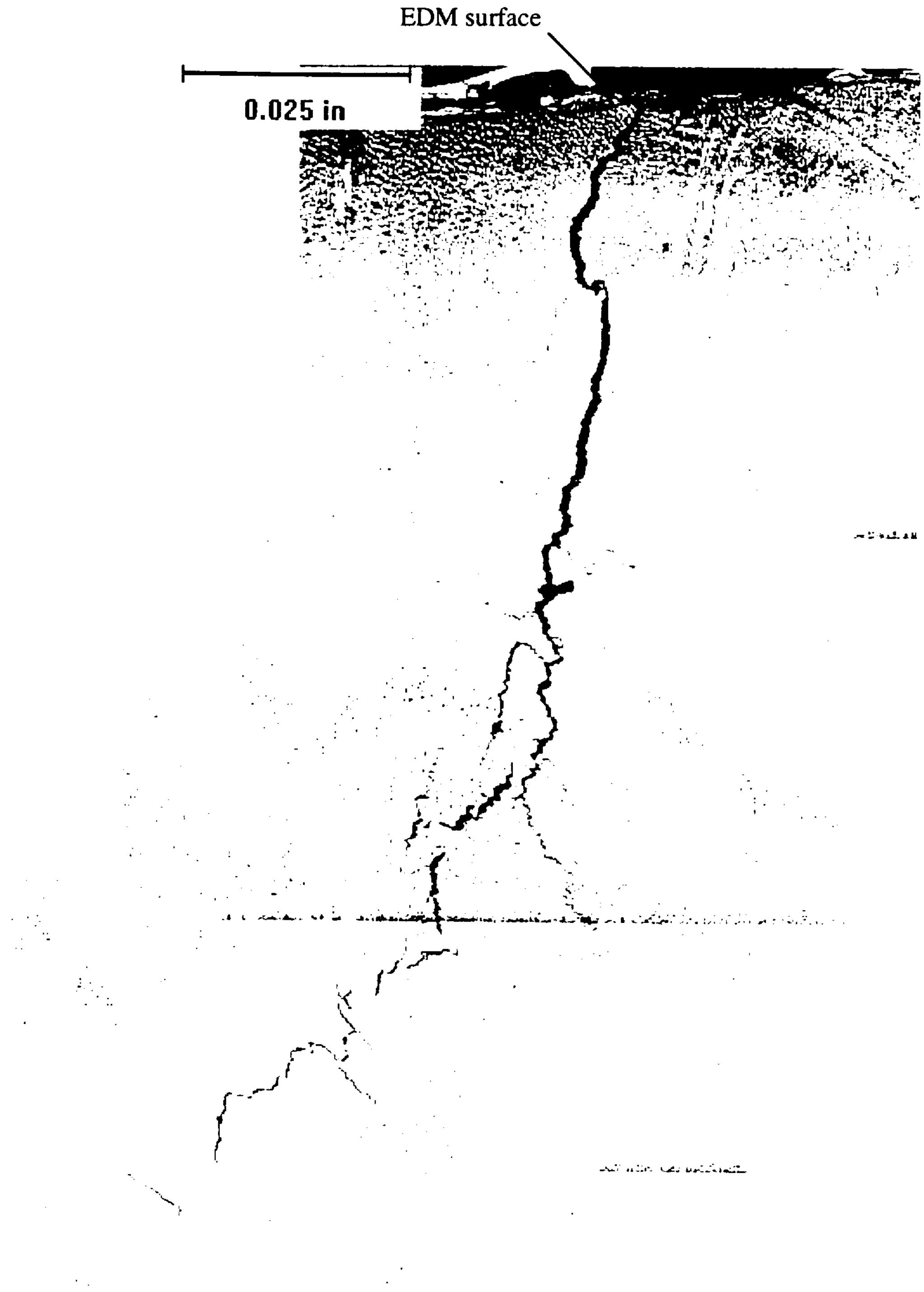


Figure 15 **Metallographic Examination results of an axial section (M2452, Figure 6) of the boat illustrating the cracking morphology. (Nital etch)**

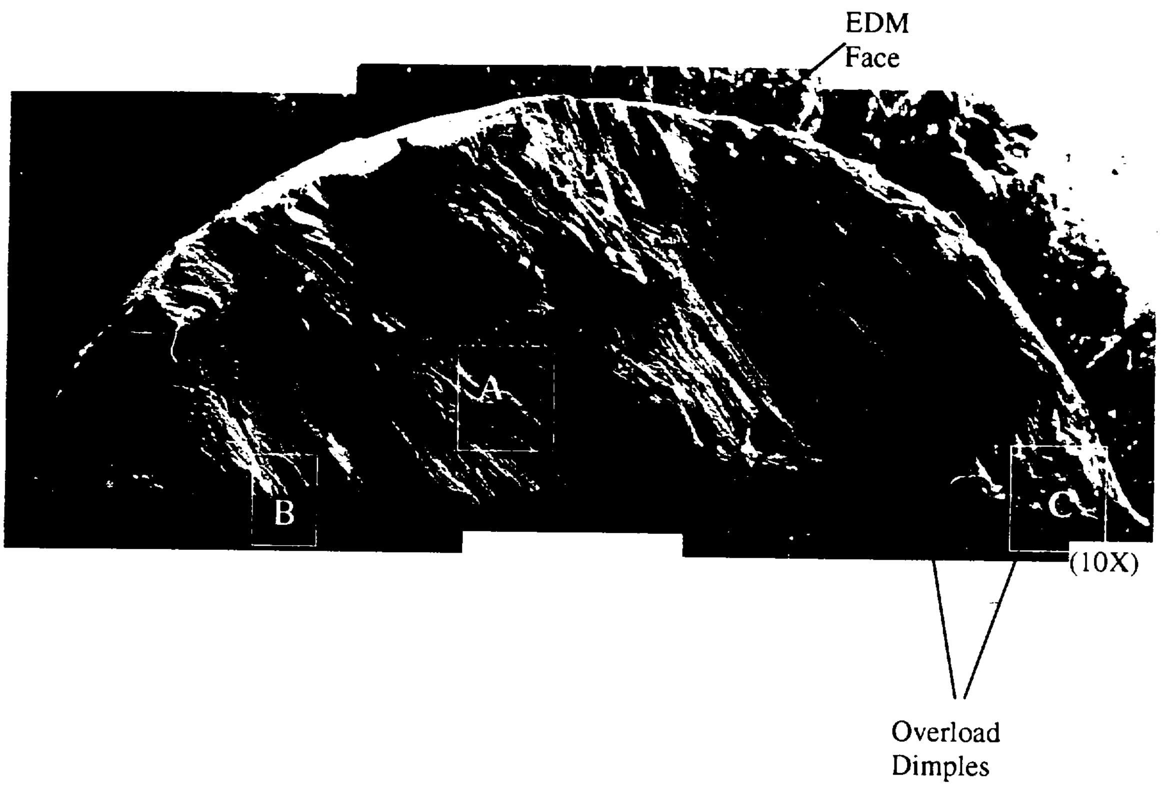
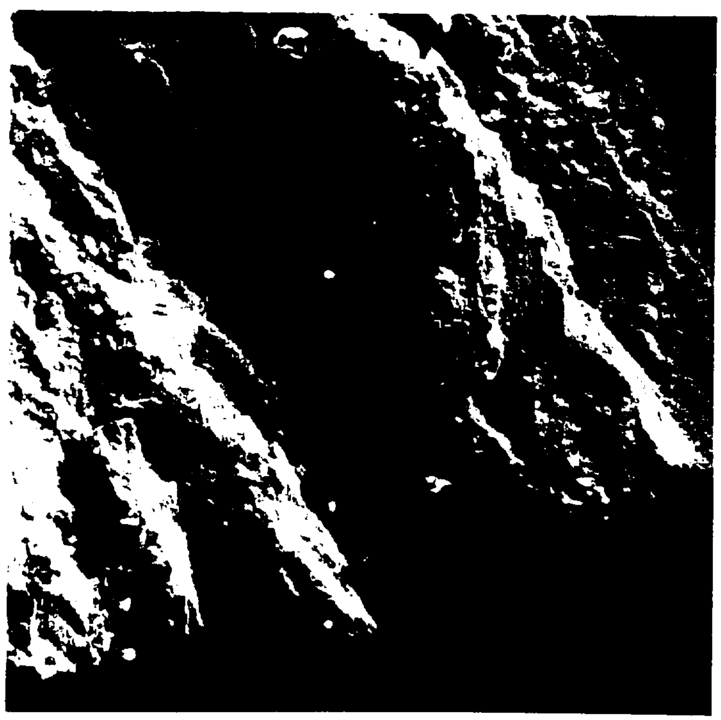


Figure 16 **Montage of SEM Fractographs of the freshly opened transverse crack through the boat, radial to the J-weld, illustrating inter-dendritic and fracture morphology. Refer to Figures 17 & 18 for details at areas A, B and C**

(350X)

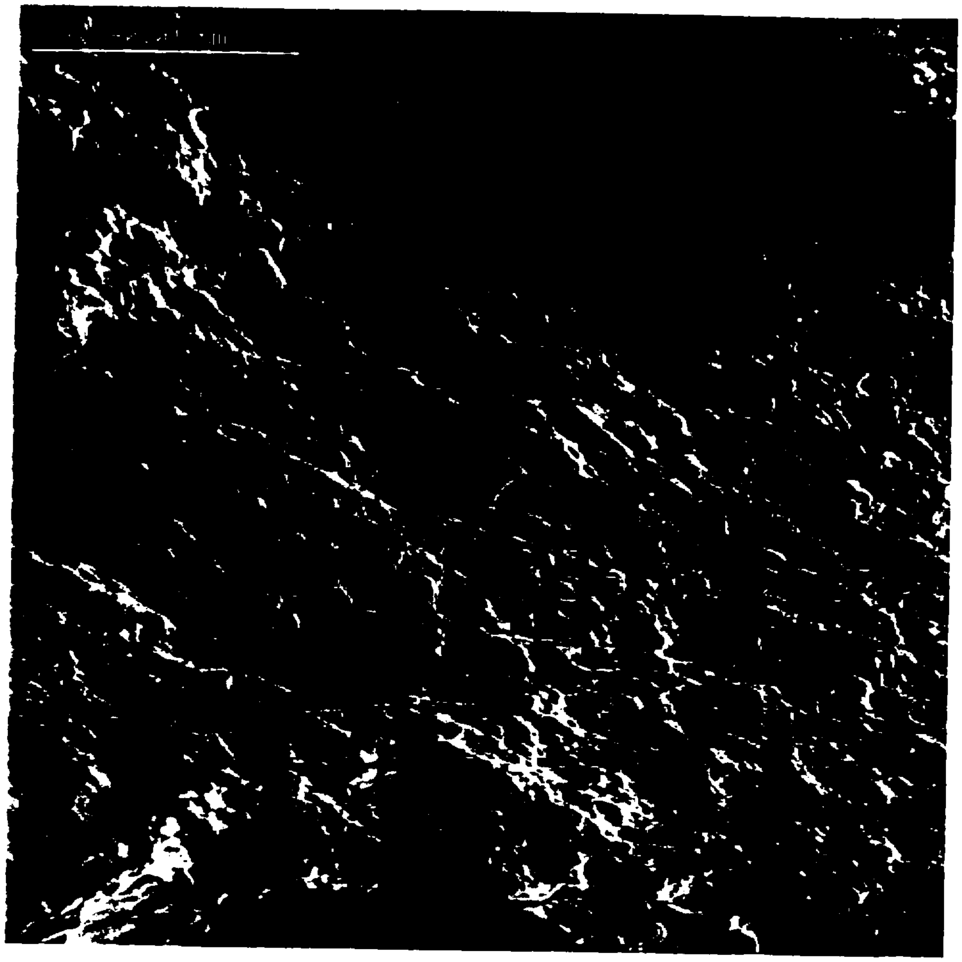
Area 'A' in Figure 16



(200X)

Area 'B' in Figure 16

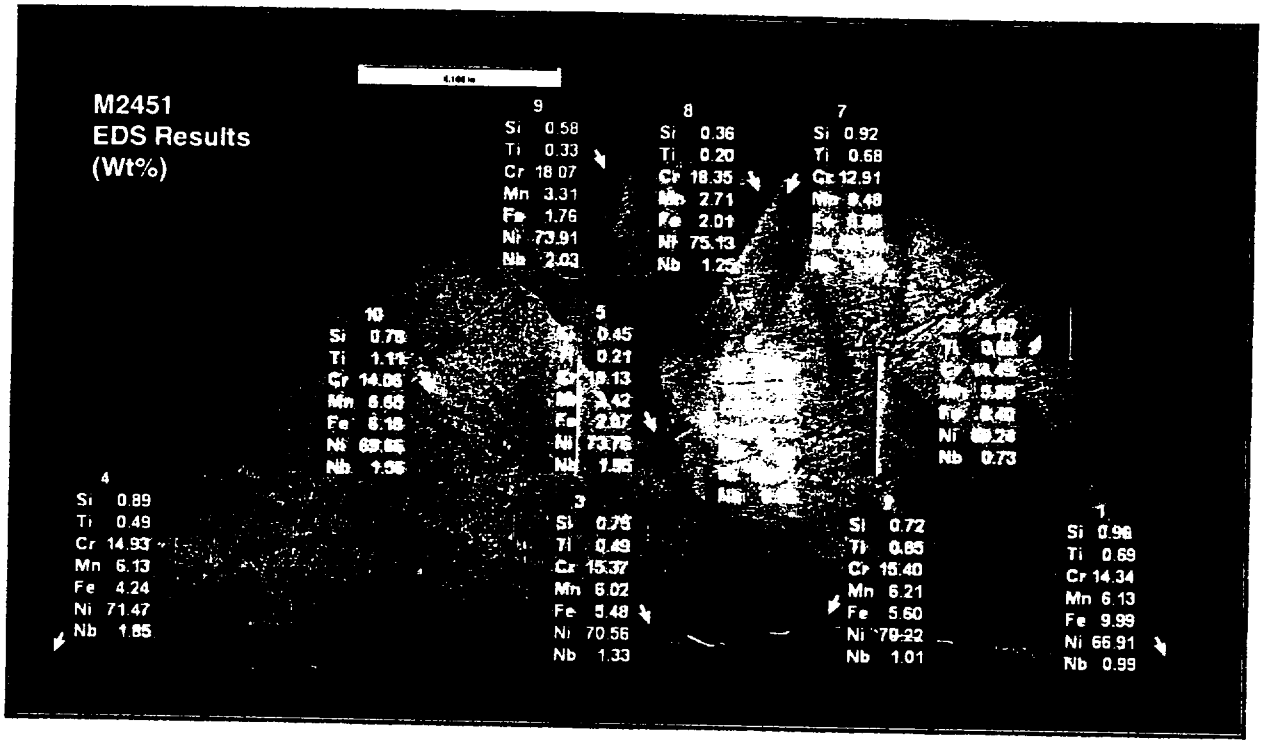
Figure 17 Oxide covered dendritic morphology of the fracture face



(560X)

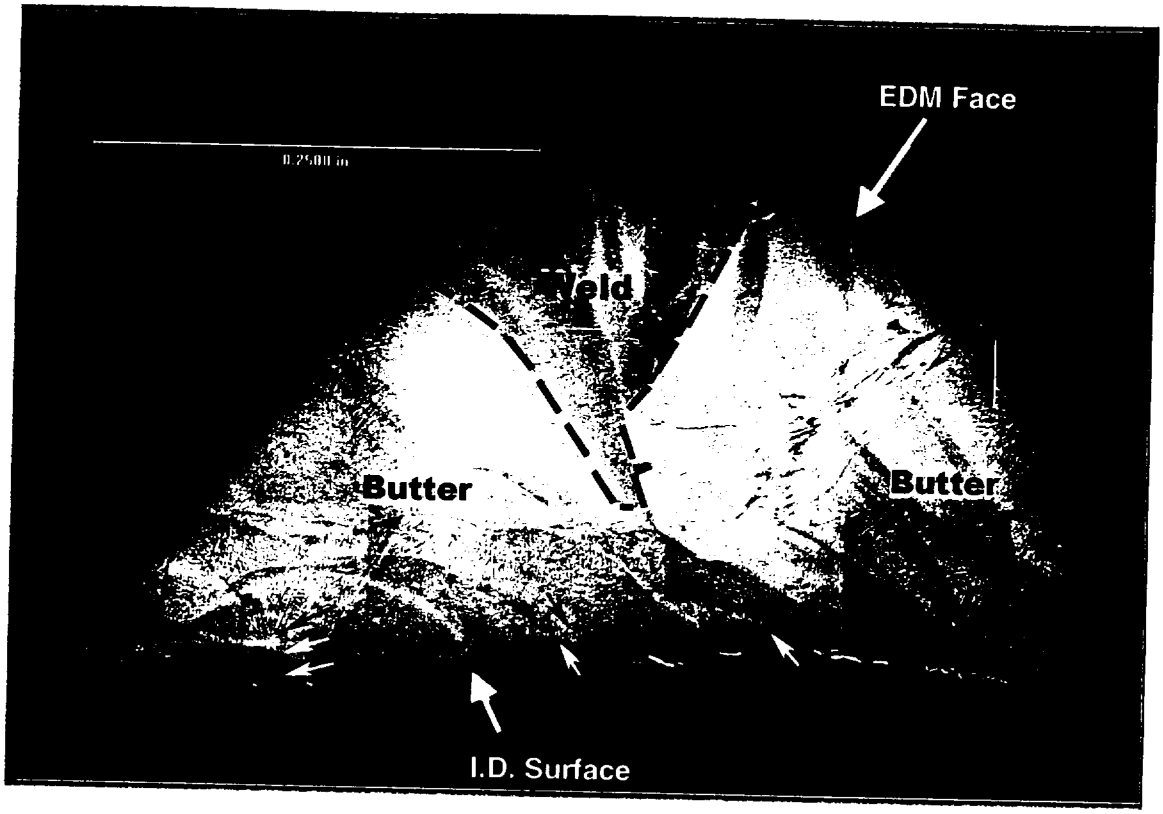
Area 'C' in Figure 16

Figure 18 Overload dimpled fracture morphology seen in the boat corner



(12X)

Figure 19 Elemental mapping of approximate quantitative EDAX chemistry analysis results of the transverse section. M2451 (The white arrows identify the locations of spot analysis)



(10X)

Figure 20 Summary of Energy Dispersive X-ray Chemistry Analysis results of the transverse section illustrating the location of the butter and weld regions. (M2451)

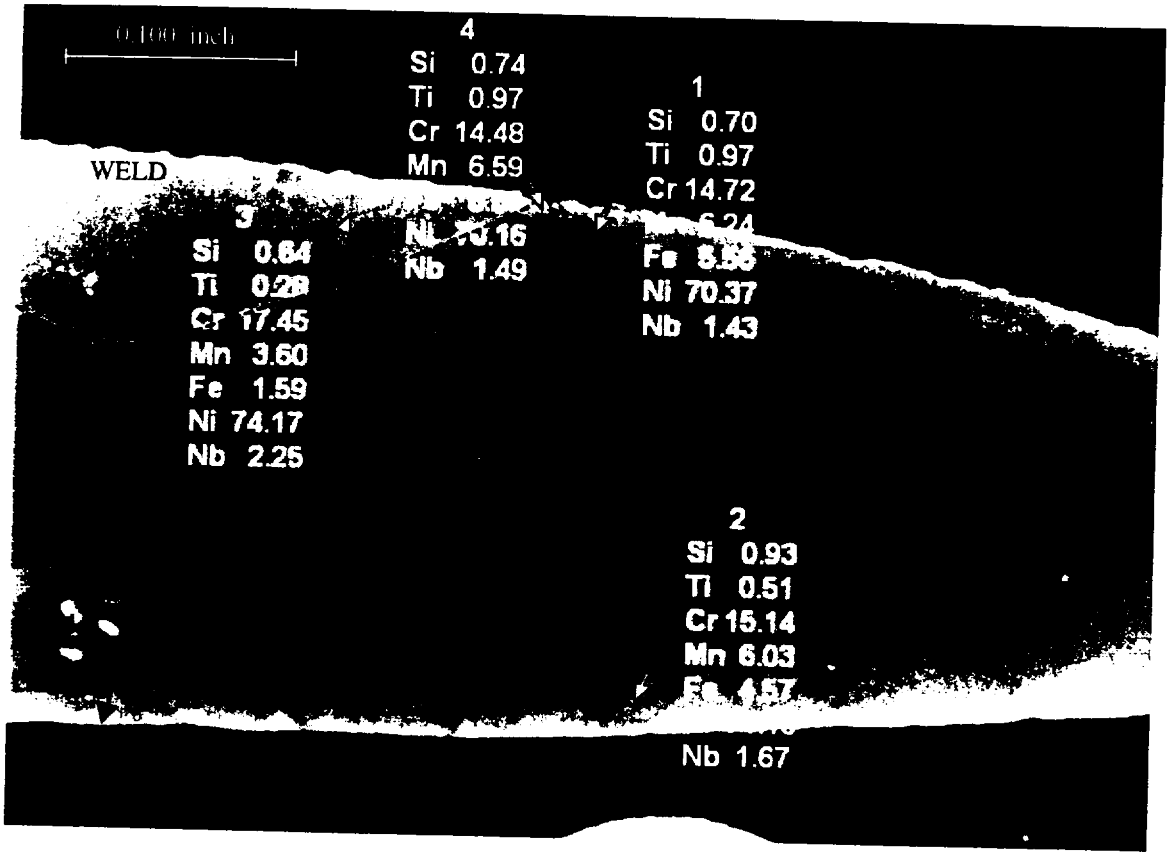
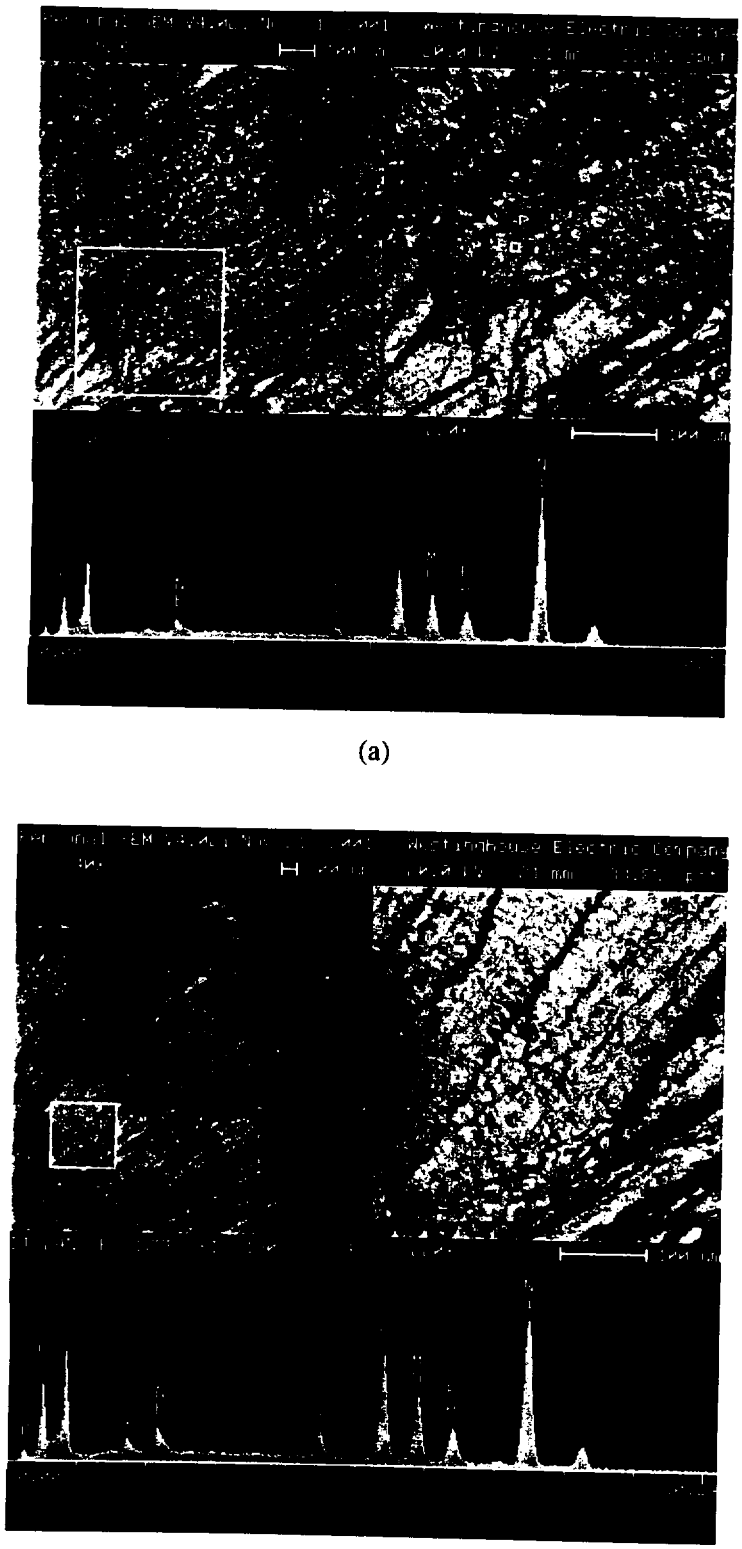


Figure 21 Energy dispersive x-ray results of the axial section illustrating the location of a crack in the butter material. (M2452). White arrows identify the locations of spot analysis.



(a)

(b)

Figure 22 **Typical EDAX Spectrums Taken from the Freshly Opened (Wide Crack) Fracture Face (See Table No. 2 for semi-quantitative analysis results). The square windows indicate the selected area for analysis.**

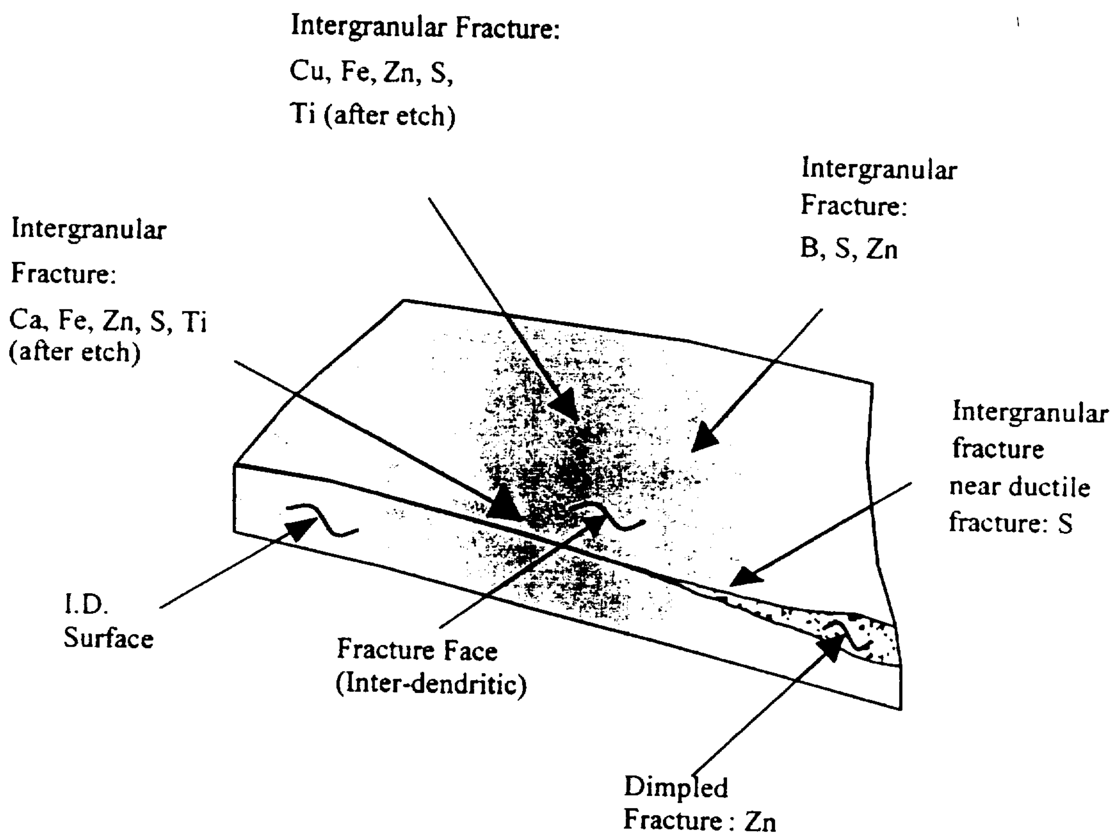
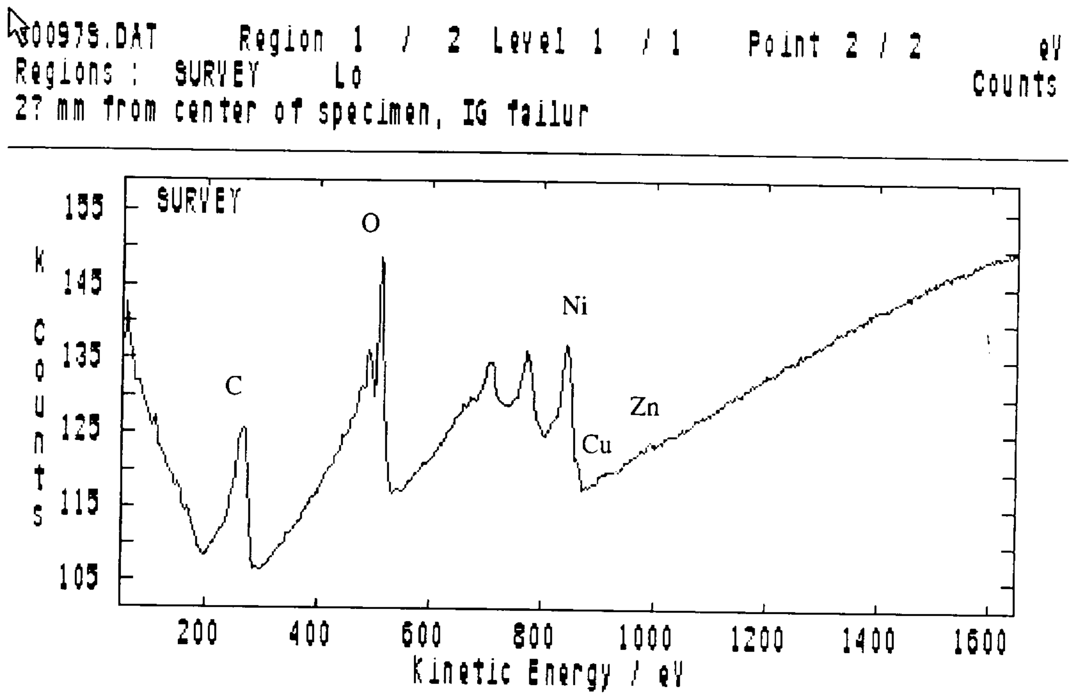


Figure 23 **Summary of Auger Electron Spectroscopy (AES) results of the freshly opened fracture face. (Area 'C' in Figure 16)**



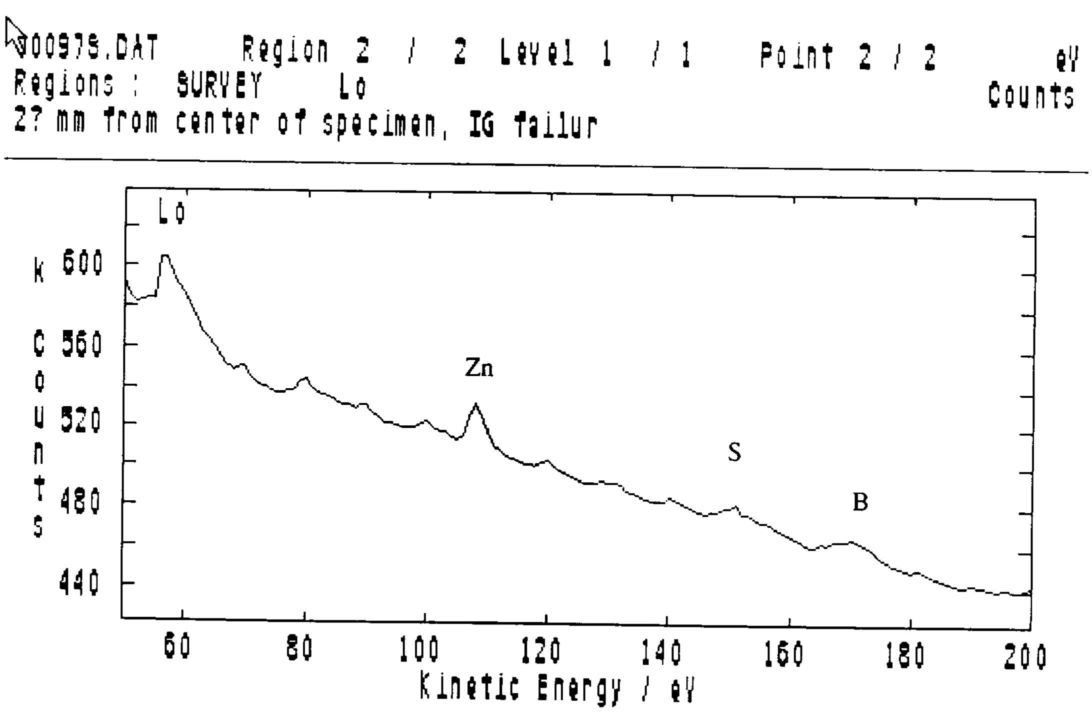


Figure 24 **Auger Electron Spectrum (AES) of interdendritic fracture face near the dimpled fracture at ID. (Area 'C' in Figure 16)**

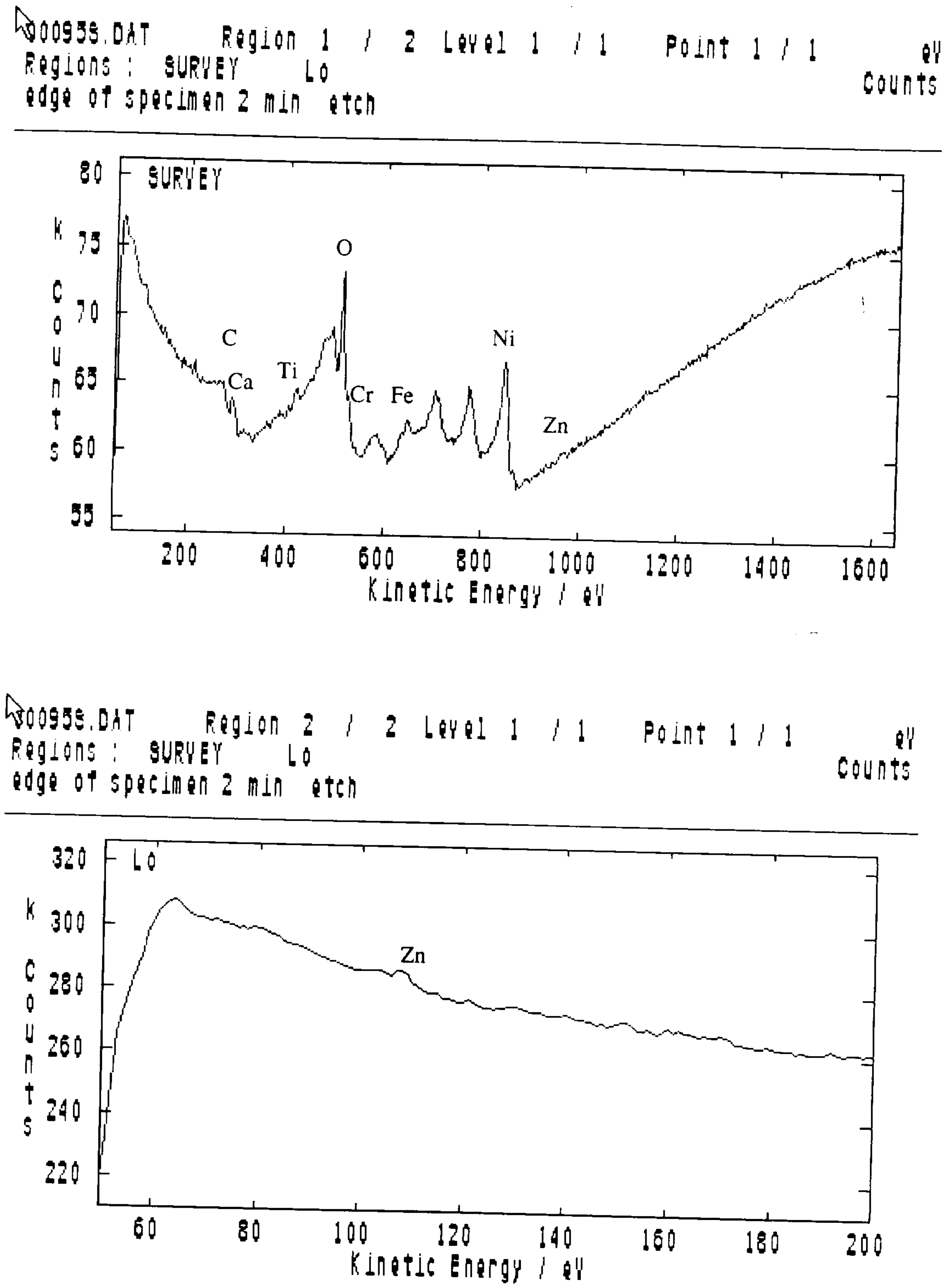


Figure 25 **Auger Electron Spectrum (AES) of the fracture region away from ID. (Area 'C' in Figure 16)**

APPENDIX A

ROTTERDAM DOCKYARD COMPANY MANUFACTURING DRAWINGS AND WELD PROCEDURES

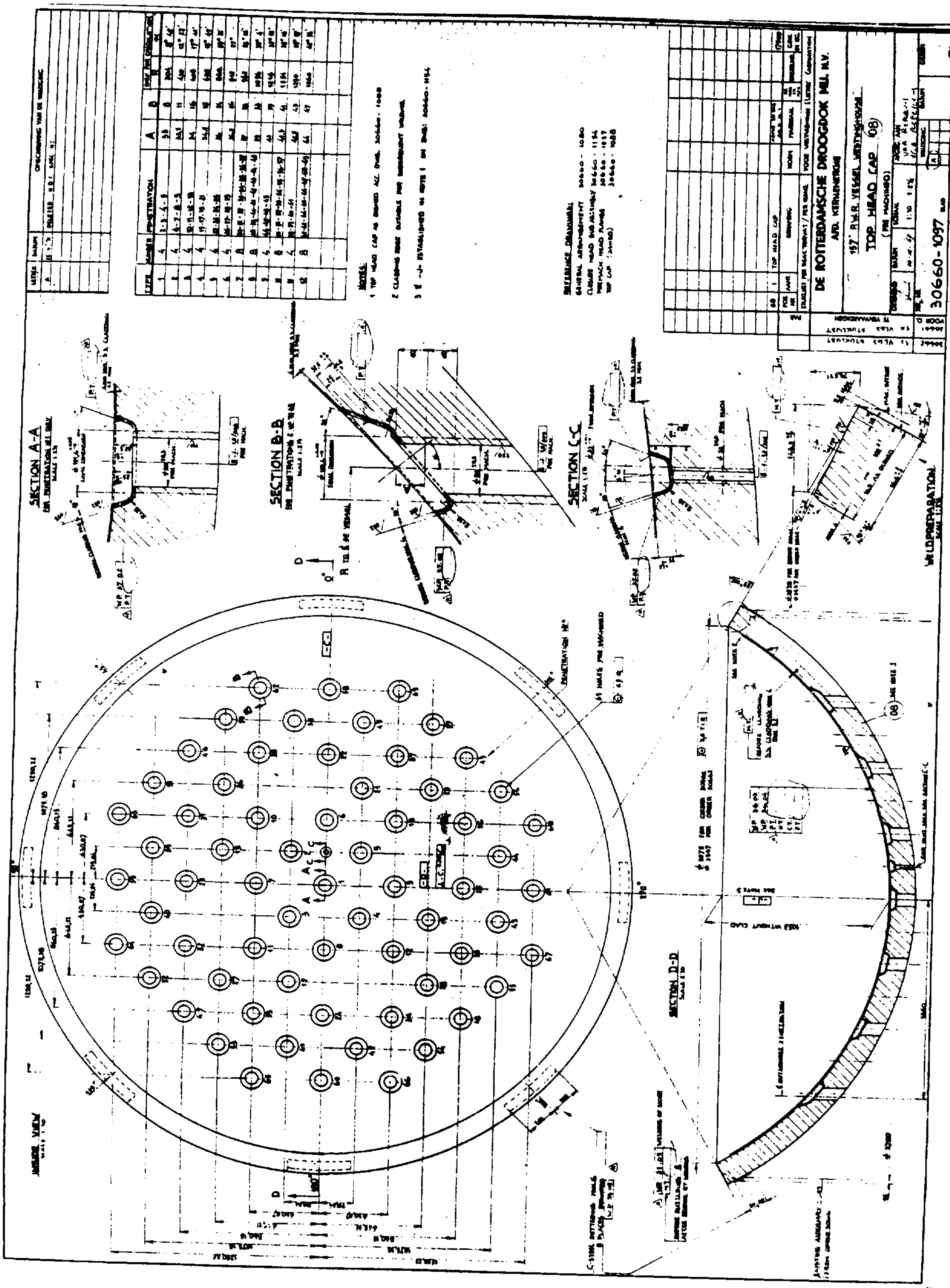
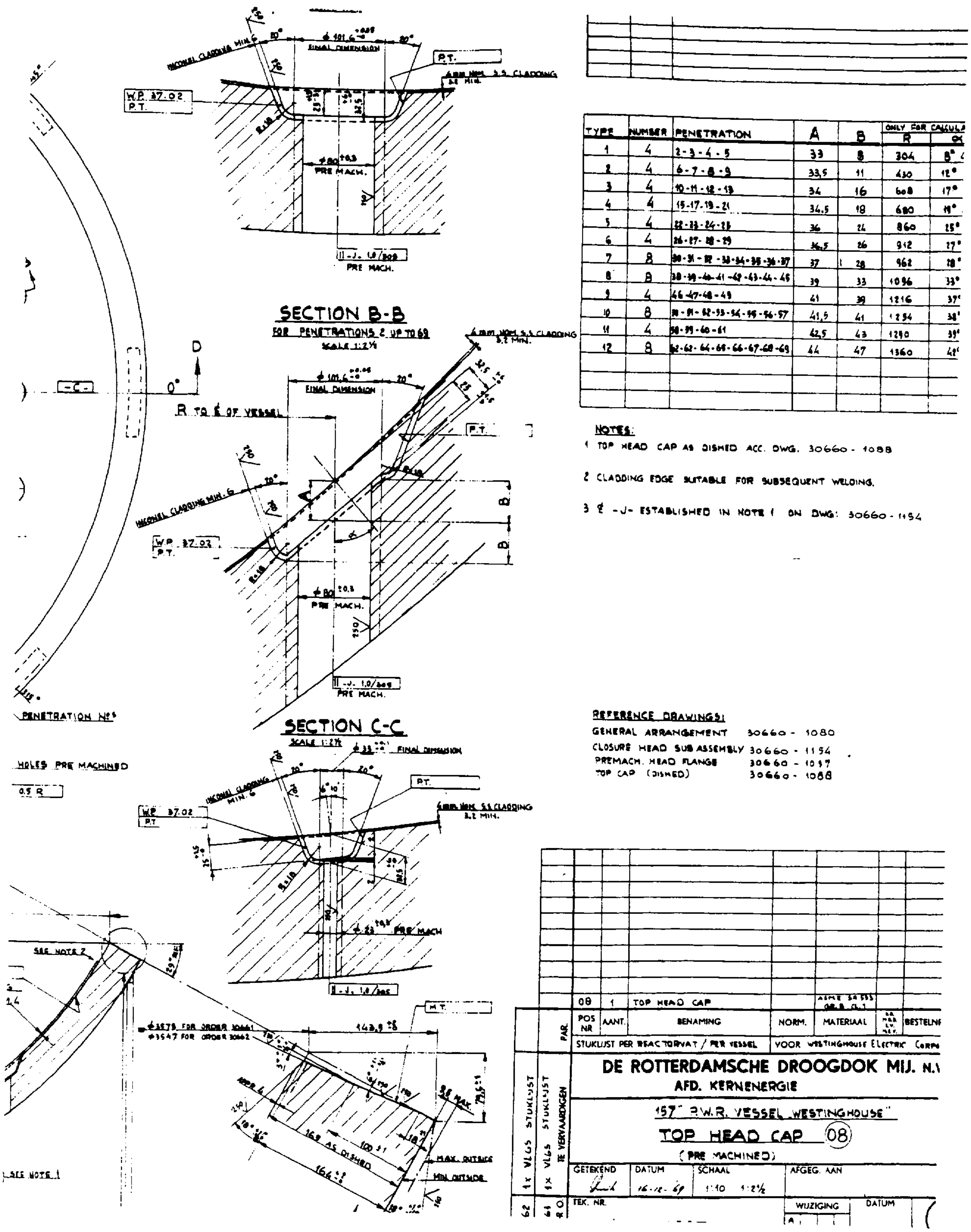


Figure A1 Reactor Vessel Closure Head Showing the CRDM Penetration Layout and J-Groove Weld Geometry



TYPE	NUMBER	PENETRATION	A	B	ONLY FOR CALCULA[TION] R	α
1	4	2-3-4-5	33	8	304	8° 4
2	4	6-7-8-9	33,5	11	430	12°
3	4	10-11-12-13	34	16	608	17°
4	4	15-17-19-21	34,5	18	680	19°
5	4	22-23-24-25	36	24	860	25°
6	4	26-27-28-29	36,5	26	912	27°
7	8	30-31-32-33-34-35-36-37	37	28	962	28°
8	8	38-39-40-41-42-43-44-45	39	33	1096	33°
9	4	46-47-48-49	41	39	1216	37°
10	8	50-51-52-53-54-55-56-57	41,5	41	1254	38°
11	4	58-59-60-61	42,5	43	1290	39°
12	8	62-63-64-65-66-67-68-69	44	47	1360	42°

NOTES:

1 TOP HEAD CAP AS DISHED ACC. DWG. 30660 - 1088

2 CLADDING EDGE SUITABLE FOR SUBSEQUENT WELDING.

3 ℄ -J- ESTABLISHED IN NOTE 1 ON DWG: 30660 - 1154

REFERENCE DRAWINGS:

GENERAL ARRANGEMENT 30660 - 1080
CLOSURE HEAD SUB ASSEMBLY 30660 - 1154
PREMACH. HEAD FLANGE 30660 - 1057
TOP CAP (DISHED) 30660 - 1088

PAR.	POS NR	AANT.	BENAMING	NORM.	MATERIAAL		BESTELN[R]
	08	1	TOP HEAD CAP		ASME SA 533 GR.B CL.1		

STUKLIJST PER REACTORVAT / PER VESSEL — VOOR WESTINGHOUSE ELECTRIC CORP.

62 — 1x VL65 STUKLIJST
64 — 1x VL65 STUKLIJST TE VERVAARDIGEN

GETEKEND | DATUM 16-12-69 | SCHAAL 1:10 1:2½ | AFGEG. AAN

TEK. NR. | WIJZIGING | DATUM

Figure A2 Detail of Section 'B-B' in Figure A1

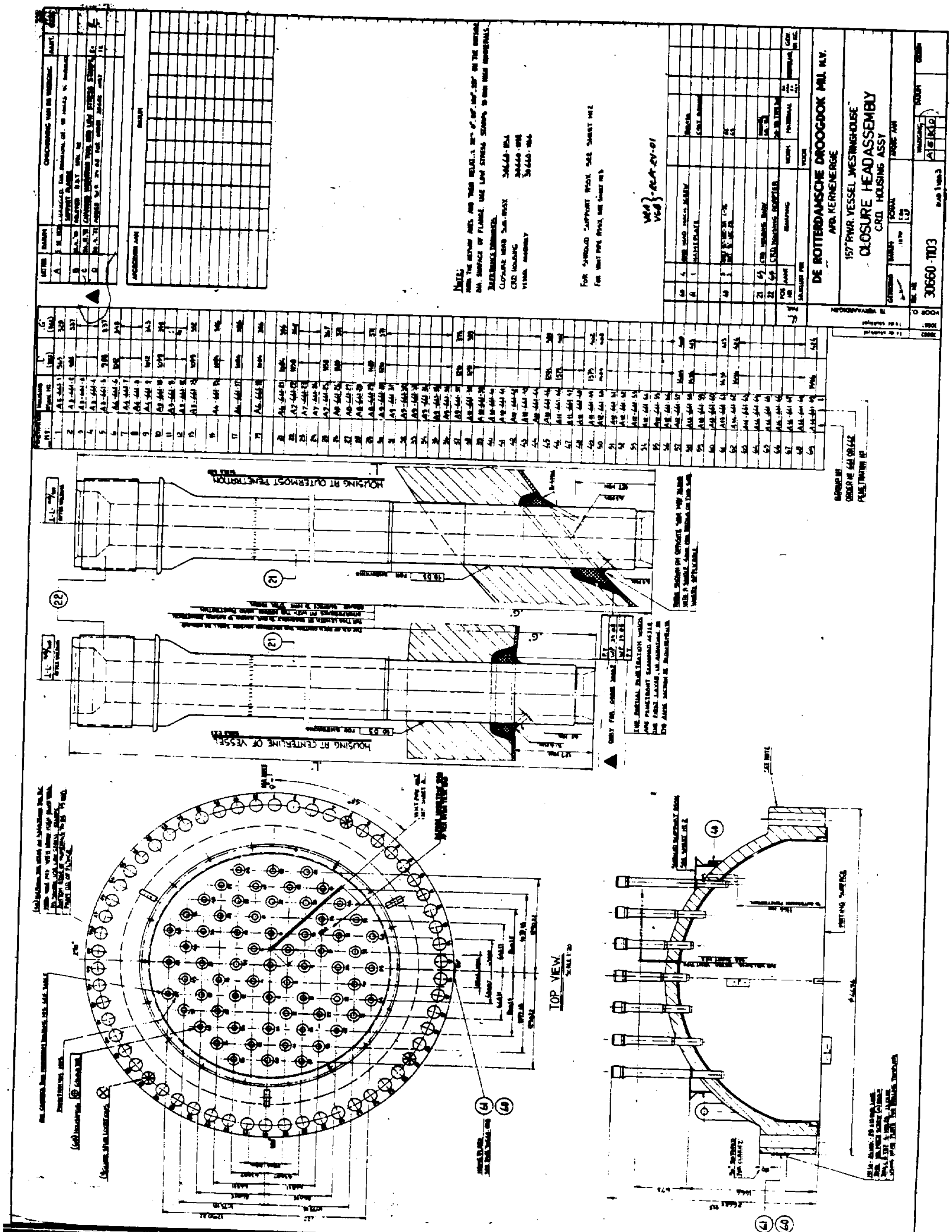


Figure A3 Reactor Vessel Closure Head Showing Penetration J-Groove Weld Joint

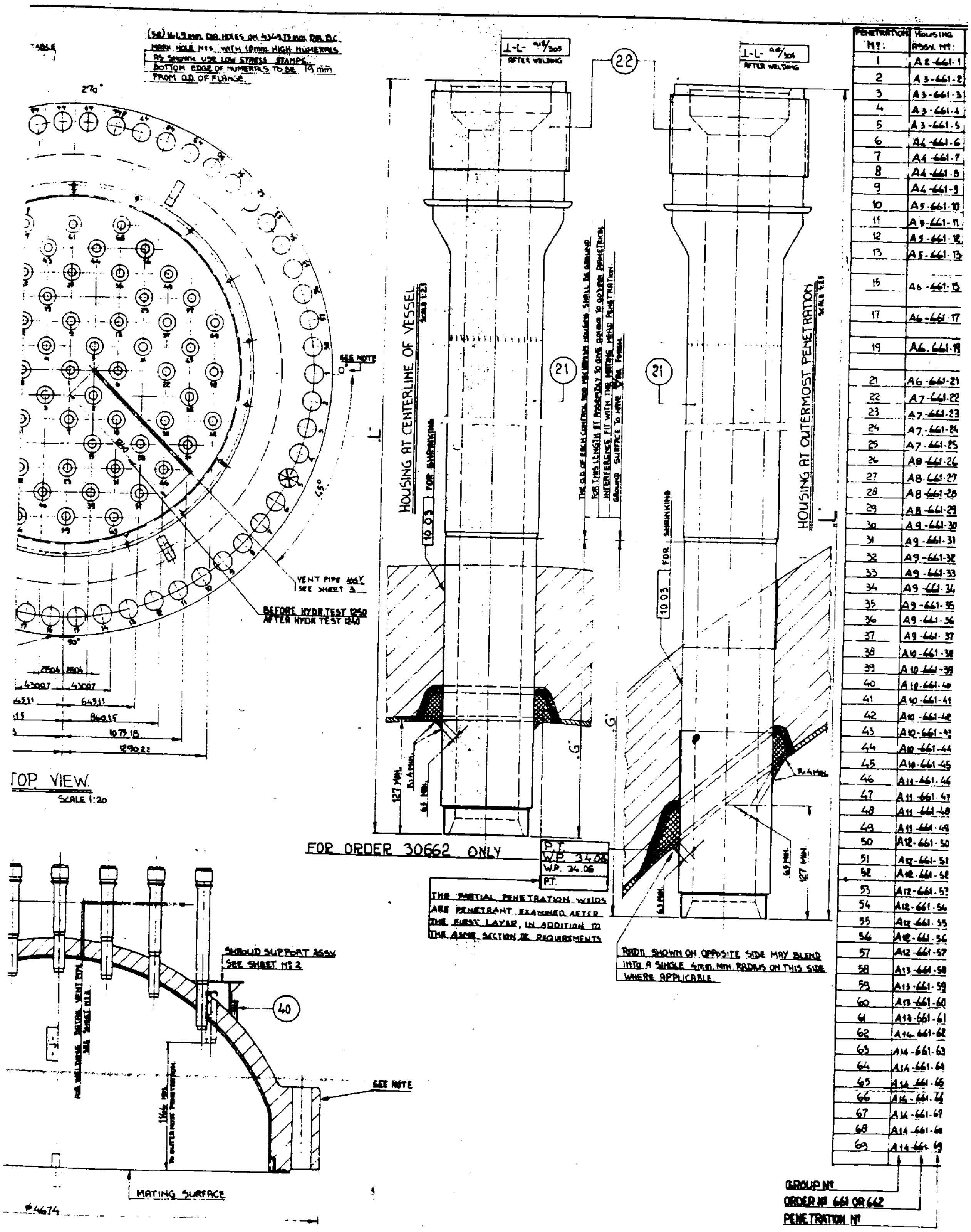


Figure A4 Details of Outer Penetration in Figure A3

APPENDIX B

CRDM J-GROOVE WELD PROCEDURES

1. Specification 37.02: Procedure for manual shielded metal arc weld overlay cladding with Inconel (F-Number 43) of low alloy steel (P-Number 12B).

2. Specification 34.06: Procedure for a combination of manual gas tungsten arc welding and manual shielded metal arc welding of solid Inconel (P-Number 43) to solid Inconel (P-Number 43) or to Inconel weld overlay cladding.

3. Specification 34.08: Procedure for a combination of manual gas tungsten arc welding and manual gas metal arc welding of solid Inconel (P-Number 43) to solid Inconel (P-Number 43) or to Inconel weld overlay cladding.

4. Specification 39.04: Procedure for repair welding in Inconel (P-Number 43) and Inconel weldments.

vMo/vdB

Quality and Metallurgical Department

Specification Section

Specification No. : 37.02
Revision No. : 9
Date : 1972-02-15

PROJECT : Nuclear vessels
R.D.M. Order No. : –
Buyer's Reference : –

SUBJECT : Procedure for manual shielded metal arc weld overlay cladding with Inconel (P-Number 43) of low alloy steel (P-Number 12B).

Qualification No.	K 611				
Qualification date	70-10-06				
Spec. - rev. No.					
Thickness range qual.(mm) *	25 min.				
Par. of this spec.	2.				

* base metal.

Spec.	Prod.	Revision based on:		
		37.02-8		37.02-9

DE ROTTE[illegible]AMSCHE DROOGDOK [illegible]ATSCHAPPIJ N.V.

Quality and Metallurgical Department

WMc/W

Specification Section

1. Application:

Multiple layer weld overlay cladding with Inconel of low alloy steel (ASTM A 508-69 Class 2 and ASTM A 533-69 Grade Class 1) in accordance with requirements of ASME III and IX.

2. Cladding technique:

Manual shielded metal arc cladding.

String travel.

3. Cladding positions.

1G and 2G.

4. Welding material and weld metal.

4.1 P-Number 43: covered electrode according to ASME SB-295 E NiCrFe - 3 (SFA-5.11).

4.2 Chemical range weld metal Inconel weld overlay cladding on P-12B material:

	C	0.11 % max.
	Mn	5.0 - 9.5 %
	Fe	15 % max.
	S	0.015 % max.
	Si	1.0 % max.
	Cu	0.50 % max.
	Ti	1.0 % max.
	Cr	12.5 - 17.0 %
	Nb + Ta	1.0 - 2.5 %
	Co	0.12 % max.
	others	0.5 % max.
	Ni	balance

DE ROTTERDAMSCHE DROOGDOK MAATSCHAPPIJ N.V.
Quality and Metallurgical Department

Specification Section

5. Drying and storage of cladding material.
According to specification No. 54.07.

6. Preheat and interpass temperature.

6.1 Range: 100 - 175° C.
To be maintained during cladding and subsequent to cladding till postheating.

6.2 In case of postheating after first layer(s) of Inconel weld overlay cladding (clad thickness 2.5 mm min.) on B-12B materials, for following layer(s):
Range: 15 - 175° C.

7. Preparation for cladding.

7.1 Qualifications.
In accordance with requirements of ASME III and IX.

7.2 Areas to be covered with clad metal.

7.2.1 Examination of areas.
Visually and by magnetic particle or liquid penetrant examination according to specification No. 23.06 or 24.06 resp.

7.2.2 Repair examined areas.
By surface conditioning, followed, if required, with repair welding according to specification No. 33.02.

7.2.3 Cleaning of areas.
By grinding, wire brushing and subsequent wiping with a cloth soaked in acetone.

Manual ... weld overlay ... 02 - 9

DE ROTTERDAMSCHE DROOGDOK MAATSCHAPPIJ N.V.

Quality and Metallurgical Department

Specification Section

8. Cladding.

8.1 Data.

diameter electrode in mm	cladding current in amps, d.c., electrode +	
	first layer	following layer(s)
3.25	—	70 - 100
4	90 - 110	100 - 130
5	—	125 - 150

8.2 Surface of weld beads to be conditioned for good appearance. After each weld pass removal of slag by chipping, grinding and wire brushing with stainless steel wire brushes.

9. Postheating.

According to specification No. 53.01.

10. Surface conditioning subsequent to postheating.

Smoothening of cladding by mechanical means as far as needed for examination and/or design.

11. Examination of cladding.

By liquid penetrant examination according to specification No. 24.06 and in addition (only for core support pads) by ultrasonic examination according to specification No. 21.[illegible].

12. Repair subsequent to examination.

According to specification No. 39.04.

Manual shielded metal arc weld overlay | 37.02 - 9

DE ROTTERDAMSCHE DROOGDOK MAATSCHAPPIJ N.V.

Quality and Metallurgical Department

QMD/Vd

Specification Section	
	Specification No. : 34.06
	Revision No. : 5
	Date : 1972-02-15

PROJECT : Nuclear vessels.

R.D.M. Order No. : –

Buyers Reference : –

SUBJECT : Procedure for a combination of manual gas tungsten arc welding and manual shielded metal arc welding of solid Inconel (P-Number 43) to solid Inconel (P-Number 43) or to Inconel weld overlay cladding.

Qualification No.	K 541	K 585			
Qualification date	70-05-01	70-08-05			
Spec. – rev. No.					
Thickness range qual. (mm)	4.7-42	4.7-305			
Par. of this spec.	2.1+2.2	2.2			

DBP/DCP/WAT/WBT/105/RV/7B

DE ROTTE[redacted]AMSCHE DROOGDOK M[redacted]TSCHAPPIJ

Quality and Metallurgical Department

vMo/EvdB

Specification Section

1. <u>Application</u>.
Welding of Inconel to Inconel (ASME SB-166, 167 or 168) or Inconel weld overlay cladding in accordance with requirements of ASME III and IX.

2. <u>Welding technique</u>.
No use of backing strip.

2.1 <u>Manual gas tungsten arc welding (for first and last layer)</u>
String and/or weave travel.
Weaving width limited to 3 mm.

2.2 <u>Manual shielded metal arc welding (for following layers)</u>.
String and/or weave travel.
Weaving width limited to 2 times electrode diameter.

3. <u>Welding position</u>.
3G (incl. of axis 30° ± 15°).

4. <u>Welding materials</u>.

4.1 <u>Manual gas tungsten arc welding</u>.
F-Number 43: bare solid filler rod according to
ASME SB-304 ER NiCr - 3 (SFA-5.14).
rod diameter 1.0, 1.6, 2.0 and 2.4 mm.
shielding gas : argon 99.99 %.

Combination of manual gas tungsten arc welding ... welding of F-43 | 4.06

4.2 Manual shielded metal arc welding.
F-Number 43: covered electrode according to
ASME SB-295 ENiCrFe - 3 (SFA-5.11) or
covered electrode Grini 7,

chemical range:	
C	0.07 % max.
Mn	3.0 - 5.0 %
Fe	2.0 - 5.0 %
S	0.015 % max.
Si	0.75 % max.
Cu	0.5 % max.
Ti	1.0 % max.
Cr	13.0 - 17.0 %
Nb	2.0 - 3.0 %
Mo	1.0 - 2.5 %
Co	0.1 % max.
Ni	balance

5. Drying and storage of welding materials.
Covered electrodes according to specification No. 54.01.

6. Preheat and interpass temperature.
Range: 15 - 175°C.

7. Preparation for welding.

7.1 Qualifications.
In accordance with requirements of ASME III and IX.

Quality and Metallurgical Department

Specification/Section

7.2 Weld edges.

7.2.1 Preparation.

By mechanical means eventually preceded by thermal cutting. All discoloration, fused edges of cut surfaces and slag remaining after thermal cutting shall be removed by machining or grinding; the depth to be machined or ground shall be at least 0.8 mm.

7.2.2 Examination prepared edges.

Visually and by liquid penetrant examination according to specification No. 24.06.

7.2.3 Repair examined edges.

By surface conditioning, followed, if required, with repair welding according to specification No. 39.04.

7.3 Marking of parts to be welded.

As far as needed for correct assembly.

7.4. Tackwelding.

By tack welds deposited in the weld groove.

7.5 Cleaning of weld edges and tack welds.

By grinding, wire brushing with stainless steel brushes and subsequent wiping with a cloth soaked in acetone.

5

8. Welding.

8.1 Data.

8.1.1 Manual gas tungsten arc welding.

diameter tungsten (2 % Thoriated) electrode in mm.	welding current in amps., d.c., electrode -.	argon flow rate in l/min.
1.0	< 80	6 - 8
1.6	70 - 140	6 - 8
2.0	100 - 175	6 - 8
2.4	130 - 230	6 - 8

8.1.2 Manual shielded metal arc welding.

diameter electrode in mm.	welding current in amps., d.c., electrode +.
3.25	70 - 100
4	100 - 130
5	125 - 150

8.2 Surface of weld beads to be conditioned for good appearance. After each weld pass removal of eventual slag by grinding and by wire brushing with stainless steel brushes.

8.3 Intermediate examination.
By liquid penetrant examination according to specification No. 24.06 in different weld stages as follows:

[illegible]

[redacted]

Quality and Metallurgical Department

Specification Section

8.3.1 General.

First layer and each ½" of weld thickness.
If back chipping or grinding is performed on the rootpass, that area shall also be liquid penetrant examined.

8.3.2 Specific.

welds between	stage
instrumentation tubes and bottom head	each layer
control rod drive housings and top head	first layer and each ½" of weld thickness
vent pipe and top head	

8.4 Intermediate repair.

According to this specification.

9. Postheating.

No requirements.

10. Surface conditioning.

Smoothening of welded joints by mechanical means as far as needed for examination and/or design.

11. Examination of welded joints.

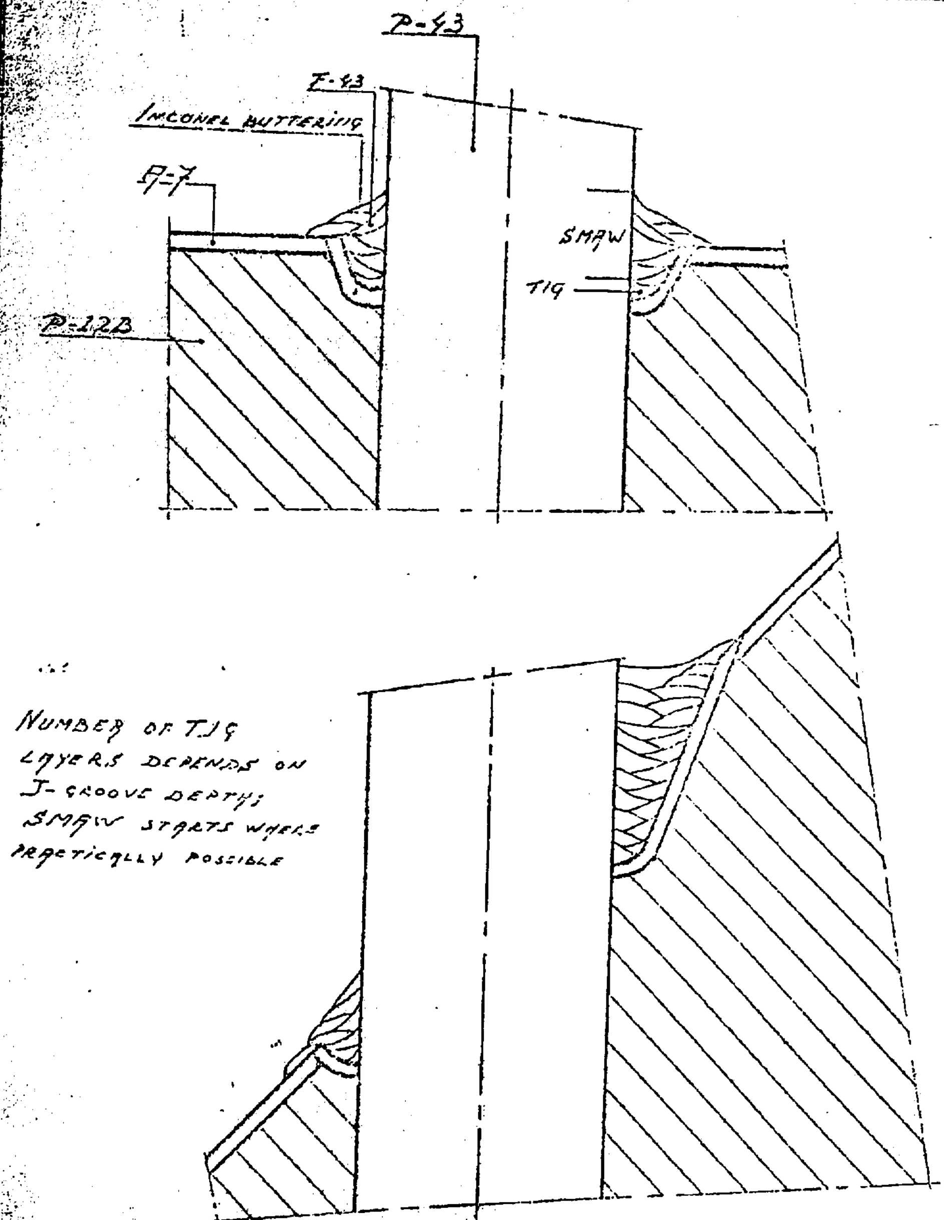
By liquid penetrant examination according to specification No. 24.06.

12. Repair subsequent to examination.

According to specification No. 39.04.

Quality and Metallurgical Department

Specification Section



Quality and Metallurgical Department

Specification Section

Specification No. : 34-08
Revision No. : 1
Date : 1972-02-21

PROJECT : Nuclear vessels
KDM Order No. : –
Buyer's Reference : –

SUBJECT : Procedure for a combination of manual gas tungsten arc welding and manual gas metal arc welding of solid Inconel (P-Number 43) to solid Inconel (P-Number 43) or to Inconel weld overlay cladding.

Scanned
5405.doc

Qualification No.	N 578				
Qualification date	71-12-30				
Spec. - rev. No.					
Thickness range qual. (mm)	[illegible].7-52				
Par. of this spec.	2.1+2.2				

SSP/ DBP/DCP/WAT/WBT/HFS/AVL/JB

Quality and Metallurgical Department

Specification Section

1. **Application.**
Welding of Inconel to Inconel (ASME SB-166, 167 or 168) or to Inconel weld overlay cladding in accordance with requirements of ASME III and IX.

2. **Welding technique.**
No use of backing strip.

2.1 **Manual gas tungsten arc welding (for first layers).**
String and/or weave travel.
Weaving width limited to 3 mm.
Argon backing gas shall be used for butt welds where the backside of the weld is not accessible for grinding and liquid penetrant examination.

2.2 **Manual gas metal arc welding (for following layers).**
String travel and/or weave travel.
Weaving width limited to 25 mm.

3. **Welding positions.**
1G and 3G (upward)

4. **Welding materials.**
F-Number 43: bare solid filler rod according to
ASME SB-304 ER NiCr - 3 (SFA-5.14).
rod diameter 0.8, 1.0, 1.6, 2.0 and 2.4 mm.
shielding gas : argon 99.99 %.

5. **Preheat and interpass temperature.**
Range: 15 - 175°C.

Quality and Metallurgical Department

...Mo and B

Specification Section

6. Preparation for welding.

6.1 Qualifications.
In accordance with requirements of ASME III and IX.

6.2 Weld edges.

6.2.1 Preparation.
By mechanical means eventually preceded by thermal cutting. All discoloration, fused edges of cut surfaces and slag remaining after thermal cutting shall be removed by machining or grinding: the depth to be machined or ground shall be at least 0.8 mm.

6.2.2 Examination prepared edges.
Visually and by liquid penetrant examination according to specification No. 24.06.

6.2.3 Repair examined edges.
By surface conditioning, followed, if required, with repair welding according to specification No. 39.04.

6.3 Marking of parts to be welded.
As far as needed for correct assembly.

6.4 Tackwelding.
By tack welds deposited in the weld groove.

6.5 Cleaning of weld edges and tack welds.
By grinding, wire brushing with stainless steel brushes and subsequent wiping with a cloth soaked in acetone.

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No. 4.13

Specification Section

7. Welding.

7.1. Data.

7.1.1 Manual gas tungsten arc welding.

diameter tungsten (2% thoriated) electrode in mm	welding current in amps., d.c., electrode -	argon flow rate in l/min.
1.0	< 80	6 - 8
1.6	70 - 140	6 - 8
2.0	100 - 175	6 - 8
2.4	130 - 230	6 - 8

7.1.2 Manual gas metal arc welding.

diameter electrode in mm	welding current in amps., d.c., electrode +	welding voltage in volts	argon flow rate	
			cup Ø mm	l/min
0.8	90 - 135	17 - 20	10	7-10
			12	10-13
			14	12-15

7.2 Surface of weld beads to be conditioned for good appearance. After each weld pass removal of oxide by wire brushing with stainless steel brushes.

7.3 Intermediate examination.
By liquid penetrant examination according to specification No. 24.06 in different weld stages as follows:

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Specification Section

7.3.1 General.

First layer and each ½" of weld thickness.

If back chipping or grinding is performed on the rootpass, that area shall also be liquid penetrant examined.

7.3.2 Specific.

welds between	stage
instrumentation tubes and bottom head	each layer
control rod drive housings and top head	first layer and each ½" of weld thickness
vent pipe and top head	

7.4 Intermediate repair.

According to this specification.

8. Postheating.

No requirements.

9. Surface conditioning.

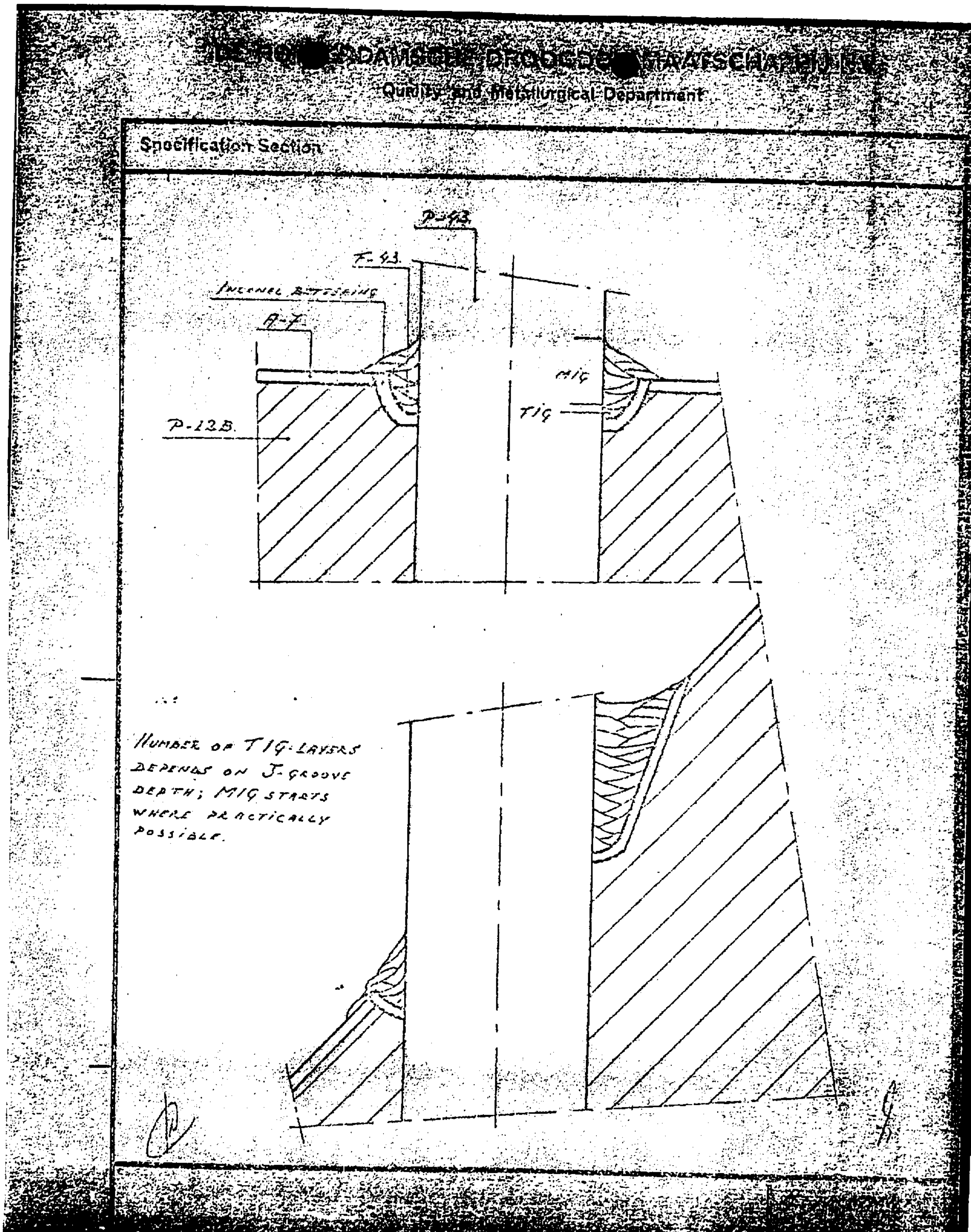
Smoothening of welded joints by mechanical means as far as needed for examination and/or design.

10. Examination of welded joints.

By liquid penetrant examination according to specification No. 24.06.

11. Repair subsequent to examination.

According to specification No. 39.04.


Quality and Metallurgical Department
Specification Section
P-43
F-43
INCONEL BUTTERING
A-7
P-12B
MIG
TIG
NUMBER OF TIG-LAYERS DEPENDS ON J-GROOVE DEPTH; MIG STARTS WHERE PRACTICALLY POSSIBLE.

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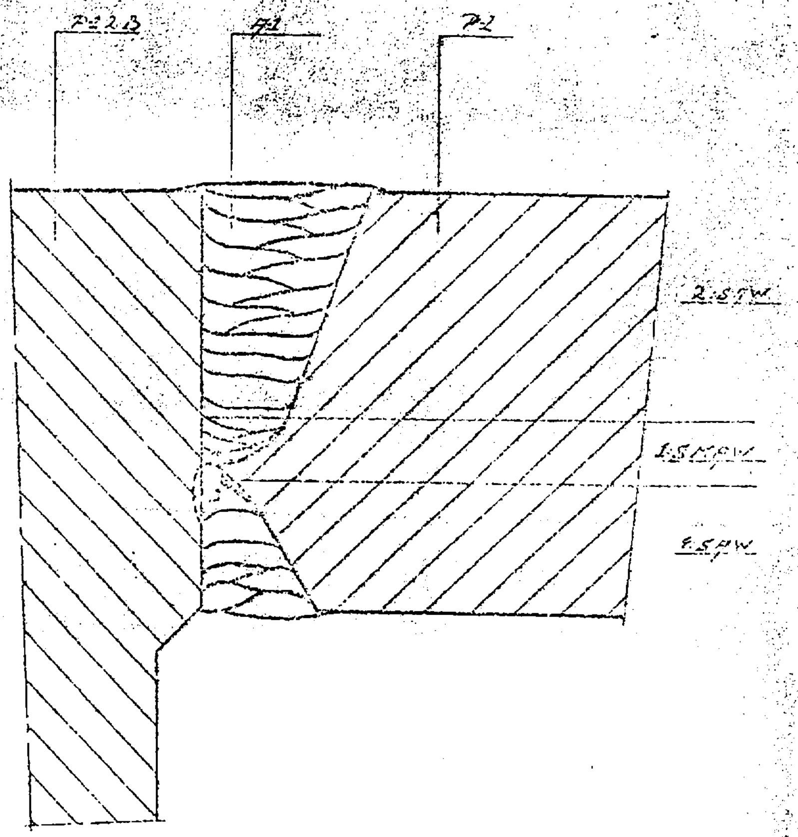
Specification Section



Specification No. [illegible]
Revision No. : 5
Date : 19[illegible]-02-15

PROJECT : Nuclear vessels
[illegible] : –
[illegible] : –

146

SUBJECT : Procedure for repair welding of Inconel (P-Number 43) and Inconel weldments.

APPROVAL STATUS
☒ APPROVED
☐ APPROVED AS NOTED
☐ RETURNED FOR CORRECTION 136 VRA
BY WSB DATE PAR 142 V&B

Qualification No.	J 556	K 541	K 585	K 611	
Qualification date	69-10-31	70-01-01	70-08-05	70-10-06	
Spec. - rev. No.					
Thickness range qual. (mm)	4.7-350	4.7-42	4.7-305	25 min.*	
Par. of this spec.	2.2	2.3	2.2	2.2	

* base metal

[illegible]	[illegible]	Revision based on:		
		39.04-5 PAR 165 (TVA)	O	39.04-6 Page 1 of 6

Specification Section

1. Application.

Repair welding of Inconel (ASME SB-168) and Inconel weldments in accordance with requirements of ASME III and IX.

2. Welding technique.

2.1 Manual gas tungsten arc welding.
String and/or weave travel.
Weaving width limited to 3 mm.

2.2 Manual shielded metal arc welding.
String and/or weave travel.
Weaving width limited to 2 times electrode diameter.

2.3 Combination of 2.1 and 2.2.

3. Welding positions.
1G and 2G for par. 2.2.
3G (incl. of axis 30° ± 15°) for par. 2.3.

4. Welding materials and weld metal.

4.1 Manual gas tungsten arc welding.
F-Number 43: bare solid filler rod according to ASME SB-304 ER NiCr -3 (SFA-5.14).
rod diameter 1.0, 1.6, 2.0 and 2.4 mm.
shielding gas: argon 99.99 %.

4.2 Manual shielded metal arc welding.

Repair welding of Inconel.	39.04 - 6
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4.2.1 F-Number 43: covered electrode according to ASME SB-295 E NiCrFe - 3 (SFA-5.11).

4.2.2 Chemical range weld metal Inconel weld overlay cladding on P-12B material:

C	0.11 % max.
Mn	5.0 - 9.5 %
Fe	15 % max.
S	0.015 % max.
Si	1.0 % max.
Cu	0.50 % max.
Ti	1.0 % max.
Cr	12.5 - 17.0 %
Nb + Ta	1.0 - 2.5 %
Co	0.12 % max.
others	0.5 % max.
Ni	balance

5. <u>Drying and storage of welding materials.</u>

Covered electrodes according to specification No. 54.01.

6. <u>Preheat and interpass temperature.</u>

6.1 Range : 15 - 175° C.

6.2 For repair welding of first layer of Inconel weld overlay cladding (clad thickness up to 2.5 mm) on P-12B materials: Range: 100 - 175° C. To be maintained during welding and subsequent to welding till postheating.

Specification Section

7. Preparation for welding.

7.1 Qualifications.
In accordance with requirements of ASMEIII and IX.

7.2 Areas to be repaired.

7.2.1 Preparation.
By mechanical means as far as needed for removal of defects and correct repair welding.

7.2.2 Examination prepared areas.
Visually and by liquid penetrant examination according to specification No. 24.06.

7.2.3 Cleaning prepared areas.
With a cloth soaked in acetone.

8. Welding.

8.1 Data.

8.1.1 Manual gas tungsten arc welding.

diameter tungsten (2% thoriated) electrode in mm.	welding current in amps, d.c., electrode -.	argon flow rate in l/min.
1.0	< 80	6 - 8
1.6	70 - 140	6 - 8
2.0	100 - 175	6 - 8
2.4	130 - 230	6 - 8

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8.1.2 Manual shielded metal arc welding.

diameter electrode in mm	welding current in amps, d.c., electrode +.
3.25	70 - 100
4	100 - 130
5	125 - 150

For repair welding of first layer of Inconel weld overlay cladding on P-12B materials:
4 mm and 90 - 110 amps only.

8.2 Surface of weld beads to be conditioned for good appearance. After each weld pass removal of eventual slag by grinding and wire brushing with stainless steel wire brushes. Examination during repair welding as specified for the original weld.

9. Postheating.

No requirements.
In case of use par. 6.2: subsequent to welding temperature to be raised to 205°C and held for two hours, after which cooling down to room temperature is permitted.

10. Surface conditioning.

Smoothening by mechanical means as far as needed for examination and/or design.

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wMo/W

Specification Section

11. Examination of repair welds.

11.1 Repair welds of P-43 base metal.
By liquid penetrant examination according to specification No. 24.06.

11.2 Repair welds of Inconel weld metal.
As specified for the original welds except that if the depth of the deposit removed does not exceed the lesser of 3/8" or 10 percent of the weld thickness the examination may be made by liquid penetrant examination according to specification No. 24.06.

12. Repair subsequent to examination.
According to this specification.

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