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WELD OVERLAYING FOR CORROSION RESISTANCE IN
COAL GASIFICATION ATMOSPHERES

QUARTERLY REPORT

FOR PERIOD March 1, 1979 - May 31, 1979

by

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MER/MATERIALS BRANCH
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FOREWARD

This report covers work performed under Contract No. EF-77-C-01-2621 for the period March 1, 1979 through May 31, 1979. The work was administered by the Fossil Energy Division of the DOE with Mr. S. Dapkunas as Project Manager. The report was prepared by E. P. Sadowski of the Inco Research and Development Center at Suffern, NY.

The work was performed under the direction of E. P. Sadowski as principal investigator. The various functions were carried out by the following personnel: L. R. Meisch - Welding; C. M. Wessner - Dy Check; F. J. Veltry - Electron Microprobe Analysis; L. R. Sephton - Metallographic and Photography; R. G. Laggett - Mechanical Testing; M. M. Yanak and R. Y. Liu - Chemical Analyses and R. H. Kane - Corrosion. The exposures in the coal gasification atmosphere were made at Martin-Marietta, Denver, CO, under sub-contract. The Program Manager at Martin-Marietta was M. E. Wakefield.

ABSTRACT

Hardness and tensile testing of weldments which were exposed to a 1% H₂S coal gasification atmosphere for 1000 hours at 982°C (1800°F) was completed in the last quarter. Corrosion evaluation of unwelded specimens of 304L, 310 SS and INCOLOY alloy 800H was completed also.

The INCONEL Filler Metal 72 and R139 overlays increased and the AWS-ER309 overlays decreased in hardness after exposure. The welding process used had very little effect on the response of the FM-72 overlays, while the R139 deposited by the SAW process had the least increase in hardness. The latter may be associated with the lower Al recovery obtained with the SAW process. Generally, the heat affected zone and base metals of all weldments decreased in hardness after exposure.

All weldments decreased in room temperature, yield and tensile strength after exposure. Most weldments suffered a decrease in tensile ductility. The 310 weldments had the largest percentage decrease and the 304L weldments the least percentage decrease in the original tensile ductility after exposure.

The corrosion atmosphere was considered to be very severe based upon the degree of corrosion obtained in the unwelded substrates. The 304L was totally consumed as mixed oxides and sulfides. Alloy 800H was severely attacked with the formation of liquid sulfide scales and extensive oxidation. Type 310 stainless steel exhibited the best resistance to the environment and was only modestly attacked in three of four samples. In areas where best corrosion resistance was obtained, a thin layer of Cr₂O₃ was found adjacent to the 310 SS alloy. The bulk of the scale formed on 800H consisted of Fe₃O₄, possibly accompanied by Fe₂NiO₄ and a small amount of FeCr₂O₄. X-ray diffraction analysis of the 304L remains showed that they consisted primarily of Fe₃O₄. The R139 and INCONEL Filler Metal 72 overlays appeared to be extremely corrosion resistant to the CGA atmosphere. A comprehensive evaluation is in progress.

1.0 OBJECTIVE

The objective of this program is the development and evaluation of weld deposited overlays to provide resistance to corrosion in coal gasification atmospheres (CGA).

44%Cr and 31%Cr-15%Fe-3.5%Al nickel-base alloys will be overlain onto lower alloyed materials in order to provide protection from the corrosive atmosphere. These materials will be compared to a conventional stainless overlay material, AWS-ER309.

After the welding procedures are established for defect-free overlays, the effects of a 1000-hour exposure on weldments in a CGA 982°C on corrosion, metallurgical stability, mechanical properties, and the diffusion of major alloying elements will be determined.

2.0 SCOPE

The program is divided into four tasks as follows:

2.1 Task I - Development of Weld Deposition Techniques and Procedures

Weld deposition techniques and procedures for three weld processes will be established. The weld processes will be gas tungsten arc with a hot wire addition, gas metal-arc and submerged-arc. Three substrates will be overlain with INCONEL Filler Metal 72 (44% Cr), R139 (31.5% Cr-3.5%Al) and AWS-ER 309. The substrates will be AISI 304L and 310 and INCOLOY* alloy 800H. Single and double layer overlays will be deposited on both sides of the substrate.

2.2 Task II - Exposure to a Coal Gasification Atmosphere

A test cell will be constructed by Martin-Marietta, Denver, and the weldments will be exposed for 1000 hours to a coal gasification atmosphere at 982°C (1800°F). The composition of the gas will be CO₂-12%, CO-18%, H₂-24%, NH₃-1%, H₂S-1% and H₂O balance. The weldments exposed will be sufficiently large for the machining of tensile, hardness and corrosion specimens after exposure.

2.3 Task III - Testing

Specimens in both the pre-and post-exposure conditions will be tested. Data will be obtained on the extent of corrosion, change in elemental distribution, microstructure, and mechanical properties as a result of exposure to a CGA.

Stress-rupture properties will be determined in air at 982°C for time periods up to 1000 hours on "as-welded" specimens consisting of both overlay and substrate.

2.4 Task IV - Collate and Analyze Data and Final Report

* Trademark of the Inco family of companies.

3.0 PROGRESS SUMMARY

3. Task I

Complete.

3.2 Task II

Complete.

3.3 Task III

Mechanical testing of samples which were exposed to a coal-gasification atmosphere was completed in this quarter. Corrosion data has been obtained on unwelded samples of substrate. Elemental distribution was obtained by microprobe analyses on two "as welded" and ten exposed samples.

3.4 Task IV

Analyses of mechanical property data is in progress.

4.0 WORK ACCOMPLISHED

TASK III - TESTING

Stress rupture testing was completed. Hardness and tensile properties were obtained on specimens obtained from the weldments exposed for 1000 hours at 982°C in a coal gasification atmosphere. The evaluation of the corrosive attack on unwelded samples after exposure was completed. Elemental distribution was obtained by microprobe analysis on two "as welded" and ten exposed weldments.

4.1 Stress-Rupture

The two remaining tests were completed in this quarter. A sample from W6218 ruptured under a stress of 14.5 MPa (2100 psi) after 1243 hours with 5% elongation. The test on the second sample (W6205) was discontinued after 2400 hours at 771°C (1400°F) under a stress 26.7 MPa (3878 psi). The specimen was inadvertently tested at a lower temperature than was desired.

4.2 Hardness

Vickers hardness numbers were determined on samples machined from exposed weldments. Values were obtained in each layer of the overlay, heat affected zone and base metal using a 10 kg load and a 2/3 objective. A minimum of five readings were obtained in each zone.

The results obtained on the exposed specimens are compared to "as welded" values in Tables I through III. The change in hardness as a function of weld process, filler metal and substrate is given in Table IV and Figures 1 and 2. The results show that the effects of the exposure in a CGA for 1000 hours at 982°C were:

1. All AWS-ER309 overlays had a decrease in hardness.
2. INCONEL Filler Metal 72 overlays had a smaller increase in hardness than the R139 overlays (Figures 1 and 2).
3. The increase in hardness in FM-72 and R139 overlays was greater in the upper layer than in the lower layer of double layer overlays.
4. The smallest increase in hardness of FM-72 and R139 overlays was obtained with FM-72 and INCOLOY alloy 800H in the single layer overlays and in the lower layer of double layer overlays. These are areas where dilution from the substrate might be expected to have most effect.

5. Welding process had very little effect on the increase in hardness of the FM-72 overlays, whereas the SAW process gave the smallest increase in hardness of the R139 overlays. The latter may be due to the lower Al recovery obtained with the SAW process.

6. Generally, hardness decreased in the heat affected zone and base metal.

4.3 Tensile Tests

Tensile tests were run in duplicate on specimens machined from the exposed weldments. The tests were run on composite specimens without any machining of the overlays. The tensile tests were made in conformance with ASTM Specification E-8. The cross-head speed was approximately .51 cm (.02 inches)/minute up to the yield strength (0.2% offset) and 2.54 cm (1.0 inch)/minute after the yield. The yield strength was measured with the extensometer attached to the substrate.

The properties which were determined on composite specimens were tensile strength, yield strength and elongation (Table V). The properties after exposure were compared to the "as welded" properties. The change in properties with emphasis on tensile ductility was considered as a measure of stability.

The effect of the exposure on the room temperature properties is affected by filler metal, substrate, number of layers and weld process. The effects of the exposure were as follows:

4.3.1 Tensile Strength. All weldments decreased in tensile strength (Figure 3). The weldments consisting of AWS-ER309 deposited on 304L retained the highest tensile strength. No clear distinction was observed between the R139 and FM-72 on 304L, 310 and 800H. Generally the R139-304L weldments were slightly stronger than the FM-72-304L weldments. FM-72-310 weldments had higher retained tensile strength than FM-72 on 800H, whereas, R139 on 800H had higher retained tensile strength than R139 on 310.

The percent decrease in the original tensile strength is given in Table VI. The 309-304L weldments had the smallest percent decrease with all weld processes. The results with FM-72 and R139 were mixed. Generally, the FM-72 weldments had a lesser percent decrease than the R139 weldments with the GMAW process, whereas the R139 had a smaller decrease with the GTAW-HW and SAW processes (except for the double layer on 310).

4.3.2 Yield Strength. Yield strength decreased on all weldments after exposure. The 309-304L weldments had the lowest yield strength after exposure (Table VII) and the R139 weldments had the highest yield strength after exposure for all weld processes and substrates.

The largest percent decrease in yield strength was obtained with the 309-304L weldments and the R139 weldments had the smallest percent decrease (Figure 4a). In general, the INCOLOY alloy 800H weldments had a smaller percent decrease in yield strength than the 310 weldments. The effects of weld process was not defined clearly (Figure 4b).

4.3.3 Tensile Elongation. Tensile ductility is considered as a good measure of stability or embrittlement. Most weldments had a loss in tensile ductility after exposure. The exceptions were several 304L weldments. The 309-304L weldments had the highest elongation after exposure (Table VIII). The 310 weldments had the lowest ductility. The FM-72 weldments had higher tensile elongation than the R139 weldments on types 310 SS and INCOLOY alloy 800H.

The percent change in original ductility due to exposure in a CGA is shown in Figure 5. The 310 weldments had the largest percent decrease and the 304 the least percent decrease. The FM-72 weldments had a lower percent decrease in tensile elongation than the R139 weldments except when deposited on 304L.

4.4 Corrosion Evaluation

The details of the 1000-hour exposure in the 1% H₂S CGA at 982°C (1800°F) were described in the last quarterly report. The test conditions were judged to be very severe based upon the evaluation of unclad base plate after exposure. The evaluation of the weldments is still in progress. Qualitatively, the R139 and FM-72 overlays appear to have excellent corrosion resistance. A description of the examination procedure and the results follow.

4.4.1 Unclad Substrate. All samples of type 304L were totally consumed as mixed oxides and sulfides with only a small kernel of metallics remaining in the center of a few of the coupons. Alloy 800H was severely attacked with the formation of liquid sulfide slags and extensive oxidation. Type 310 stainless steel exhibited the best resistance to the environment, being attacked to a relatively minor degree.

This section describes the behavior of the alloys in some detail, based on metallographic and x-ray diffraction observations.

Four coupons of each alloy were exposed. After weighing, one half of each sample was masked and the scale removed by a fine air-driven abrasive spray. A descaled weight change was then calculated as if the entire sample had been stripped. The masked portion was used for metallographic and microprobe examination. Weight change and penetration data are presented in Table IX. The behavior of each alloy is described separately below.

It was not possible to retain the sample orientations relative to the positions in test, but variations are likely to result from non-uniform exposure to the coal gasification atmosphere, especially between samples and support or adjacent coupons. The appearance of the coupons is shown in Figure 6 after removal from the test cell. They are grouped in a similar, but not identical, manner to the way in which they were exposed.

4.4.1.1 Type 310 Stainless Steel. The type 310 stainless steel samples are pictured in Figure 7; only one sample was noticeably attacked, but there was no evidence of liquid sulfide formation.

Samples 6 through 8 showed similar penetration depths. This was true on average, but mean depths of attack from area to area in a given sample could vary by 50%, depending upon the local character. Figure 8, taken of sample 7, shows typical features of the attack. The outer layer of scale consists of mixed metal oxides and sulfides. The bulk of the oxide, which is single phase, is likely to be an iron-chromium spinel. With increasing depth, the oxide became more compact, and in regions showing best resistance to attack, a thin uniform layer of Cr_2O_3 was observed to form adjacent to the alloy. Below this was a zone of solid sulfides containing Cr, and, occasionally, Mn. Phase identification was based on microprobe analysis.

Coupon 5 was found to be most heavily scaled, although this was not obvious from the sample appearance. Again, some areas of the sample were protected by a chromia subscale and penetration was shallow. Other regions, such as in Figure 9, were more heavily attacked. The mixed oxide-sulfide, the increased scale compactness, absence of continuous chromium oxide, and subscale sulfides can be seen here.

Delta ferrite, semicontinuous along grain boundaries, was present in all the samples of type 310. Penetration of sulfur down the grain boundaries led to the formation of duplex or triplex internal sulfides at the expense of the ferrite. These do not appear to have been liquid at the test temperature.

A dispersion of deoxidation products was found in the alloy, having the appearance of $MnO \cdot Cr_2O_3$. These were more numerous just below the scale, often associated with intragranular sulfides, and can be differentiated from the sulfides by their cubic section outline and slight relief due to their hardness. Their occurrence is judged to be of no consequence to the alloy behavior.

4.4.1.2 INCOLOY Alloy 800H. In contrast to the behavior of type 310 stainless steel, alloy 800H was found to be severely attacked, as shown in Figures 6 and 10. Liquid sulfide slagging was observed on the sample. Much of this outer scale was loose and could not be practically handled metallographically, hence x-ray diffraction analysis was performed.

The bulk of the scale consisted of Fe_3O_4 , possibly accompanied by Fe_2NiO_4 with a small amount of $FeCr_2O_4$. In one sample pattern there appeared peaks related to phases of the type $(CrM)_2S_4$, but these could not be unambiguously identified.

Table IX shows the degree of surface loss and the measured weight changes. All samples of alloy 800H were found to contain grain boundary sulfides to the depth of maximum attack in the sections examined. Near the surface some of these were liquid at the test temperature, and corrosion was excessive. In only a few areas was a protective subscale allowed to form and sulfidation in these regions was limited. Elsewhere, as shown in Figure 11 for sample 800-10, non-protective iron-rich oxide scales were produced mixed with several species of sulfides; grain boundary sulfides are clearly shown in the unetched section. This microstructure is typical, with only variations in the degree of attack from sample to sample. The light, metallic region below the outer scale was found to be iron-nickel alloy almost totally depleted of chromium. In addition to the massive sulfides above this zone, finely divided sulfides, predominately high in Cr with little Ni or Fe present, were spread throughout the outer oxide. The light grain boundary phase deeper within the sample is $Cr_{23}C_6$ containing a small amount of iron; this is not a result of exposure to the gasifier atmosphere.

4.4.1.3 Type 304 Stainless Steel. All the samples were practically destroyed (Figure 12); x-ray diffraction of the remains revealing primarily Fe_3O_4 with some small peaks that could not be reliably indexed. A partial section of sample 1, the only one with any recognizable metallic core, is shown in Figure 13. No sound alloy remained.

4.4.2 Clad Substrates. The appearance of the 27.9 cm (11 inches) by 17.4 cm (6-5/8 inches) weldments after the 1000-hour exposure in CGA at 982°C (1800°F) are shown in Figures 14 through 27. The filler metal, substrate and weld process used in making each weldment is given in Table X. Each figure consists of six weldments for a particular filler metal deposited on the same substrate using the three different weld processes. For example, Figure 14 shows the appearance of the AWS-ER309 overlays on a 304L substrate. The lowest two code numbers in each series were made by the GMAW process. The next two higher code numbers were made with the SAW process and the highest two codes were made with the GTAW-HW process. The odd numbered codes are single layer overlays and the even numbered codes are double layer overlays. The weldments numbered 00 through 21 correspond to welds 6200 through 6220 and 6321 in Table X. Figures 15, 17, 19, 21, 23, 25 and 27 are edge views of the weldments in Figures 14, 16, 18, 20, 22, 24 and 26 showing the difference in corrosion resistance between the overlay and substrate. Of particular note is the appearance of the SAW process overlays of R139 when compared to the gas process deposits (Figures 22, 24 and 26). A more protective scale appears to have formed on the inert gas process deposited R139 overlay which is probably due to the higher retained Al contents in the deposits. Whether more protection was obtained with the inert gas process will be established when cross-sections are examined. The cross-sections which have been examined indicate that the R139 and FM-72 overlays gave excellent corrosion resistance.

The results of x-ray scans of a thin scale that formed on the surface of W6190 and of the overlay adjacent to the scale are shown in Figure 28. W6190 was a double layer of FM-72 deposited on 304L by the GTAW-HW process. In Figure 28, the light areas correspond to the concentration of the elements shown in each photograph. As shown, the scale was free of iron, high in chromium and oxygen and contained slightly higher titanium in the scale than in the overlay. It is believed that the scale is Cr_2O_3 with possibly a small amount of titanium.

4.5 Elemental Distribution

Elemental distribution of Ni, Cr, Mn, Fe, Ti and Al was determined on "as welded" weldments of R139 overlain on INCOLOY alloy 800H and 304L by the GTAW-HW process (Table XI). The distribution of Ni, Cr, Mn, Fe, Ti and Si was obtained on ten INCONEL Filler Metal 72 weldments after exposure for 1000 hours in a coal gasification atmosphere (CGA) at 982°C (1800°F). The results are given in Tables XII through XVI. Figures 29 through 35 show the distribution of various elements before and after exposure. The microprobe analysis was obtained on different samples from the same weldment before and after exposure which accounts for differences in the location of the interface. Certain trends appear to be evident. Cr and Ni were more segregated after exposure than in the "as welded" condition (Figures 29 through 32). Cr increased and Ni decreased simultaneously at the same point and vice versa. This is believed to be due to precipitation of the alpha chromium phase. Fe appears to be more evenly distributed between layers after exposure when deposited by the SAW and GMAW processes, whereas no change was observed in the GTAW-HW double layer overlay (Figures 33 and 34). The exposure appeared to have very little effect on the Mn distribution (Figure 35), whereas Ti appeared to migrate toward the surface (Figure 35). A larger number of samples will have to be examined before any specific trends can be established.

5.0 FUTURE WORK

5.1 Task III

Microprobe analyses for elemental distribution and corrosion evaluation will continue.

5.2 Task IV

Data are being collated and analyzed for the final report.

6.0 OPEN ITEMS

There are no open items.

7.0 OVERALL STATUS

The number and complexity of the corrosion samples are requiring more time than was anticipated. Otherwise, the program is progressing satisfactorily.

TABLE I

VHN OF WELDMENTS - BEFORE AND AFTER EXPOSURE - SAW PROCESS

Condition Location Substrate	As Welded - Double Layer											
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	201	-	-	201	-	-	183	-	-	178	-	-
FM-R139	201	217	218	203	214	212	182	214	182	178	212	181
FM-72	192	189	185	187	193	197	191	179	167	191	176	170
Condition Location Substrate	1000 Hrs in CGA at 982°C (1800°F) - Double Layer											
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	183	-	-	180	-	-	149	-	-	151	-	-
FM-R139	289	278	301	239	211	248	144	159	148	149	161	154
FM-72	227	250	237	216	232	209	145	158	140	142	150	153
Condition Location Substrate	As Welded - Single Layer											
	Overlay			Heat Affected Zone						Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	196	-	-				172	-	-	176	-	-
FM-R139	189	196	191				171	188	175	173	193	175
FM-72	180	194	187				170	175	162	169	169	170
Condition Location Substrate	1000 Hrs in CGA at 982°C (1800°F) - Single Layer											
	Overlay			Heat Affected Zone						Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	178	-	-				150	-	-	149	-	-
FM-R139	234	243	261				144	166	142	152	167	154
FM-72	232	254	210				140	172	136	144	177	151

TABLE II

VHN OF WELDMENTS - BEFORE AND AFTER EXPOSURE - GMAW PROCESS

Condition Location Substrate	As Welded - Double Layer											
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	196	-	-	192	-	-	180	-	-	179	-	-
FM-R139	206	190	200	197	189	206	195	183	176	195	176	178
FM-72	194	200	197	186	193	206	175	195	177	178	194	177
	1000 Hrs in CGA											
Condition Location Substrate	Overlay			Lower Layer			Heat Affected Zone			Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	163	-	-	158	-	-	155	-	-	150	-	-
FM-R139	337	342	322	319	286	278	144	158	145	150	162	148
FM-72	242	249	243	228	239	233	134	170	139	144	168	150
	As Welded - Single Layer											
Condition Location Substrate	Overlay						Heat Affected Zone			Base Metal		
	304L	310	800H				304L	310	800H	304L	310	800H
FM-309	186	-	-				179	-	-	183	-	-
FM-R139	196	185	197				192	182	171	192	182	179
FM-72	174	188	201				173	185	181	172	177	174
	1000 Hrs in CGA											
Condition Location Substrate	Overlay						Heat Affected Zone			Base Metal		
	304L	310	800H				304L	310	800H	304L	310	800H
FM-309	156	-	-				151	-	-	152	-	-
FM-R139	322	302	305				150	162	143	152	167	152
FM-72	219	266	218				141	184	143	146	178	150

TABLE III

VHN OF WELDMENTS - BEFORE AND AFTER EXPOSURE - GTAW-HW PROCESS

Condition Location Substrate	As Welded - Double Layer														
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal					
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H			
FM-309	194	-	-	180	-	-	179	-	-	196	-	-			
FM-R139	180	201	187	189	202	183	185	205	166	198	197	176			
FM-72	189	200	199	190	214	190	179	179	170	193	193	167			
Condition Location Substrate	After 1000 Hrs in CGA at 982°C (1800°F)														
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal					
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H			
FM-309	180	-	-	159	-	-	152	-	-	158	-	-			
FM-R139	303	320	321	200	314	256	146	163	146	155	158	154			
FM-72	250	250	237	251	247	186	136	166	146	138	156	162			
Condition Location Substrate	As Welded - Single Layer														
	Overlay			Heat Affected Zone						Base Metal					
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H			
FM-309	190	-	-							172	-	-	185	-	-
FM-R139	181	189	178							182	194	161	184	187	166
FM-72	177	189	182							178	179	169	179	178	166
Condition Location Substrate	After 1000 Hrs in CGA at 982°C (1800°F)														
	Overlay			Heat Affected Zone						Base Metal					
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H			
FM-309	163	-	-							157	-	-	157	-	-
FM-R139	248	286	287							150	164	140	149	170	150
FM-72	221	256	205							149	154	141	143	158	148

TABLE IV

CHANGE IN VICKERS HARDNESS NUMBER AFTER CGA EXPOSURE

Condition Location Substrate	GMAW Process - Double Layer											
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	-33	-	-	-34	-	-	-25	-	-	-29	-	-
FM-R139	+131	+152	+122	+122	+97	+72	-51	-25	-31	-45	-14	-30
FM-72	+48	+49	+46	+42	+46	+2	-41	-25	-38	-34	-26	-27

Condition Location Substrate	GMAW Process - Single Layer											
	Overlay						Heat Affected Zone			Base Metal		
	304L	310	800H				304L	310	800H	304L	310	800H
FM-309	-30	-	-				-28	-	-	-31	-	-
FM-R139	+126	+117	+108				-42	-20	-28	-40	-15	-27
FM-72	+45	+78	+17				-32	-1	-42	-26	+1	-24

Condition Location Substrate	SAW Process - Double Layer											
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	-18	-	-	-21	-	-	-24	-	-	-27	-	-
FM-R309	+88	+61	+83	+36	-3	+36	-38	-55	-34	-29	-51	-27
FM-72	+35	+61	+52	+29	+39	+12	-46	-21	-27	-49	-26	-17

Condition Location Substrate	SAW Process - Single Layer											
	Overlay						Heat Affected Zone			Base Metal		
	304L	310	800H				304L	310	800H	304L	310	800H
FM-309	-18	-	-				-22	-	-	-27	-	-
FM-R139	+45	+47	+70				-27	-22	-33	-21	-26	-21
FM-72	+42	+60	+33				-30	-3	-26	-25	+8	-19

Condition Location Substrate	GTAW-HW Process - Double Layer											
	Upper Layer			Lower Layer			Heat Affected Zone			Base Metal		
	304L	310	800H	304L	310	800H	304L	310	800H	304L	310	800H
FM-309	-14	-	-	-21	-	-	-27	-	-	-38	-	-
FM-R139	+123	+119	+134	+111	+112	+73	-39	-42	-20	-43	-39	-22
FM-72	+61	+50	+38	+61	+33	-4	-43	-13	-24	-55	-37	-5

Condition Location Substrate	GTAW-HW Process - Single Layer											
	Overlay						Heat Affected Zone			Base Metal		
	304L	310	800H				304L	310	800H	304L	310	800H
FM-309	-27	-	-				-15	-	-	-28	-	-
FM-R139	+67	+97	+99				-32	-30	-21	-35	-17	-16
FM-72	+44	+67	+23				-29	-25	-28	-36	-20	-18

TABLE V
ROOM TEMPERATURE TENSILE PROPERTIES AFTER EXPOSURE

No. (a)	Process	Filler Metal	Substrate	0.2% Yield Strength		Tensile Strength		% Elongation in 50.4 cm (2 in)
				MPa	psi	MPa	psi	
6180	GMAW	AWS-ER309	304L	195	28,250	515	74,650	50.7
6181	"	"	"	186	26,950	471	68,250	47.0
6182	SAW	"	"	202	29,300	521	75,500	48.7
6183	"	"	"	191	27,700	496	71,900	44.2
6184	GTAW-HW	"	"	201	29,200	526	76,550	49.7
6185	"	"	"	192	27,850	522	75,750	64.0
6186	GMAW	INCONEL Filler Metal 72	"	239	34,650	414	60,000	32.5
6187	"	"	"	198	28,750	408	59,150	34.5
6188	SAW	"	"	245	35,500	369	53,550	25.5
6189	"	"	"	210	30,450	338	49,050	26.5
6190	GTAW-HW	"	"	232	33,650	378	54,900	31.5
6191	"	"	"	196	28,450	382	55,450	30.2
6192	GMAW	"	310	238	34,500	439	63,650	18.0
6193	"	"	"	236	34,250	432	62,600	12.0
6194	SAW	"	"	223	32,400	393	57,050	15.5
6195	"	"	"	214	31,000	358	51,900	20.0
6196	GTAW-HW	"	"	266	38,550	414	60,050	12.5
6197	"	"	"	231	33,500	375	54,550	20.5
6198	GMAW	"	INCOLOY Alloy 800H	245	35,500	382	55,400	20.5
6199	"	"	"	220	31,850	415	60,150	20.2
6200	SAW	"	"	245	35,500	384	55,750	20.5
6201	"	"	"	222	32,200	374	54,250	18.5
6202	GTAW-HW	"	"	230	33,350	396	57,500	20.2
6203	"	"	"	218	31,600	435	63,050	25.2
6204	GMAW	R139	304L	287	41,650	457	66,250	51.5
6205	"	"	"	231	33,550	393	57,000	56.2
6206	SAW	"	"	273	39,650	385	55,800	39.5
6207	"	"	"	225	32,650	426	61,750	50.0
6208	GTAW-HW	"	"	285	41,300	393	57,000	36.0
6209	"	"	"	219	31,700	432	62,700	46.7
6210	GMAW	"	310	309	44,750	386	56,050	10.7
6211	"	"	"	273	39,600	384	55,700	11.0
6212	SAW	"	"	264	38,350	348	50,400	9.7
6213	"	"	"	244	35,400	390	56,600	11.0 (b)
6214	GTAW-HW	"	"	317	45,950	443	64,300	10.7
6215	"	"	"	265	38,500	434	62,900	14.0
6216	GMAW	"	INCOLOY Alloy 800H	314	45,600	406	58,900	18.2
6217	"	"	"	268	38,850	382	55,350	16.5
6218	SAW	"	"	303	43,900	385	55,900	18.7
6219	"	"	"	259	37,500	407	59,000	21.0
6220	GTAW-HW	"	"	336	48,750	477	69,150	18.2 (b)
6321	"	"	"	271	39,250	444	64,350	16.2

NOTE: (a) Even numbered welds are double layer overlays and odd numbered welds are single layer overlays.
(b) One sample broke outside gage length.

TABLE VI

PERCENT DECREASE IN ORIGINAL TENSILE STRENGTH
DUE TO EXPOSURE

Process Substrate	SAW - Double Layer			SAW - Single Layer		
	<u>304L</u>	<u>310</u>	<u>800H</u>	<u>304L</u>	<u>310</u>	<u>800H</u>
FM-309	11.1	-	-	12.3	-	-
FM-R139	33.4	41.9	34.4	28.2	33.6	29.4
FM-72	34.8	34.0	33.0	40.5	38.5	34.4

Process Substrate	GMAW - Double Layer			GMAW - Single Layer		
	<u>304L</u>	<u>310</u>	<u>800H</u>	<u>304L</u>	<u>310</u>	<u>800H</u>
FM-309	10.8	-	-	15.6	-	-
FM-R139	23.2	37.1	32.0	31.8	34.4	33.8
FM-72	29.8	26.2	35.0	27.3	25.2	27.7

Process Substrate	GTAW-HW - Double Layer			GTAW-HW - Single Layer		
	<u>304L</u>	<u>310</u>	<u>800H</u>	<u>304L</u>	<u>310</u>	<u>800H</u>
FM-309	8.9	-	-	7.4	-	-
FM-R139	33.0	25.0	18.9	26.5	27.6	22.6
FM-72	35.1	33.8	35.6	35.9	38.9	27.8

TABLE VII

0.2% YIELD STRENGTH-MPa (Psi) AFTER
EXPOSURE IN CGA

Process Substrate	SAW - Double Layer			SAW - Single Layer		
	304L	310	800H	304L	310	800H
FM-309	202 (29,300)	-	-	191 (27,700)	-	-
FM-R139	272 (39,650)	264 (38,350)	303 (43,900)	225 (32,650)	244 (35,400)	259 (37,500)
FM-72	245 (35,500)	223 (32,400)	245 (35,500)	210 (30,450)	214 (31,000)	222 (32,200)
Process Substrate	GMAW - Double Layer			GMAW - Single Layer		
	304L	310	800H	304L	310	800H
FM-309	195 (28,250)	-	-	186 (26,950)	-	-
FM-R139	287 (41,650)	309 (44,750)	314 (45,600)	231 (33,550)	273 (39,600)	268 (38,850)
FM-72	239 (34,650)	238 (34,500)	245 (35,500)	198 (28,750)	236 (34,250)	220 (31,850)
Process Substrate	GTAW-HW - Double Layer			GTAW-HW - Single Layer		
	304L	310	800H	304L	310	800H
FM-309	201 (29,200)	-	-	192 (27,850)	-	-
FM-R139	285 (41,300)	317 (45,950)	336 (48,750)	219 (31,700)	265 (38,500)	271 (39,250)
FM-72	232 (33,650)	266 (38,550)	230 (33,350)	196 (28,450)	231 (33,500)	218 (31,600)

TABLE VIII

TENSILE ELONGATION (PERCENT IN 50.8 mm)
AFTER EXPOSURE

Process Substrate	SAW - Double Layer			SAW - Single Layer		
	<u>304L</u>	<u>310</u>	<u>800H</u>	<u>304L</u>	<u>310</u>	<u>800H</u>
FM-309	48.5	-	-	44.0	-	-
FM-R139	39.5	9.5	18.5	50.0	11.0	21.0
FM-72	25.5	18.0	20.5	26.5	12.0	18.5

Process Substrate	GMAW - Double Layer			GMAW - Single Layer		
	<u>304L</u>	<u>310</u>	<u>800H</u>	<u>304L</u>	<u>310</u>	<u>800H</u>
FM-309	50.5	-	-	47.0	-	-
FM-R139	51.5	10.5	18.0	56.0	11.0	16.5
FM-72	32.5	15.5	20.5	34.5	20.0	20.0

Process Substrate	GTAW-HW - Double Layer			GTAW-HW - Single Layer		
	<u>304L</u>	<u>310</u>	<u>800H</u>	<u>304L</u>	<u>310</u>	<u>800H</u>
FM-309	49.5	-	-	64.0	-	-
FM-R139	38.0	10.5	18.0	46.5	14.0	18.0
FM-72	31.5	12.5	20.0	30.0	20.5	25.0

TABLE IX

WEIGHT CHANGE AND PENETRATION DATA FOR UNWELDED SAMPLES OF
304L, 310 and 800H

Sample	Surface Loss, μm	Max. Depth of Affected Metal, μm	Change in Weight mg/cm ²	
			Undescaled	Descaled
304-1	- - -	Not Measurable - - -	-308	-1346
304-2	"	"	-318	-1329
304-3	"	"	-472	-1266
304-4	"	"	-639	Destroyed
310-5	15	320	+30.6	-85.8
310-6	30	114	+6.2	-129.1
310-7	20	147	+9.0	-55.5
310-8	15	117	+12.4	-20.2
800H-10	287	2675	+43.0	-320.4
800H-11	104	2670	+206.8	-261
800H-12	180	2570	+72.2	-413
800H-13	198	1090	-40.5	-163

TABLE X

TEST SPECIMEN MATERIALS

<u>Specimen No.</u>	<u>Process(a)</u>	<u>Substrate</u>	<u>Filler Metal</u>
6180 (c)	GMAW	304L	309
6181	"	"	"
6182	SAW	"	"
6183	"	"	"
6184	GTAW-HW	"	"
6185	"	"	"
6186	GMAW	"	72 (b)
6187	"	"	"
6188	SAW	"	"
6189	"	"	"
6190	GTAW-HW	"	"
6191	"	"	"
6192	GMAW	310	"
6193	"	"	"
6194	SAW	"	"
6195	"	"	"
6196	GTAW-HW	"	"
6197	"	"	"
6198	GMAW	800H	"
6199	"	"	"
6200	SAW	"	"
6201	"	"	"
6202	GTAW-HW	"	"
6203	"	"	"
6204	GMAW	304L	R139
6205	"	"	"
6206	SAW	"	"
6207	"	"	"
6208	GTAW-HW	"	"
6209	"	"	"
6210	GMAW	310	"
6211	"	"	"
6212	SAW	"	"
6213	"	"	"
6214	GTAW-HW	"	"
6215	"	"	"
6216	GMAW	800H	"
6217	"	"	"
6218	SAW	"	"
6219	"	"	"
6220	GTAW-HW	"	"
6321	"	"	"

- NOTES:
- (a) GMAW = Gas Metal Arc
 - SAW = Submerged Arc
 - GTAW-HW = Gas Tungsten Arc with hot wire
 - (b) INCONEL Filler Metal 72
 - (c) Even numbered welds are double layer overlays, odd numbered welds are single layer overlays.

TABLE XI

DISTRIBUTION OF ELEMENTS IN R139 OVERLAYS (GTAW-HW PROCESS)

W6209-304L Substrate - Single Layer							W6220-800H Substrate - Double Layer						
Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Al	Distance from Surface (mm)	Ni	Cr	Fe	Mn	Ti	Al
0	34.83	29.03	31.96	.86	.33	2.68	0	42.10	28.74	22.13	.65	.29	2.95
1	34.66	29.20	31.63	1.05	.14	2.11	1	42.72	32.26	20.51	.73	.31	3.36
2	36.11	28.85	28.54	1.18	.21	2.46	2	42.30	31.63	18.84	.80	.38	3.36
3	35.54	28.71	31.65	.82	.19	2.30	3	42.84	31.72	21.00	.78	.32	3.01
4	33.18	26.80	36.76	1.11	.13	2.04	4	42.71	32.76	20.37	.73	.41	3.34
4.1	33.84	28.62	32.08	1.16	.21	2.29	5	39.29	27.78	30.01	.55	.34	2.12
4.2	34.28	28.44	32.66	1.01	.19	2.06	6	39.66	28.80	28.25	.75	.30	2.91
Interface							7	38.20	27.64	30.48	.61	.26	2.31
4.3	10.02	19.30	68.58	1.83	.00	.00	7.1	36.21	26.67	32.43	.49	.32	1.68
4.4	10.13	18.88	67.52	1.79	.00	.02	7.2	37.72	26.81	32.02	.65	.35	2.32
4.5	9.91	18.90	68.19	1.87	.00	.00	Interface						
9.2 (a)	9.67	18.99	68.58	1.74	.00	.00	7.3	30.69	20.44	45.02	.76	.21	.39
							7.4	30.76	20.33	45.08	.78	.36	.39
							7.5	31.25	20.35	45.98	.77	.31	.43
							12.2 (a)	31.17	21.08	45.98	.69	.30	.44

NOTE: (a) 5 mm from Interface.

TABLE XII

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON
304L-GMAW PROCESS AFTER EXPOSURE (a)

<u>Weld 6186 - Double Layer</u>							<u>Weld 6187 - Single Layer</u>						
<u>Distance from Surface (mm) (b)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>	<u>Distance from Surface (mm) (b)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>
0	50.73	37.44	8.95	.20	1.16	.19	0	39.73	33.03	23.19	.31	.67	.30
1	43.30	46.55	7.67	.38	.52	.09	1	38.56	35.25	23.12	.62	.25	.18
2	49.02	41.73	7.24	.32	.46	.12	2	38.92	31.58	24.25	.75	.21	.24
3	50.61	40.25	7.53	.34	.54	.15	3	39.69	33.52	24.60	.68	.20	.22
4	39.73	44.30	13.88	.42	.29	.21	4	40.67	32.62	23.66	.71	.06	.24
5	44.94	34.22	17.45	.52	.27	.21	4.5	38.83	32.92	25.35	.73	.06	.24
6	40.21	41.42	17.09	.53	.32	.19	4.6	37.03	33.88	24.97	.78	.10	.27
7	46.15	34.13	19.28	.62	.06	.18	4.7	39.51	33.07	24.68	.81	.16	.28
7.5	38.16	39.32	18.94	.49	.04	.20	4.8	39.48	33.50	25.06	.89	.17	.28
7.6	42.59	36.61	19.37	.62	.12	.17	Interface						
7.7	44.41	35.44	20.29	.60	.23	.15	4.9	10.25	20.38	66.84	1.44	.00	.42
7.8	41.08	34.62	19.86	.55	.12	.23	5.0	9.69	18.75	68.53	1.71	.00	.56
7.9	39.90	34.04	17.61	.36	.04	.19	5.1	10.06	18.96	69.45	1.72	.05	.56
8.0	41.74	35.57	19.39	.68	.17	.11	5.2	10.10	18.47	68.54	1.70	.02	.51
8.1	33.48	41.65	25.29	.98	.11	.22	9.8 (c)	9.89	18.53	68.39	1.81	.00	.59
Interface													
8.2	9.04	18.86	67.25	1.63	.03	.43							
8.3	9.85	18.72	68.64	1.74	.00	.47							
8.4	9.89	18.55	68.80	1.81	.00	.62							
8.5	9.68	18.76	69.31	1.77	.01	.45							
13.1 (c)	9.55	19.11	68.46	1.81	.00	.45							

NOTES: (a) 1000 hours in coal gasification atmosphere at 982°C.
 (b) Below scale.
 (c) 5 mm from Interface.

TABLE XIII

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON
304L - AFTER EXPOSURE - SAW PROCESS

<u>Weld 6188 - Double Layer</u>							<u>Weld 6189 - Single Layer</u>						
<u>Distance from Surface (a) (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>	<u>Distance from Surface (a) (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>
0	53.22	37.59	7.00	.36	.13	.53	0	43.35	33.29	21.10	.44	.05	.41
1	52.61	38.29	8.02	.62	.14	.49	1	43.11	32.31	22.10	.70	.05	.40
2	40.09	51.92	5.11	.58	1.11	.48	2	40.36	32.91	24.26	.92	.11	.51
3	29.08	63.58	8.31	.68	.21	.47	3	41.01	31.99	20.73	.79	.06	.49
4	52.79	37.11	6.05	.43	.15	.31	4	41.15	31.79	22.09	.84	.13	.47
5	46.28	44.90	8.56	.58	.17	.51	5	41.16	33.36	24.14	.89	.31	.48
6	49.92	37.31	11.40	.49	.16	.49	6	41.31	33.36	23.32	.90	.65	.42
7	41.85	35.41	22.19	.52	.12	.52	6.1	39.48	34.94	21.94	.92	.11	.38
8	42.51	34.82	19.43	.77	.11	.47	6.2	37.54	32.40	24.63	.82	.04	.53
9	33.76	44.79	23.51	.85	.42	.41	Interface						
9.5	41.30	36.04	23.40	.90	.06	.47	6.3	5.41	65.08	28.47	.88	.22	.45
9.6	42.26	34.28	22.39	.90	.21	.61	6.4	20.26	26.98	50.46	.99	.04	.48
9.7	39.17	33.35	21.94	.71	.47	.37	6.5	7.40	25.31	67.53	1.22	.00	.48
9.8	41.38	32.71	25.57	.96	.11	.43	11.2 (b)	10.31	19.18	66.60	1.70	.01	.67
9.9	39.13	39.00	27.27	1.05	.15	.45							
Interface													
10.0	10.07	20.04	66.42	1.39	.00	.51							
10.1	10.08	19.10	66.25	1.69	.00	.45							
10.2	10.30	18.79	66.44	1.73	.03	.67							
14.9 (b)	10.36	18.86	66.79	1.77	.00	.54							

NOTES: (a) Below scale.
(b) 5 mm from Interface.

TABLE XIV

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON
304L-GTAW-HW PROCESS - AFTER EXPOSURE

<u>Weld 6190 - Double Layer</u>							<u>Weld 6191 - Single Layer</u>						
<u>Distance from Surface (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>	<u>Distance from Surface (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>
0 (a)	33.91	51.75	13.18	.32	.15	.30	0 (a)	39.19	33.20	27.34	.36	.02	.37
1	46.40	40.49	13.42	.43	.15	.24	1	34.83	30.58	31.91	.75	.00	.30
2	50.75	35.71	14.00	.46	.31	.19	2	36.95	32.46	30.58	.82	.11	.25
3	46.88	38.54	14.95	.46	.14	.23	3	34.35	32.06	32.41	.73	.04	.37
4	46.94	35.85	14.11	.45	.21	.21	4	35.00	32.11	32.27	.84	.06	.30
5	40.29	32.47	26.34	.68	.06	.28	4.1	33.79	33.49	31.84	.60	.20	.25
5.5	36.59	32.70	26.33	.76	.41	.23	4.2	33.34	29.81	34.37	1.08	.08	.32
5.6	35.97	38.73	25.05	.80	.44	.24	Interface						
5.7	39.60	34.21	26.32	.78	.35	.29	4.3	19.09	25.78	49.34	1.26	.00	.46
5.8	39.49	33.01	27.23	.84	.18	.18	4.4	9.94	19.12	68.28	1.58	.00	.65
5.9	38.03	33.12	26.58	.75	.31	.36	4.5	10.48	19.56	67.68	1.49	.00	.72
6.0	37.85	32.48	29.47	.84	.24	.33	9.2 (b)	10.24	19.48	68.11	1.41	.00	.54
6.1	36.39	32.53	29.93	.84	.21	.31	(c)	13.39	18.99	65.44	.73	.22	.21
Interface													
6.2	27.47	27.98	40.69	1.15	.19	.39							
6.3	10.06	19.38	67.79	1.56	.01	.46							
6.4	9.82	19.53	68.61	1.76	.00	.54							
11.1 (b)	9.54	19.02	66.82	1.66	.01	.53							

NOTES: (a) Below scale.
 (b) 5 mm from Interface.
 (c) Phase near fusion line in weld.

TABLE XV

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON
310 SS - GMAW PROCESS - AFTER EXPOSURE

<u>Weld 6192 - Double Layer</u>							<u>Weld 6193 - Single Layer</u>						
<u>Distance from Surface (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>	<u>Distance from Surface (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>
0 (a)	52.36	25.35	11.06	.21	.00	.32	0 (a)	37.63	35.98	25.52	.47	.01	.26
1	44.63	43.70	7.60	.40	.45	.15	1	34.12	37.23	26.59	.85	.11	.36
2	46.51	42.51	9.50	.46	.18	.30	2	38.89	34.63	24.23	.95	.09	.28
3	43.05	42.49	10.93	.34	.26	.20	3	41.35	31.01	25.97	.87	.13	.32
4	49.98	36.57	9.53	.39	.20	.21	4	39.91	31.84	21.51	.94	.08	.28
5	36.69	51.06	10.99	.33	.19	.16	5	39.51	32.40	25.63	.91	.07	.32
6	40.79	34.08	20.72	.85	.35	.29	5.1	38.49	35.42	24.89	.82	.03	.40
7	36.96	37.09	23.17	.79	.07	.32	5.2	38.41	35.68	25.03	.85	.08	.35
8	40.86	32.28	22.56	.43	.03	.06	5.3	40.30	32.17	23.19	.79	.28	.34
8.1	24.91	49.96	22.35	.79	.03	.27	5.4	40.06	31.21	24.66	.85	.37	.32
8.2	41.24	32.96	21.12	.87	.10	.31	5.5	41.33	31.64	23.99	.46	.04	.21
8.3	43.76	29.67	17.30	.78	.04	.32	5.6	39.74	34.92	24.99	.86	.07	.31
8.4	40.17	31.92	23.14	.89	.29	.33	5.7	41.25	31.89	24.38	.91	.05	.38
Interface							5.8	38.27	30.67	23.96	.82	.07	.33
8.5	24.57	41.17	31.45	1.26	.13	.31	5.9	27.35	28.31	40.62	.84	.18	.30
8.6	22.60	26.57	44.34	1.57	.00	.41	Interface						
8.7	19.66	25.73	48.73	1.70	.00	.28	6.0	13.92	36.41	43.35	1.04	.00	.26
13.4 (b)	18.52	25.67	51.56	1.68	.00	.28	6.1	19.07	24.87	49.53	1.22	.00	.27
							6.2	19.12	25.32	51.66	1.31	.00	.45
							10.9 (b)	20.24	24.77	48.82	1.65	.00	.44

NOTES: (a) Below scale.
(b) 5 mm from Interface.

TABLE XVI

DISTRIBUTION OF ELEMENTS IN INCONEL FILLER METAL 72 OVERLAYS ON
310 SS - SAW PROCESS - AFTER EXPOSURE

<u>Weld 6194 - Double Layer</u>							<u>Weld 6195 - Single Layer</u>						
<u>Distance from Surface (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>	<u>Distance from Surface (mm)</u>	<u>Ni</u>	<u>Cr</u>	<u>Fe</u>	<u>Mn</u>	<u>Ti</u>	<u>Si</u>
0 (a)	55.81	38.62	5.82	.19	.04	.46	0 (a)	47.51	35.02	17.26	.26	.05	.71
1	55.96	38.35	5.45	.55	.12	.45	1	48.01	34.63	16.08	.81	.06	.37
2	55.61	38.67	5.80	.45	.16	.38	2	47.27	34.79	17.33	.78	.10	.38
3	55.91	38.40	5.98	.38	.15	.29	3	47.21	32.80	18.11	.83	.12	.47
4	56.00	38.32	5.52	.51	.14	.38	4	47.05	32.15	18.56	.76	.05	.43
5	54.97	38.99	5.95	.54	.19	.44	5	47.57	34.44	17.34	.77	.06	.46
6	55.57	37.91	3.78	.53	.11	.38	5.5	44.94	34.82	17.42	.71	.12	.37
7	48.01	35.84	16.25	.72	.08	.46	5.6	44.27	34.84	18.45	.76	.16	.49
8	47.92	35.16	16.04	.82	.04	.49	5.7	32.88	38.14	18.72	.70	.25	.46
9	47.06	34.99	16.77	.81	.11	.40	5.8	20.77	34.03	37.63	.86	.12	.50
10	45.88	35.17	17.42	.91	.00	.45	5.9	19.19	31.67	50.65	.67	.00	.21
10.1	45.51	35.01	11.13	.79	.05	.39	6.0	19.54	27.31	52.56	1.20	.00	.45
10.2	47.10	34.23	18.13	.95	.16	.48	Interface						
10.3	45.54	33.52	20.41	1.07	.35	.52	6.1	19.94	25.41	53.12	1.55	.00	.41
Interface							6.2	19.30	26.14	52.37	1.68	.03	.50
10.4	24.14	29.45	42.11	1.39	.00	.44	6.3	20.32	25.25	53.40	1.46	.00	.66
10.5	21.13	26.47	44.57	1.51	.00	.44	11.0 (b)	17.87	24.68	53.53	1.83	.00	.36
10.6	19.52	26.33	49.41	1.72	.00	.40							
15.3 (b)	19.06	25.51	50.22	1.68	.00	.45							

NOTES: (a) Below scale.
(b) 5 mm from Interface.

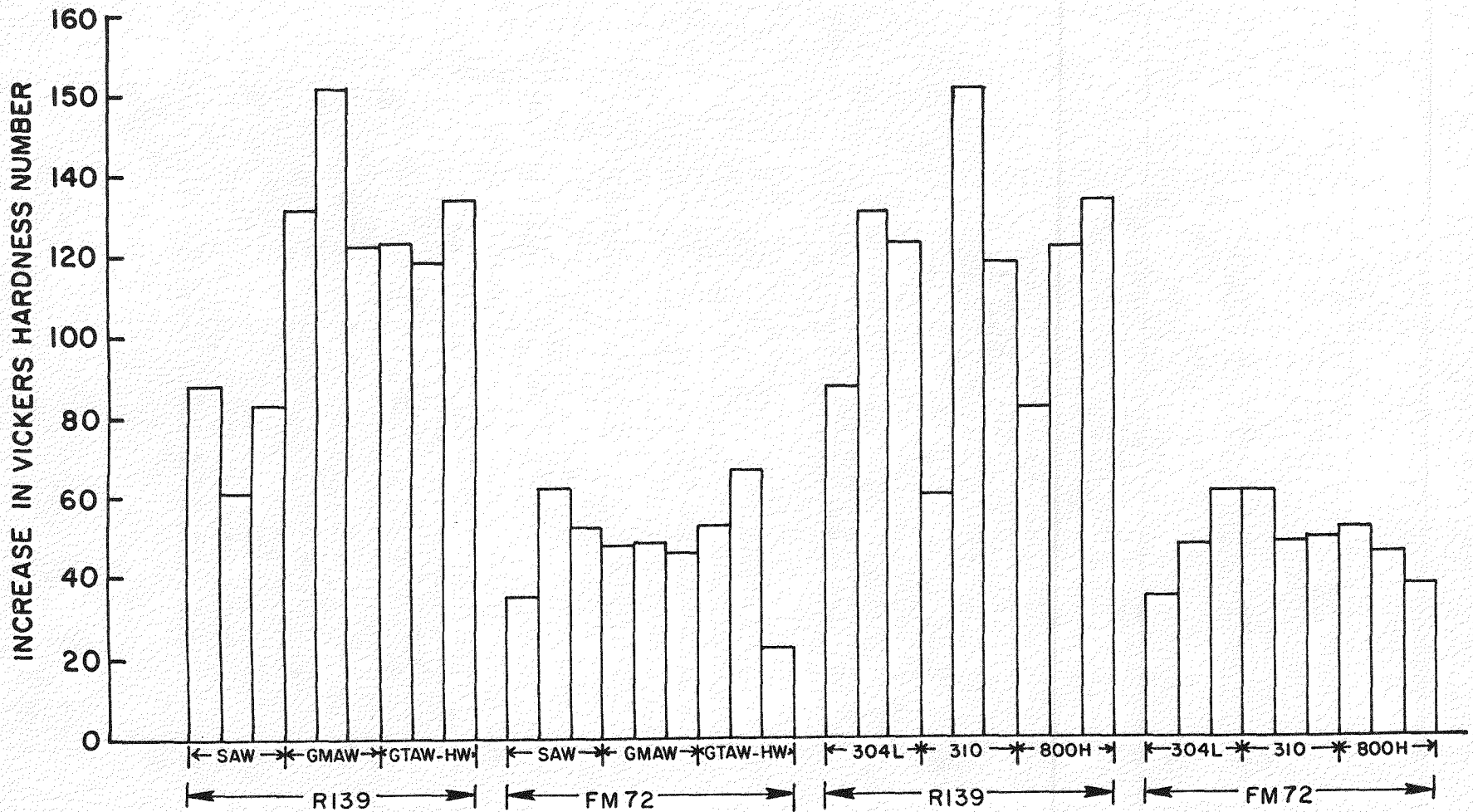


FIGURE I - EFFECT OF FILLER METAL, WELD PROCESS AND SUBSTRATE ON INCREASE IN HARDNESS OF UPPER LAYER OF DOUBLE LAYER OVERLAYS AFTER EXPOSURE IN A COAL GASIFICATION ATMOSPHERE.

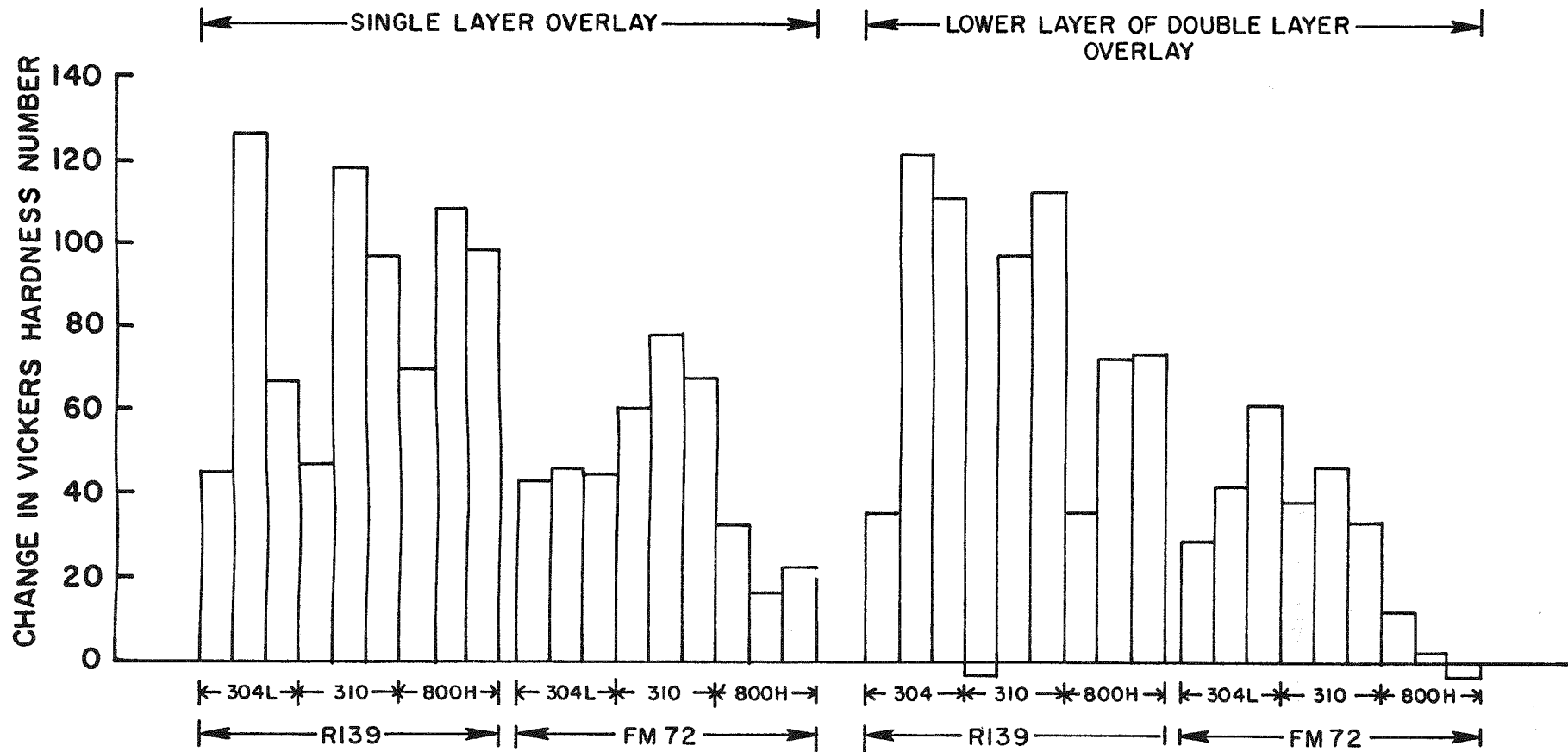


FIGURE 2 - EFFECT OF FILLER METAL AND SUBSTRATE ON CHANGE IN OVERLAY HARDNESS AFTER EXPOSURE IN A COAL GASIFICATION ATMOSPHERE.

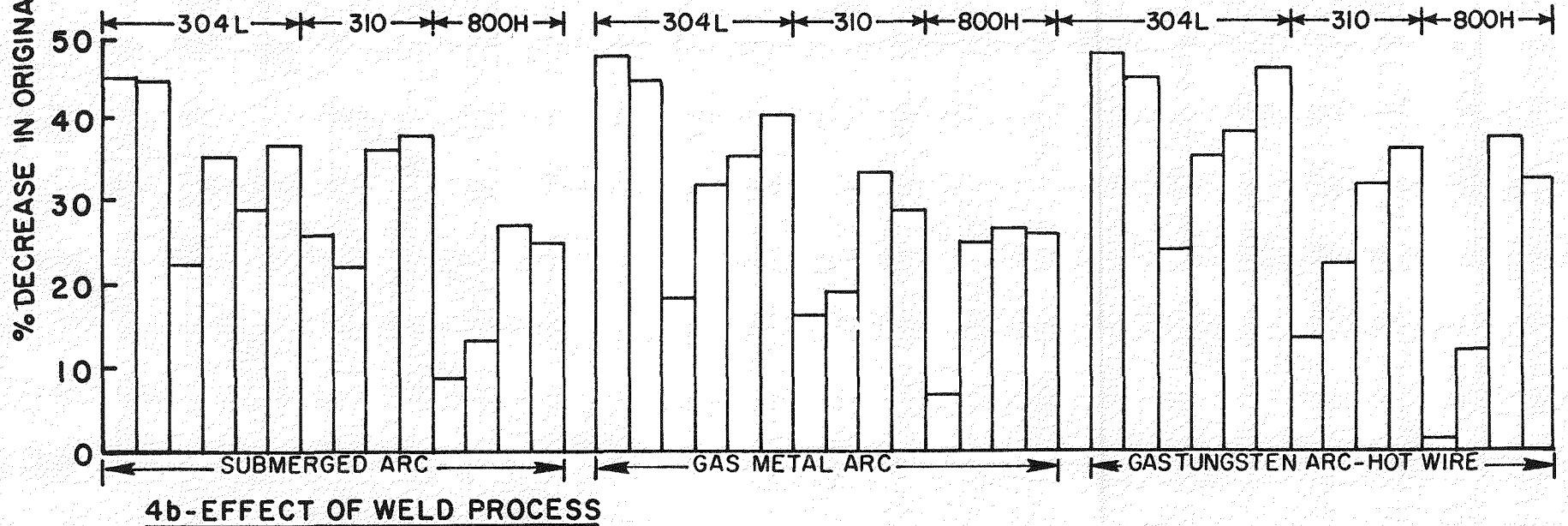
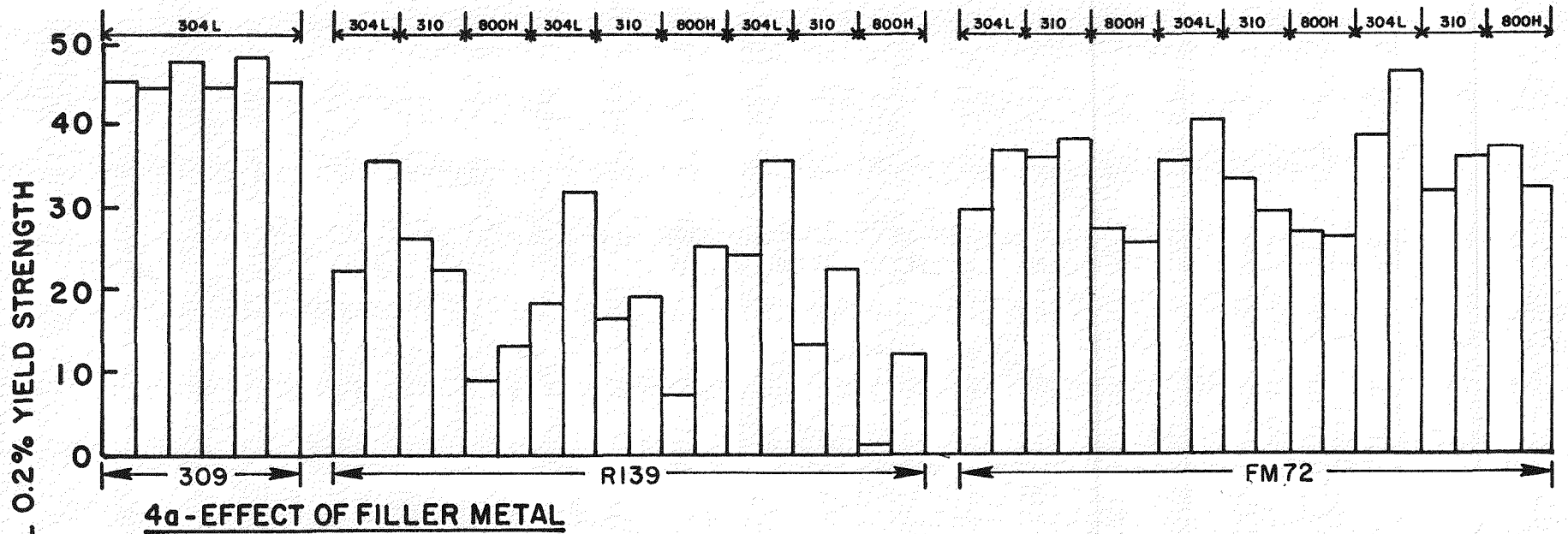


FIGURE 4 - EFFECT OF FILLER METAL AND WELD PROCESS ON PERCENT DECREASE IN ROOM TEMPERATURE YIELD STRENGTH AFTER EXPOSURE IN A CGA.

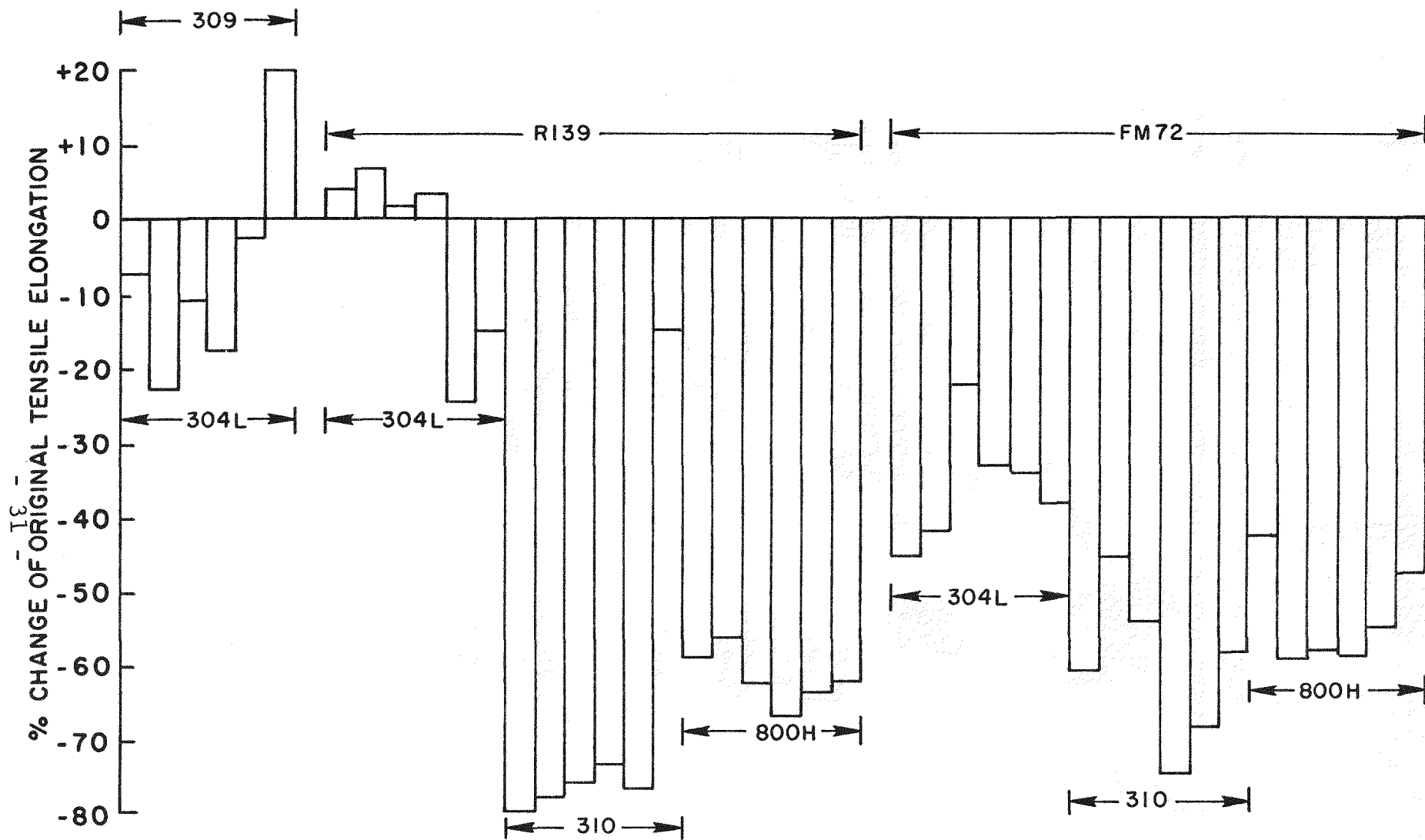
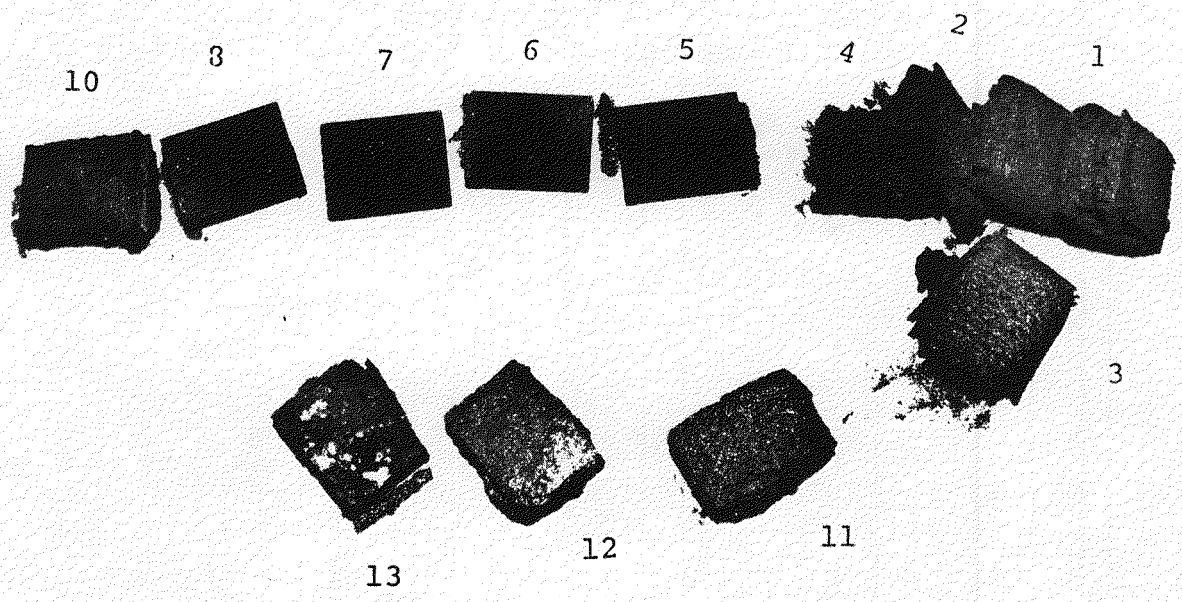


FIGURE 5 - EFFECT OF FILLER METAL AND SUBSTRATE ON THE % CHANGE IN TENSILE ELONGATION AFTER EXPOSURE IN A COAL GASIFICATION ATMOSPHERE - 3 WELD PROCESSES.

1-4, 304L
5-8, 800H
10-13, 800H

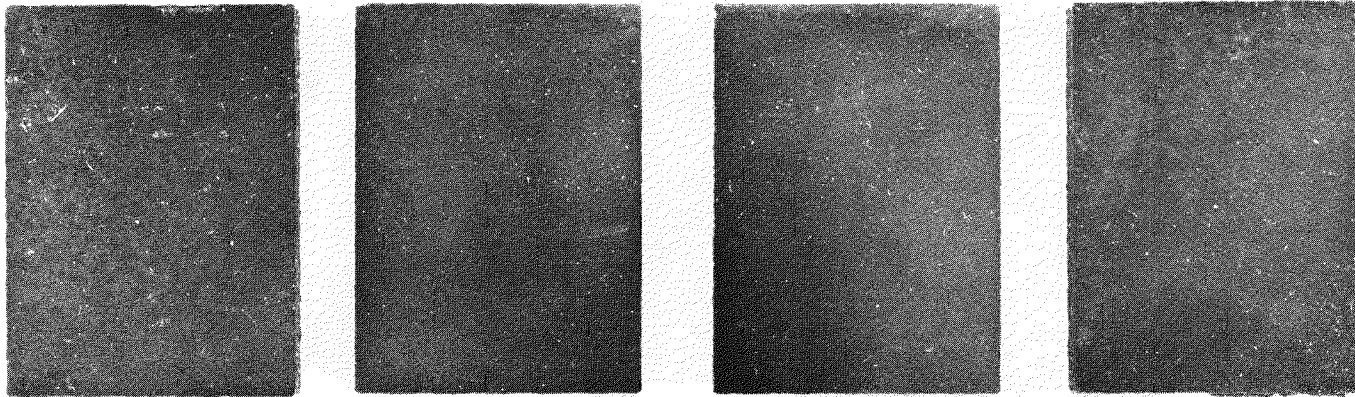


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EM 00239-79

FIGURE 6: Appearance of test coupons after removal from test cell.

P.R. 4062.8



PN 2-75239

Approx. 1.5X

FIGURE 7: Appearance of type 310 stainless steel samples after exposure to coal gasifier atmosphere; samples 5 through 8, left to right.

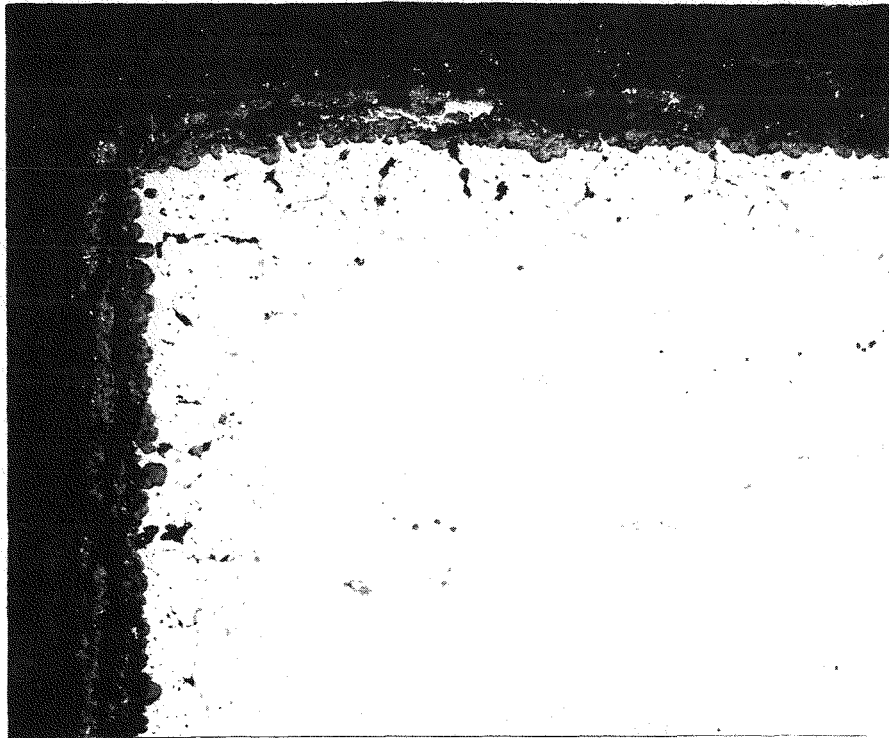


PN 1-75530

200X

FIGURE 8: Structure of type 310 stainless steel sample 7.
Unetched

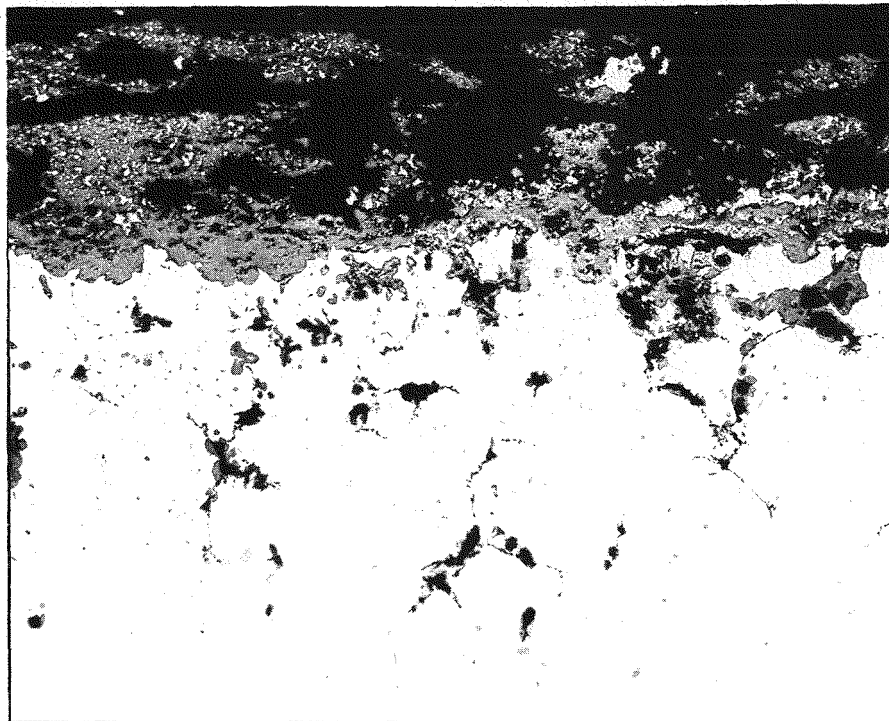
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PN 1-75523

100X

(a)

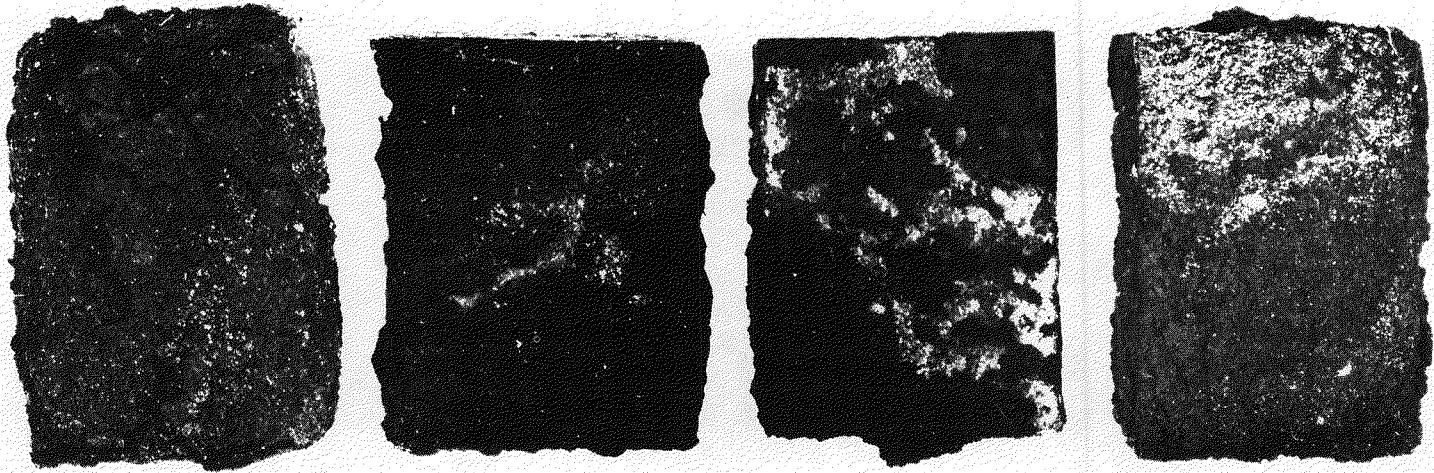


PN 1-75524

200X

(b)

FIGURE 9: Structures of sample 310-5. Continuous chromia has not formed. Note solid subscale sulfides and delta ferrite.



PN 2-75241

Approx. 1.5X

FIGURE 10: Appearance of samples of alloy 800H.

P.R. 4062.8



PN's 1-75495,6

50X

FIGURE 11: Microstructure of sample 10, alloy 800H.
Unetched

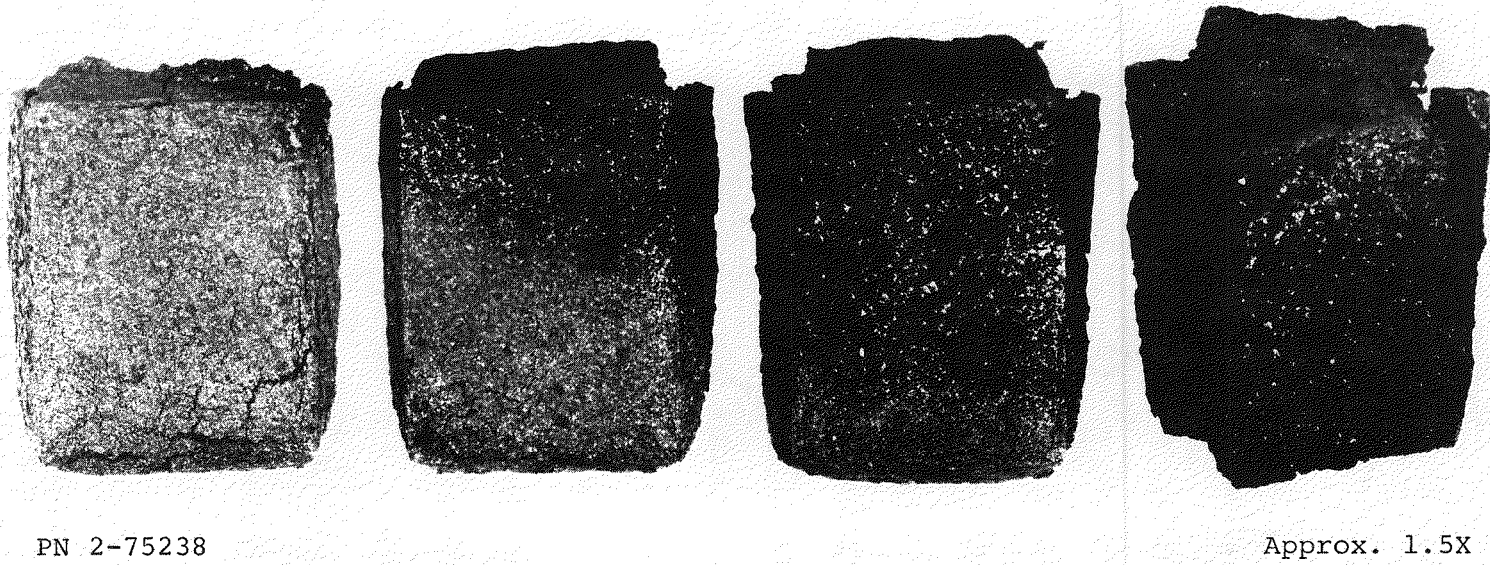
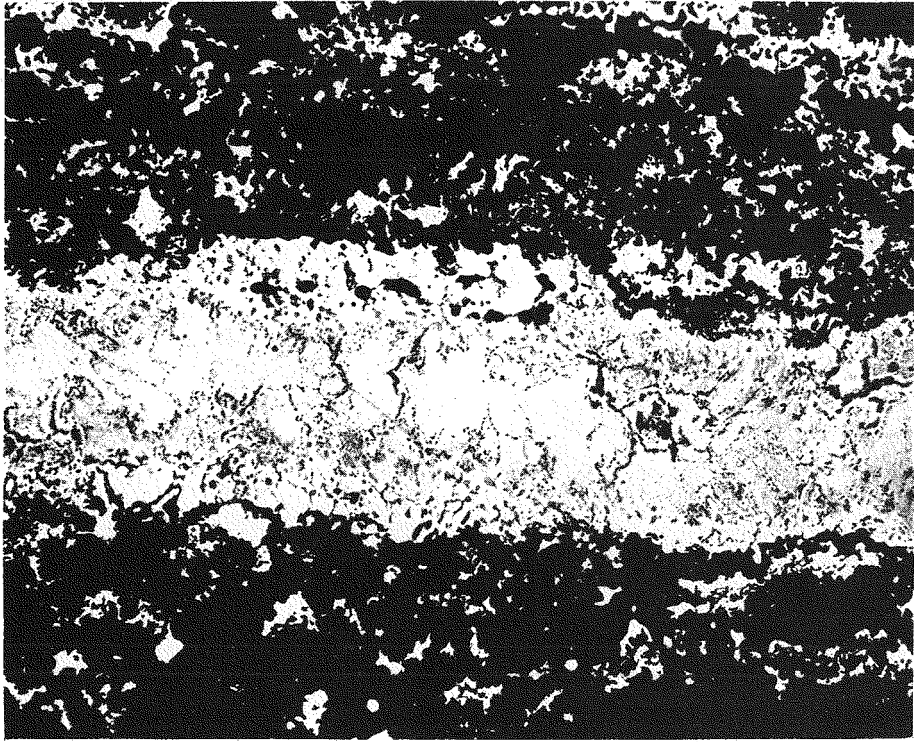


FIGURE 12: Appearance of type 304L samples.

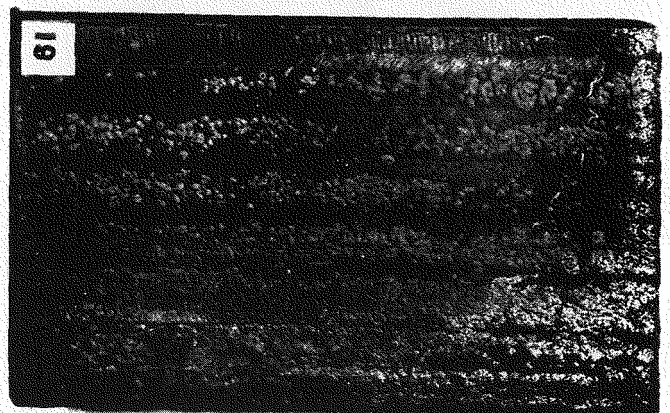
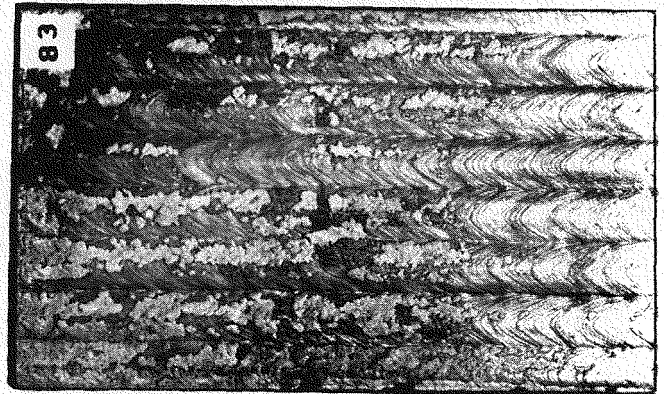
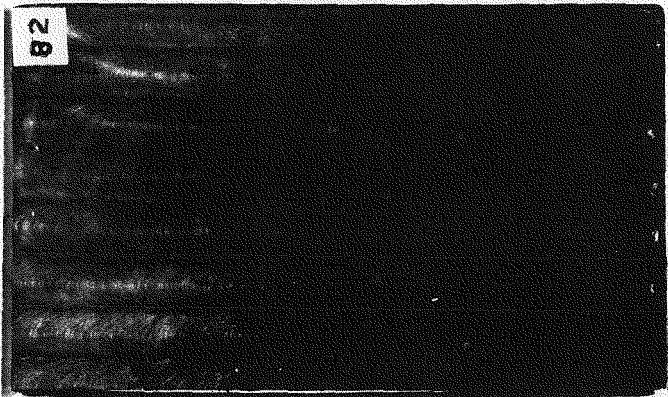
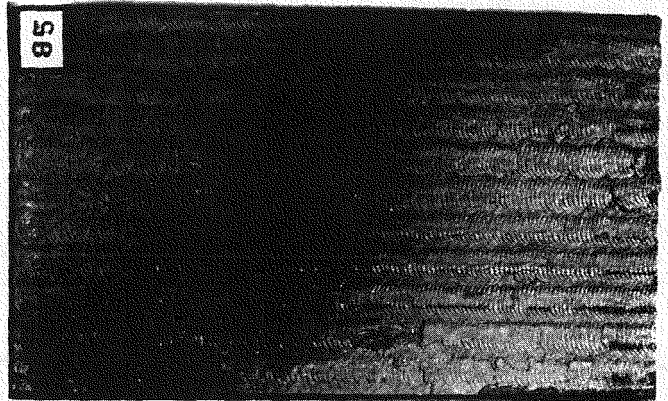
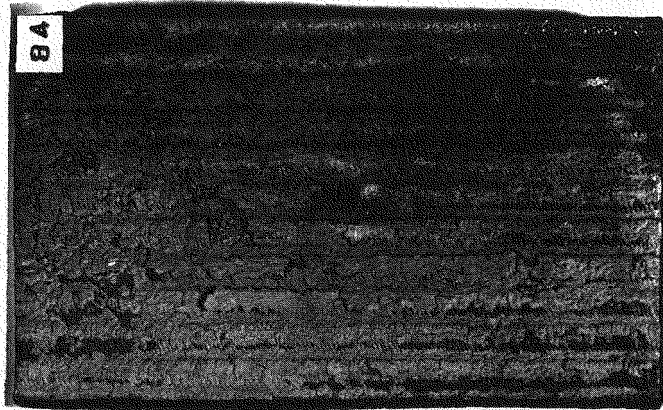


PN 1-75503

20X

FIGURE 13: Partial section of exposed 304L coupon 304-1.
Unetched

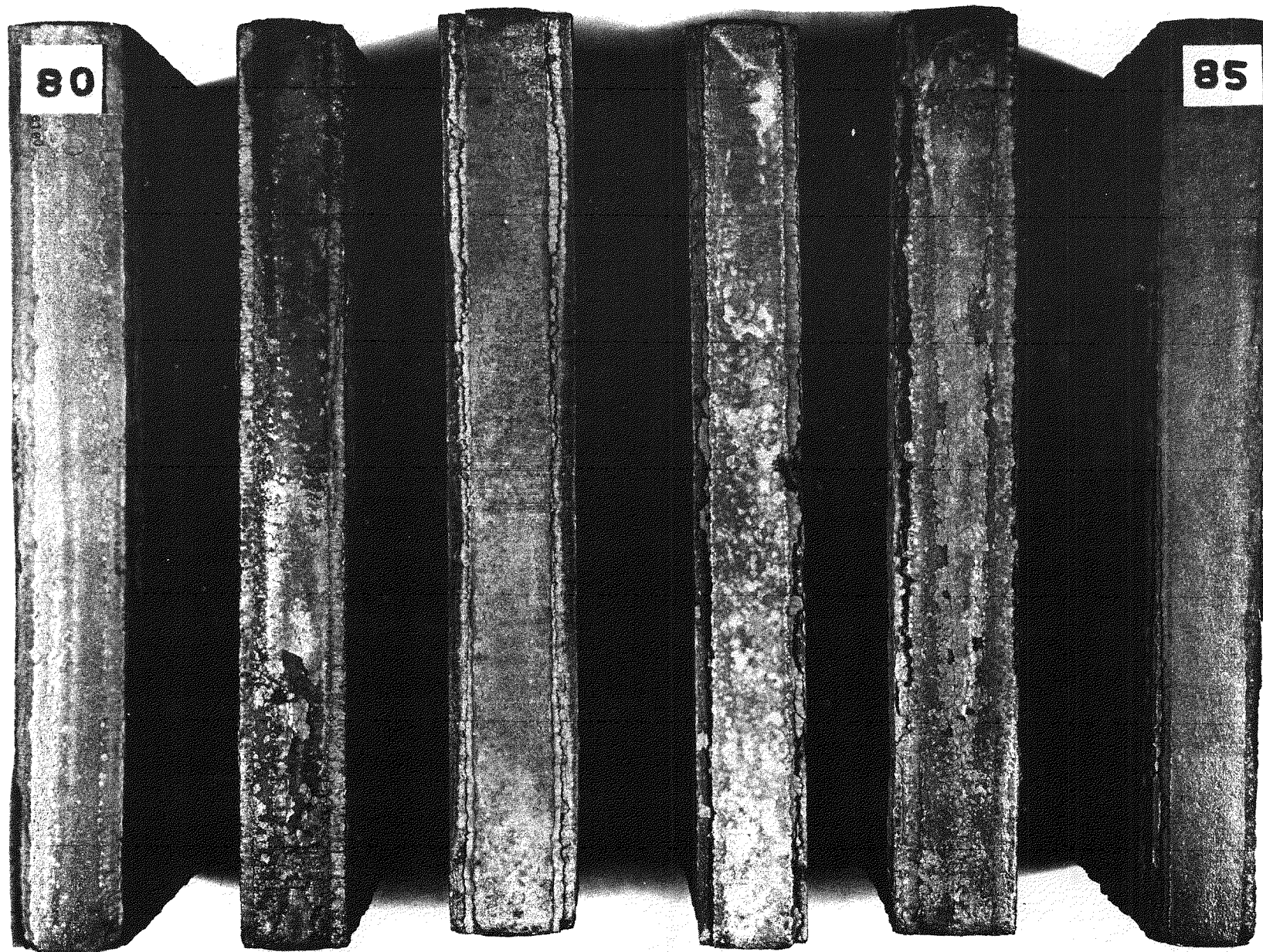
P.R. 4062.8



PN 2-75901

Approx. 3/10X

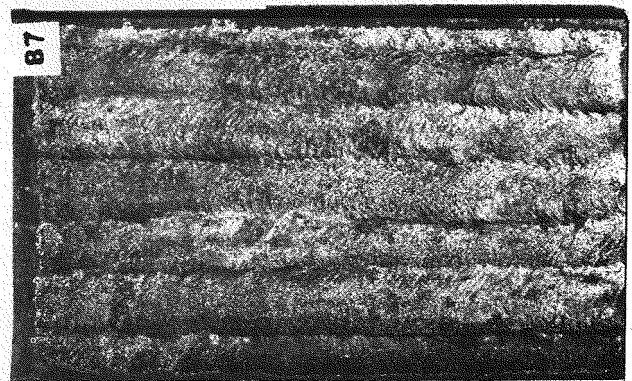
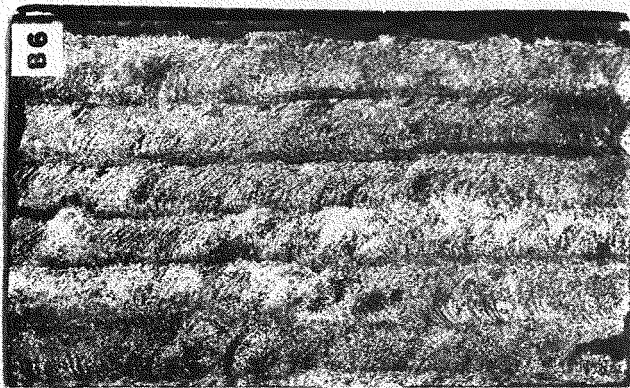
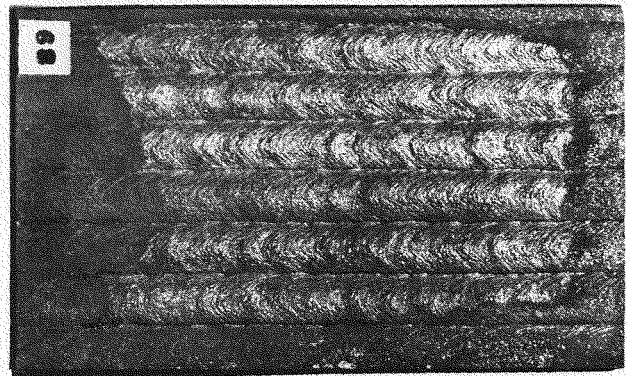
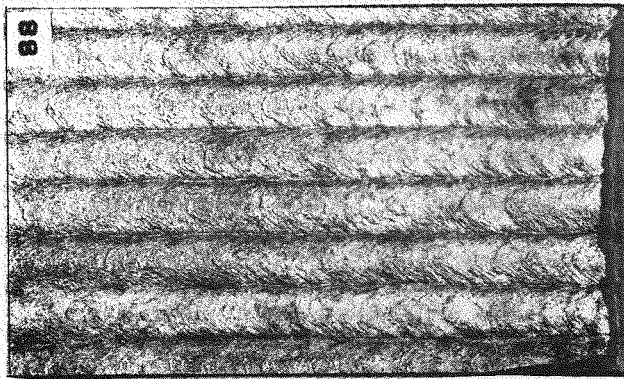
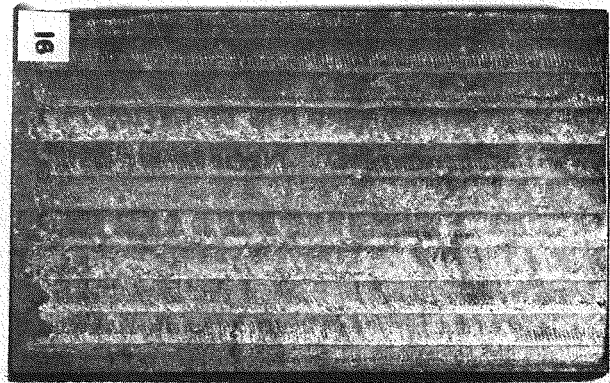
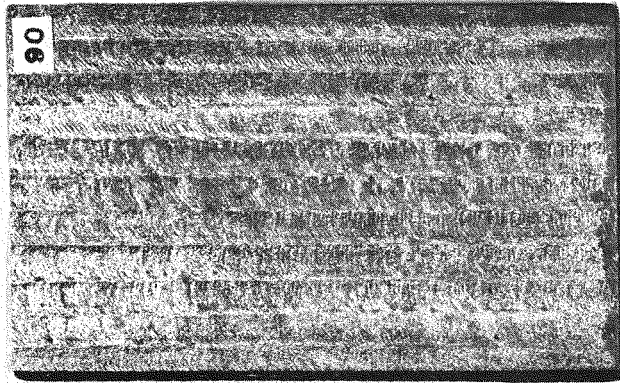
FIGURE 14: AWS-ER 309 overlays on 304L after exposure.



PN 2-75902

Approx. 1/2X

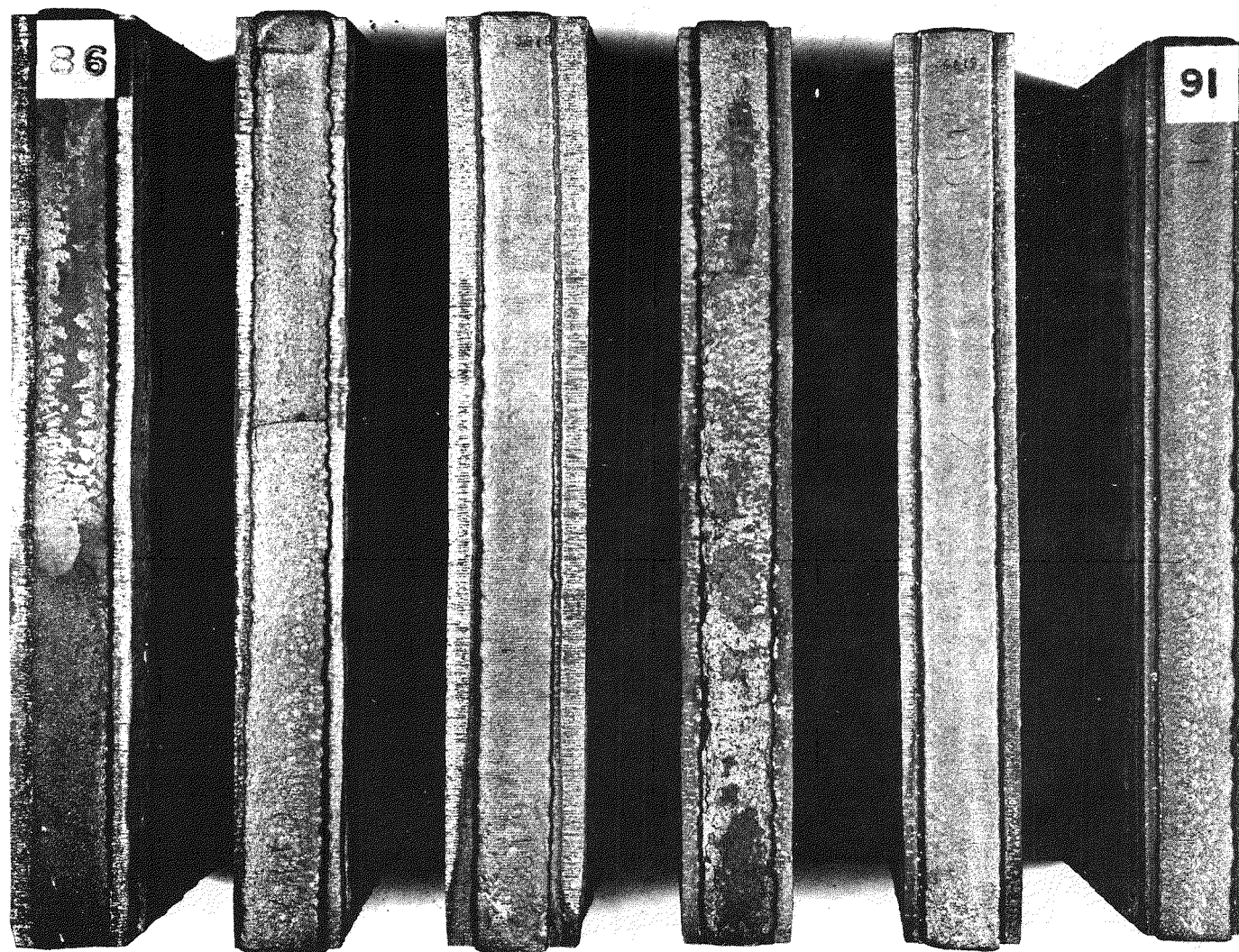
FIGURE 15: Edge view of 309-304L weldments after exposure.



PN 2-75903

Approx. 3/10X

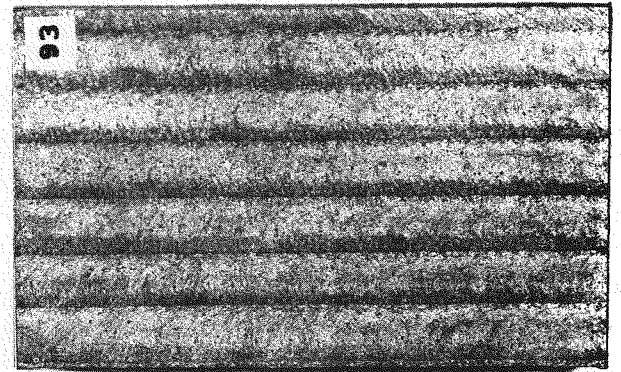
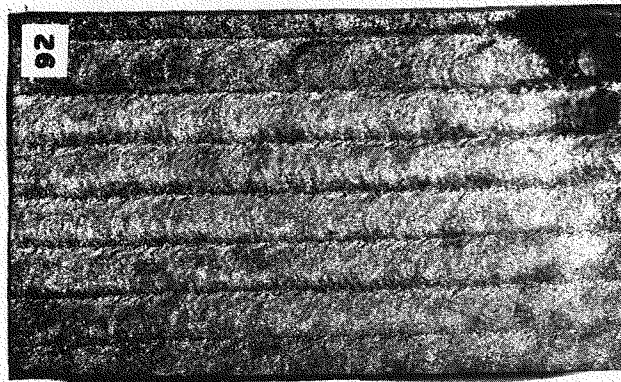
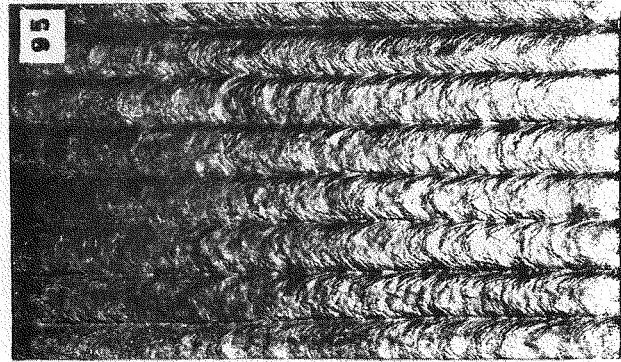
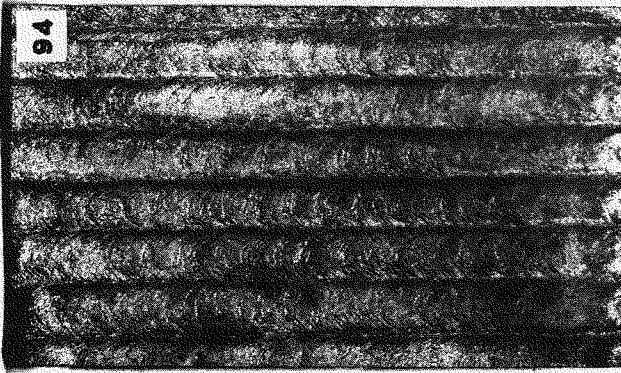
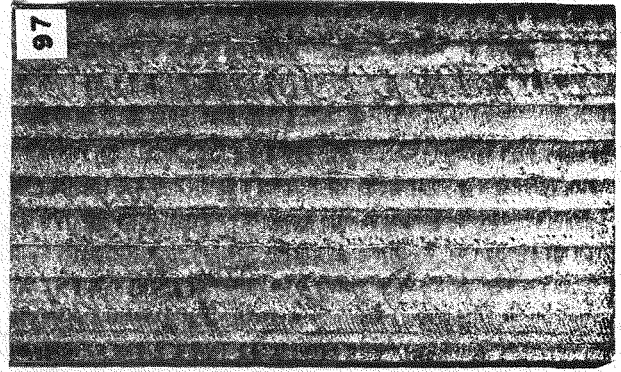
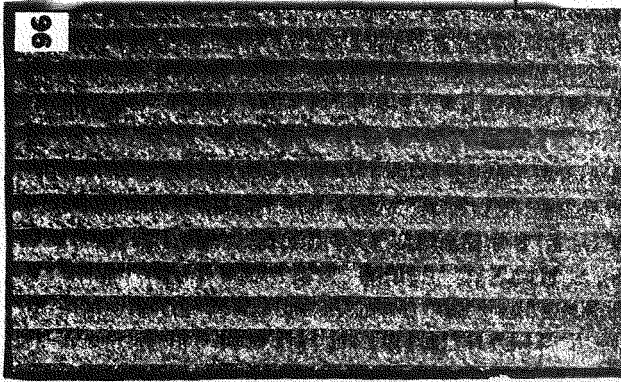
FIGURE 16: INCONEL FM72 overlays on 304L after exposure.



PN 2-75904

Approx. 1/2X

FIGURE 17: Edge view of INCONEL FM72-304L weldments after exposure.

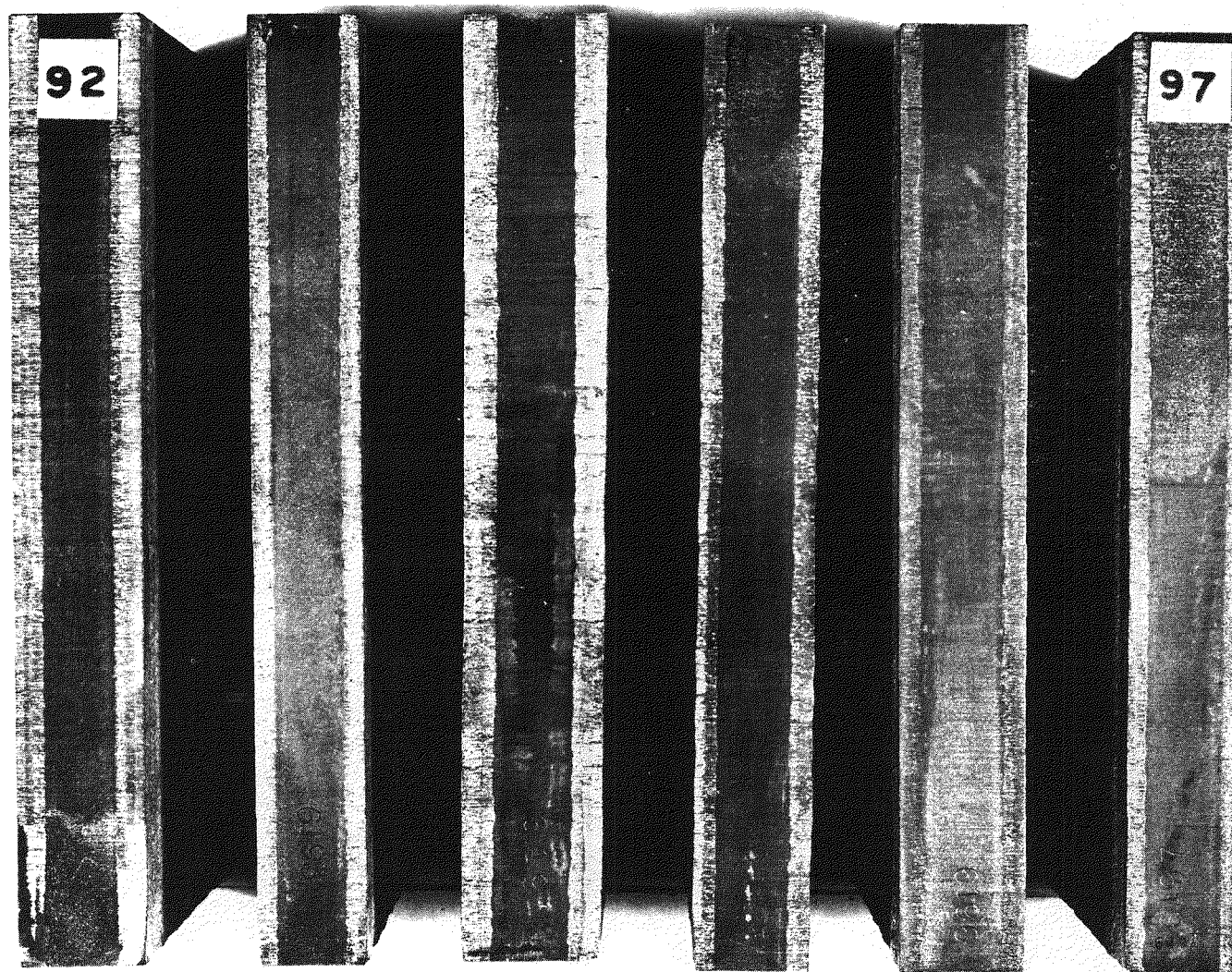


PN 2-75905

Approx. 3/10X

FIGURE 18: INCONEL FM72 overlays on 310SS after exposure.

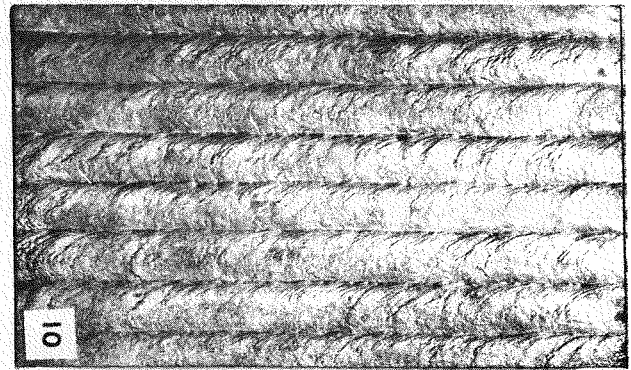
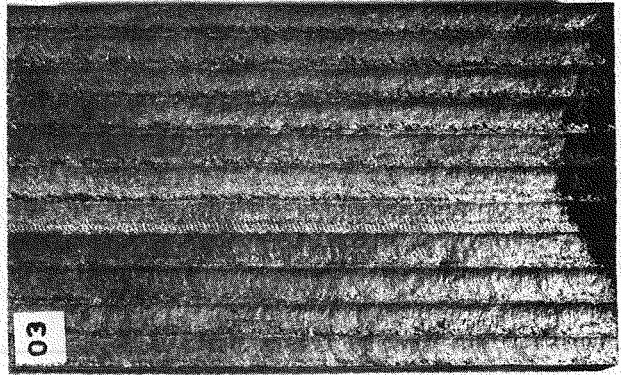
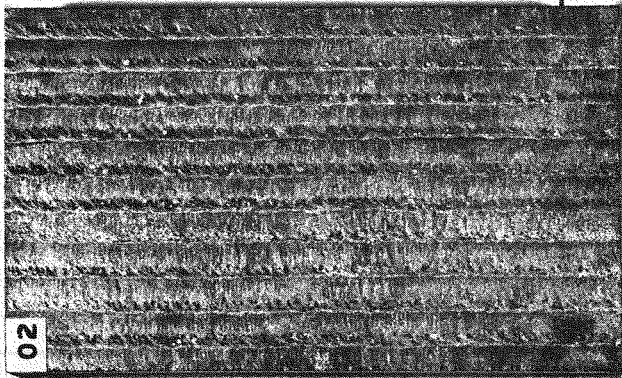
P.R. 4062.8



PN 2-75906

Approx. 1/2X

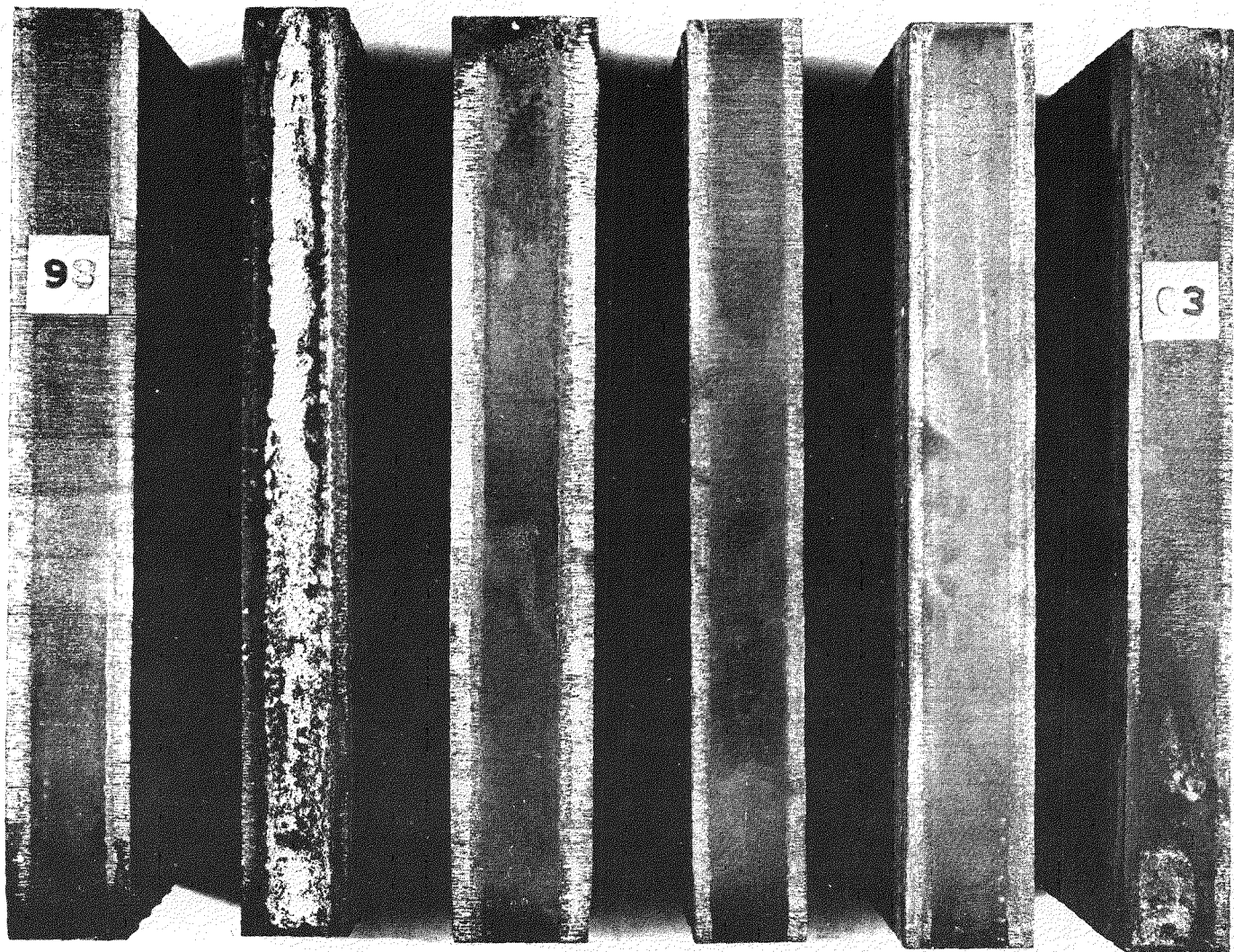
FIGURE 19: Edge view INCONEL FM72-310SS weldments after exposure.



PN 2-75907

Approx. 3/10X

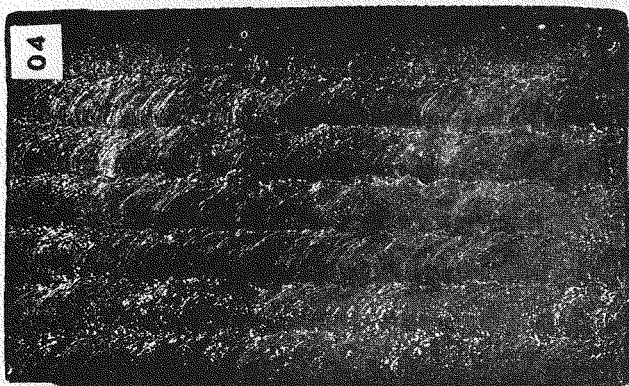
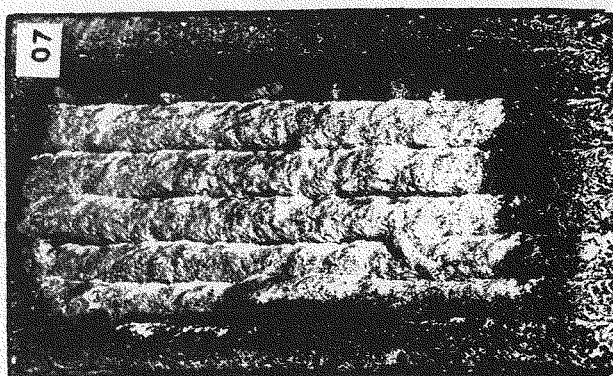
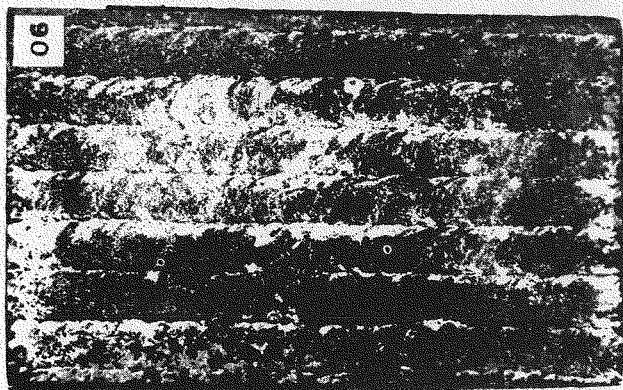
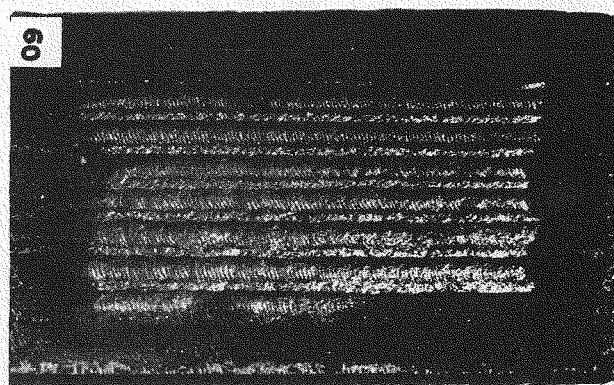
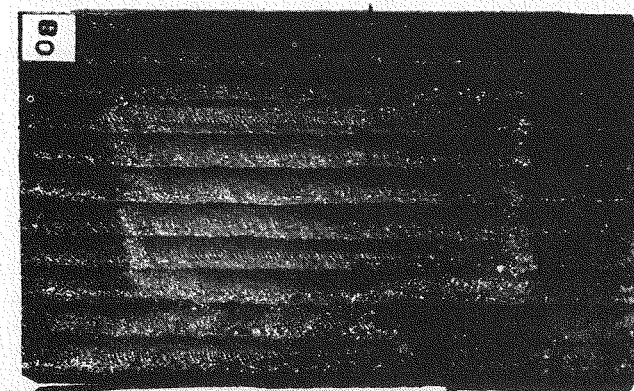
FIGURE 20: INCONEL FM72 overlays on INCOLOY alloy 800H after exposure.



PN. 2-75908

Approx. 1/2X

FIGURE 21: Edge view, INCONEL FM72 overlays - 800H weldments after exposure.

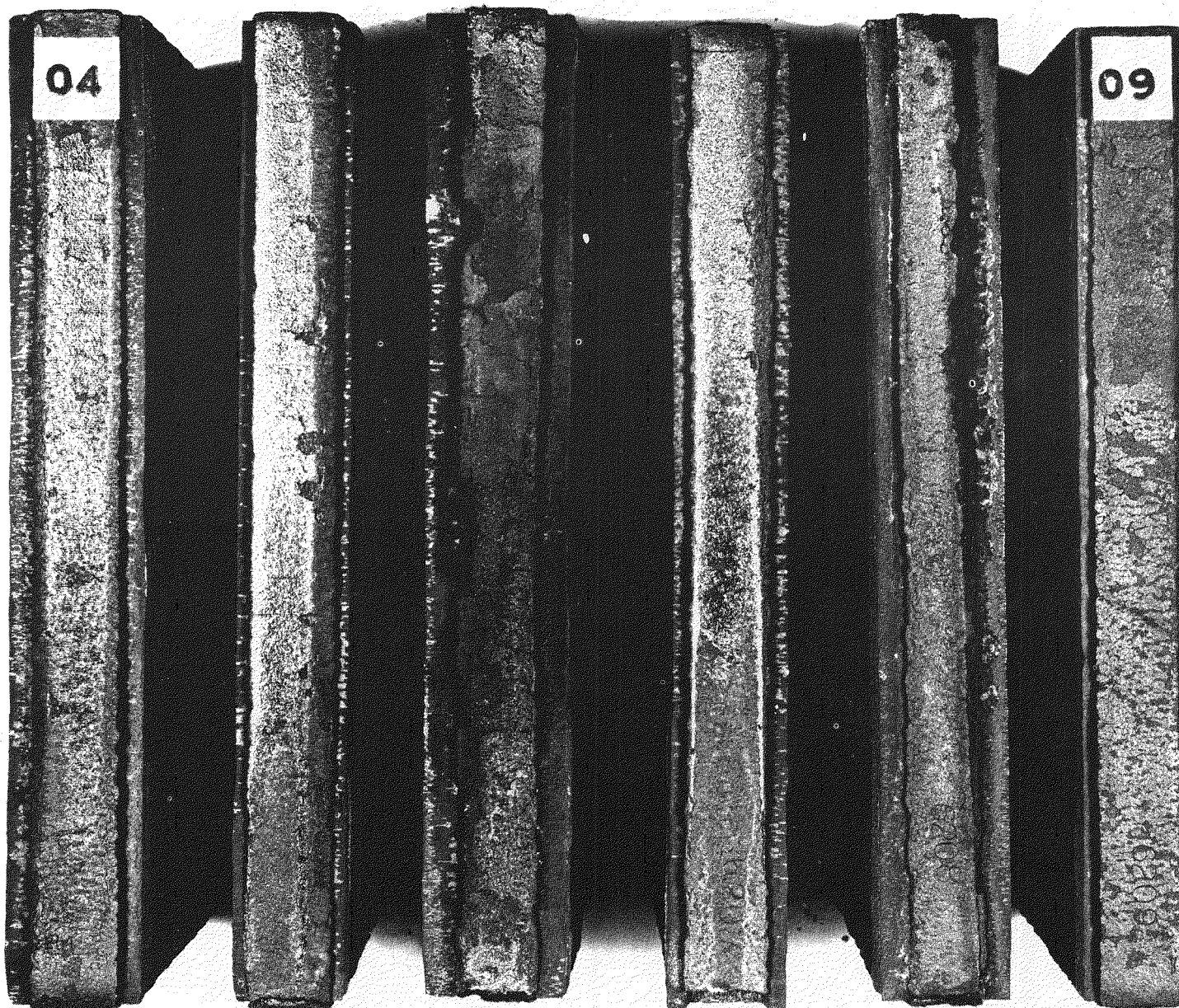


PN 2-75909

Approx. 3/10X

FIGURE 22: Filler Metal R139 overlays on 304L after exposure.

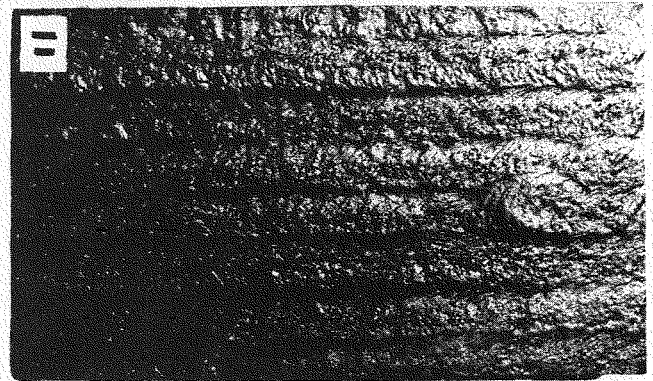
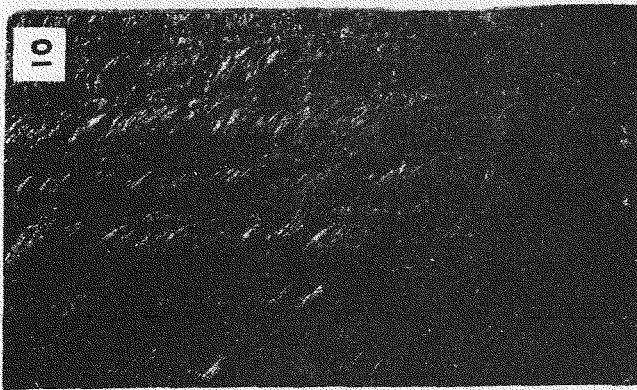
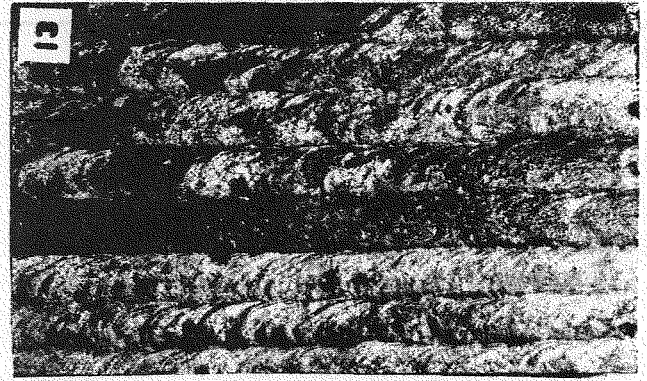
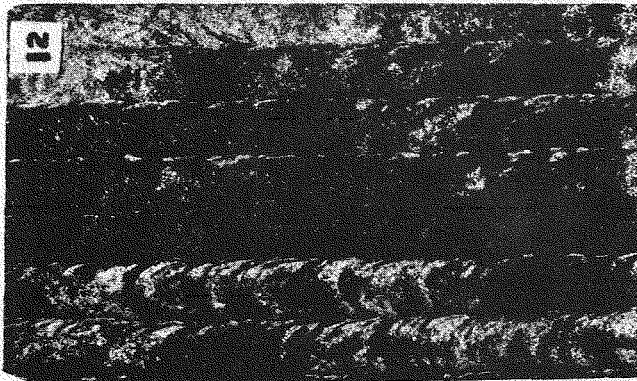
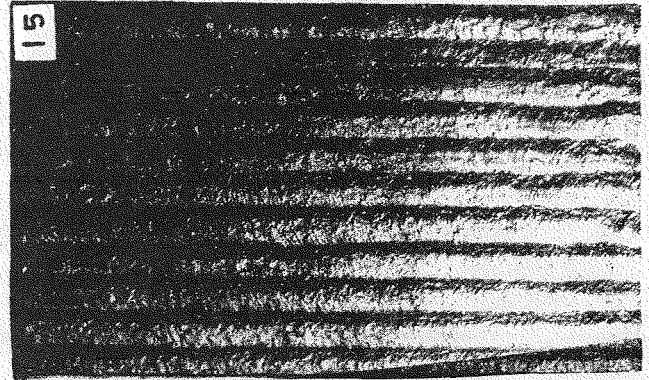
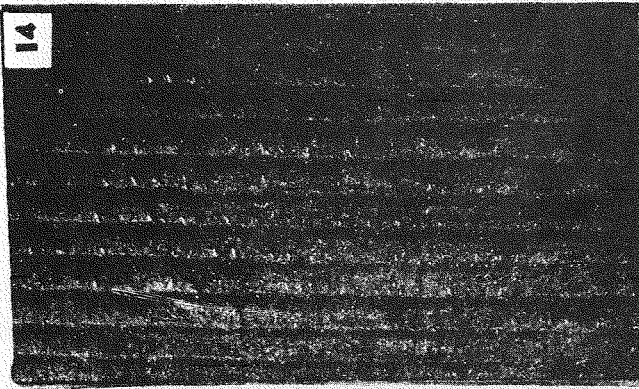
P.R. 4062.8



PN 2-75910

Approx. 1/2X

FIGURE 23: Edge view, Filler Metal R139-304L weldments after exposure.

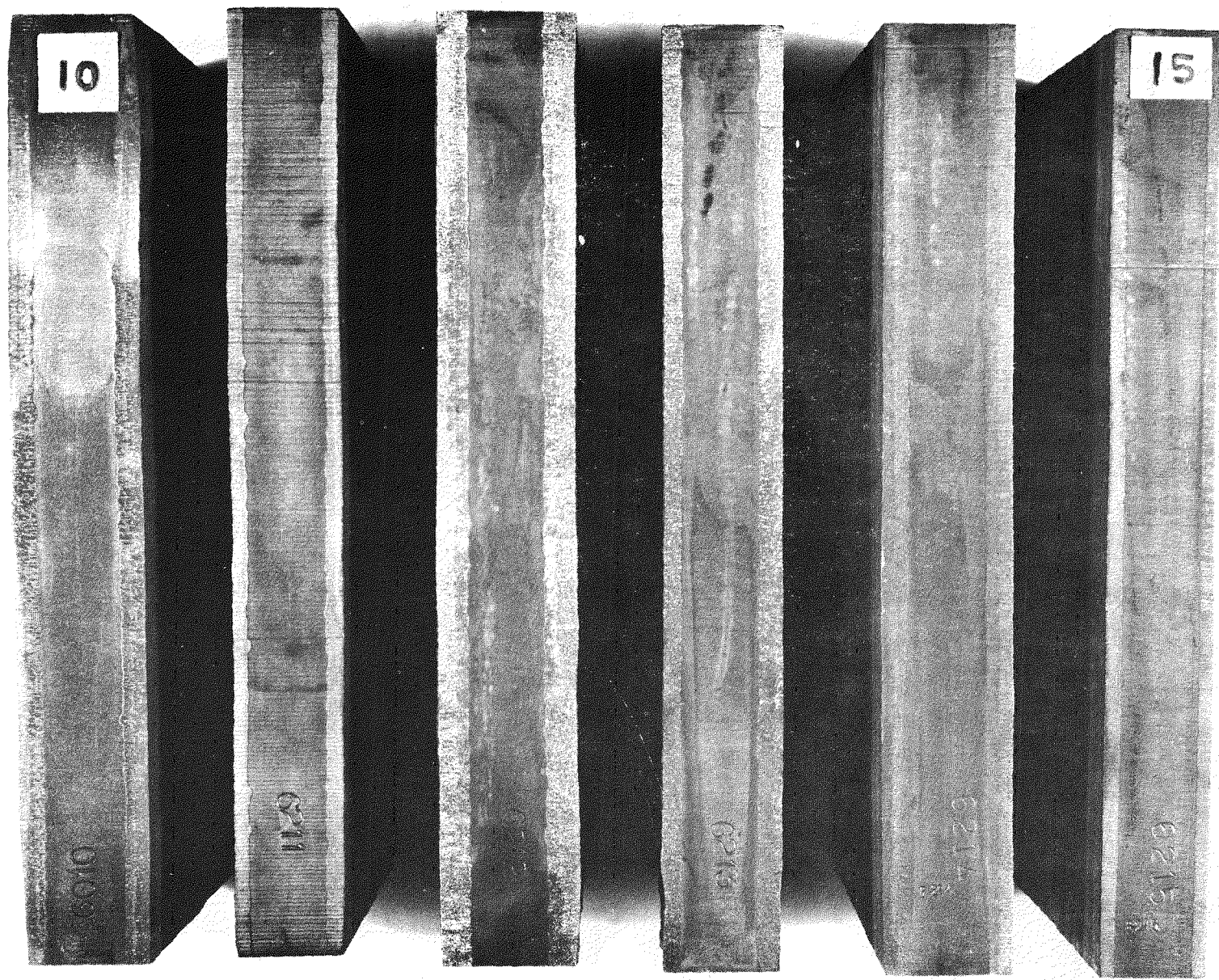


PN 2-75911

Approx. 3/10X

FIGURE 24: Filler Metal R139 overlays on 310SS after exposure.

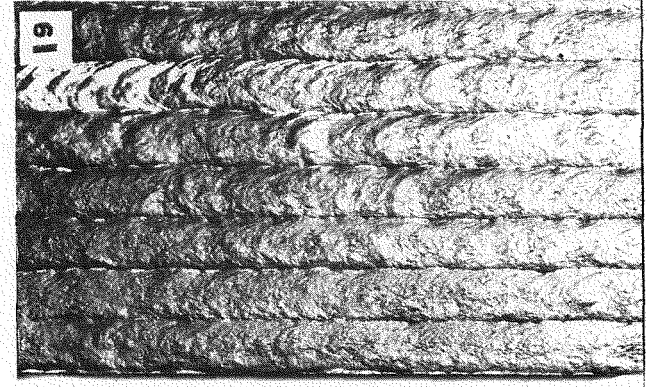
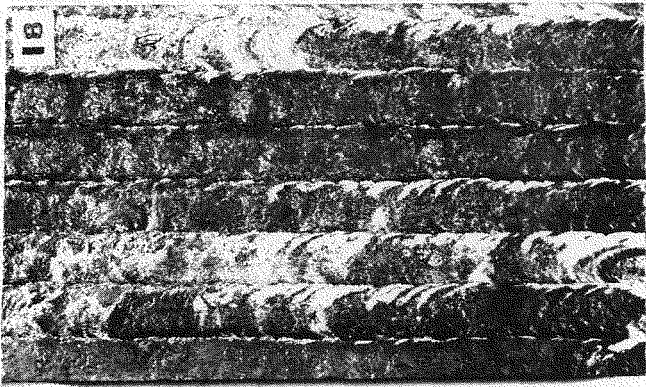
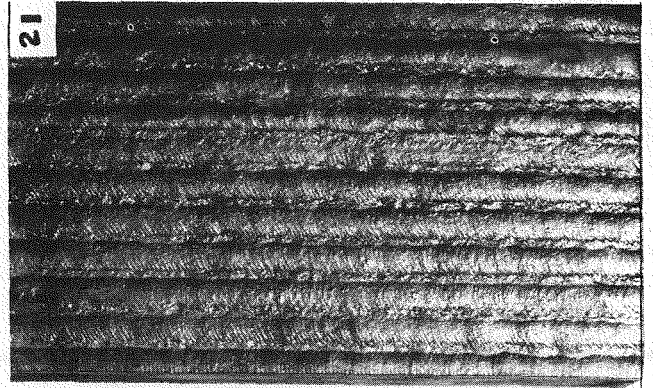
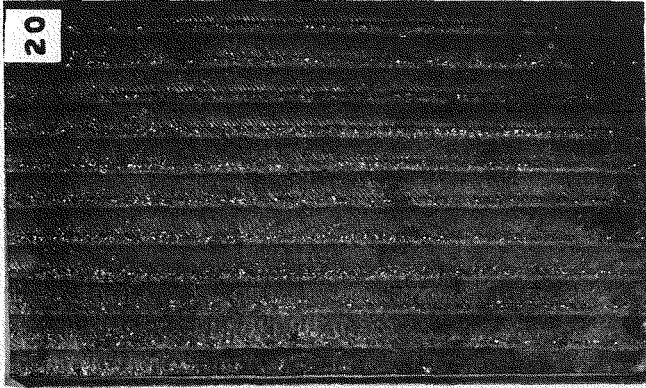
P.R. 4062.8



PN 2-75912

Approx. 1/2X

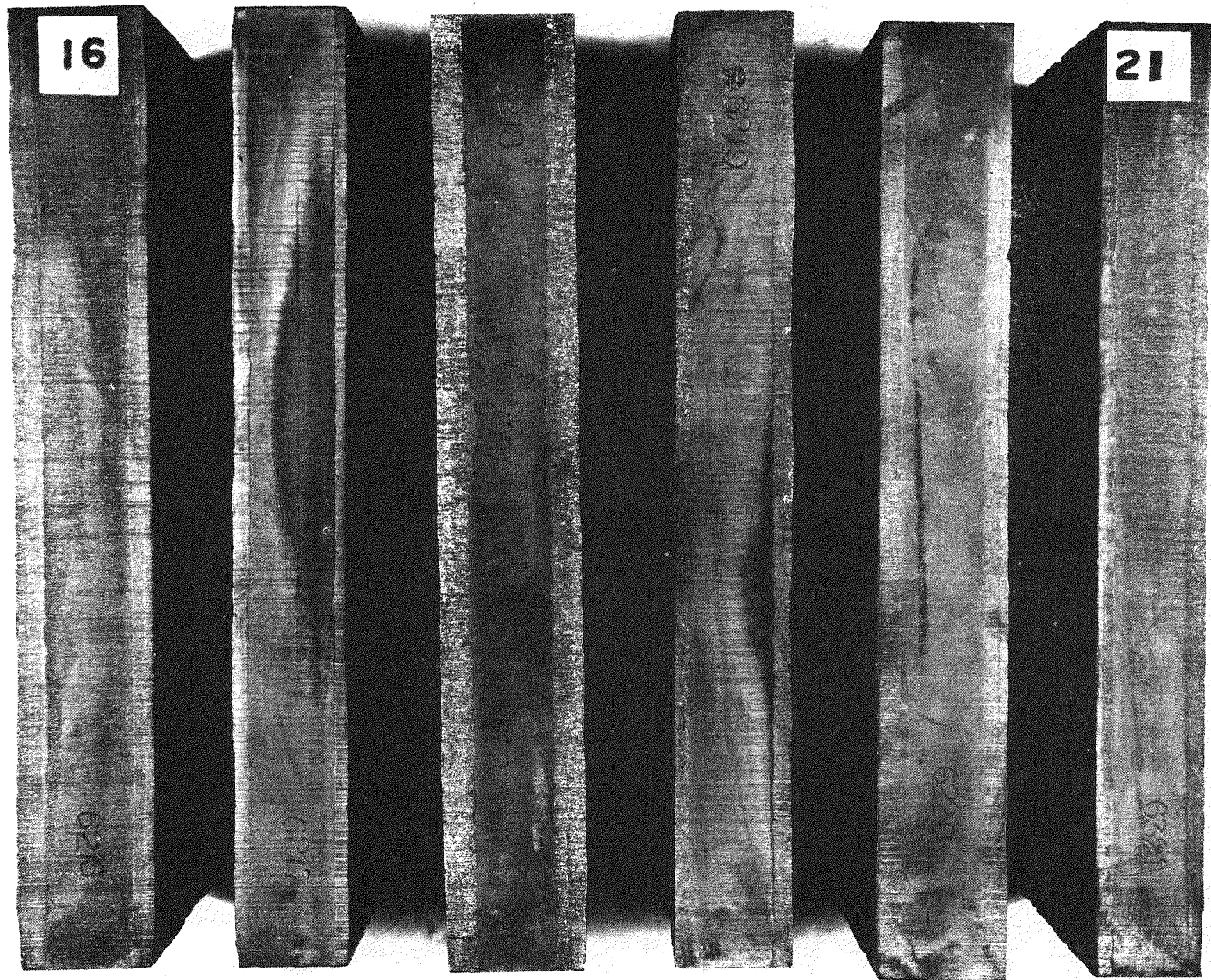
FIGURE 25: Edge view-Filler Metal R139-310SS weldments after exposure.



PN 2-75913

Approx. 3/10X

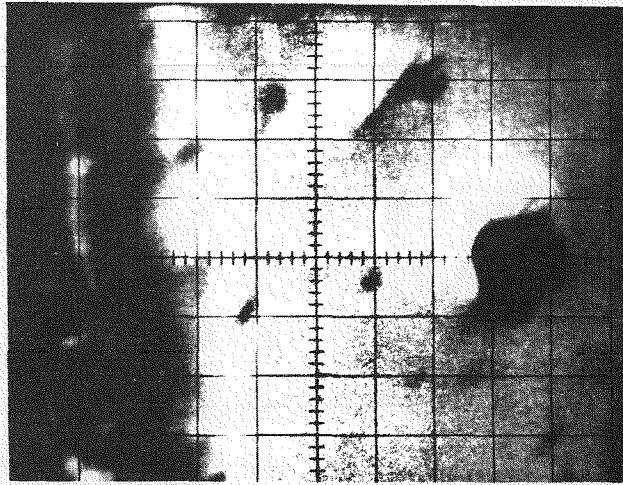
FIGURE 26: Filler Metal R139 overlays on INCOLOY alloy 800H after exposure.



PN 2-75914

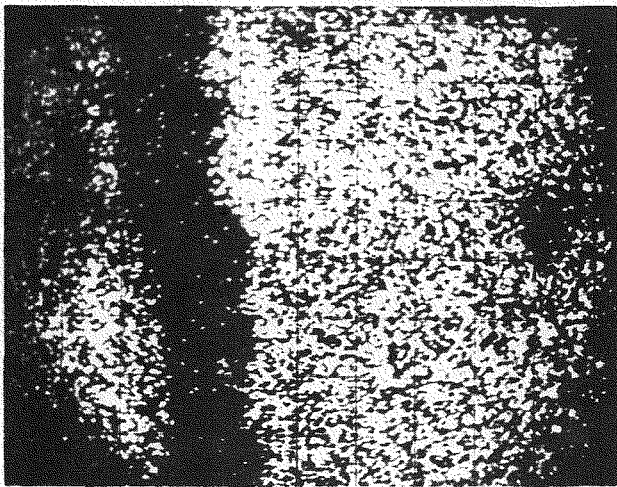
Approx. 1/2X

FIGURE 27: Edge view-Filler Metal R139-INCOLOY alloy 800H weldments after exposure.



6190

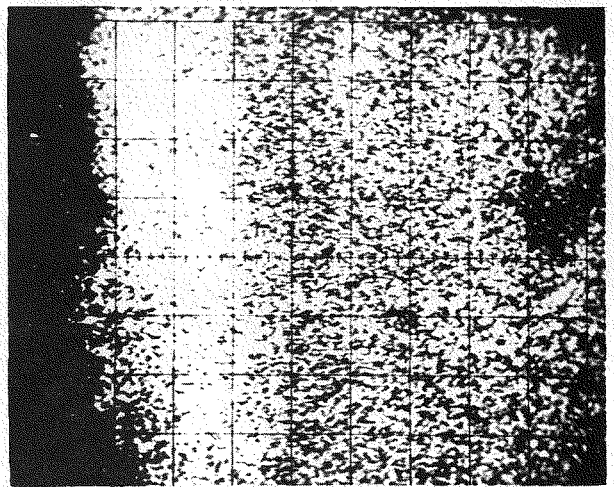
2000X



6190

Fe

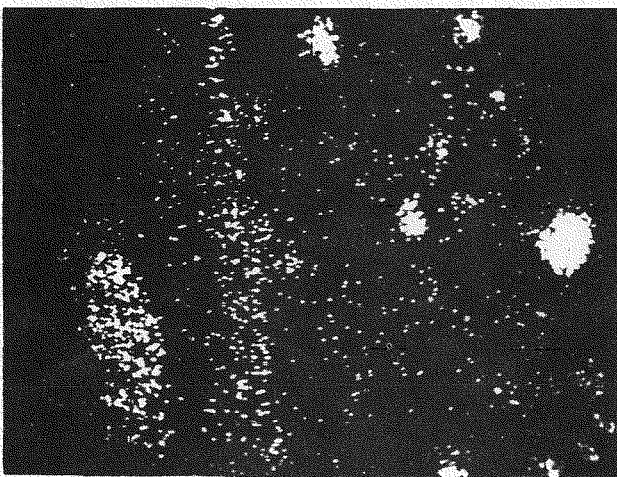
2000X



6190

Cr

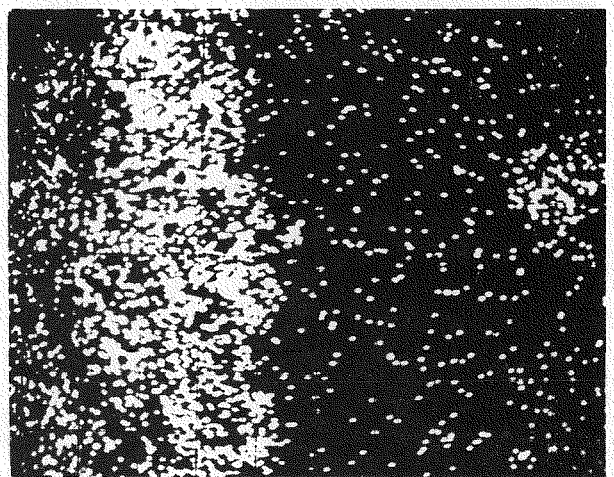
2000X



6190

Ti

2000X



6190

O₂

2000X

FIGURE 28: X-ray scans of scale and overlay of W6190.

P.R. 4062.8

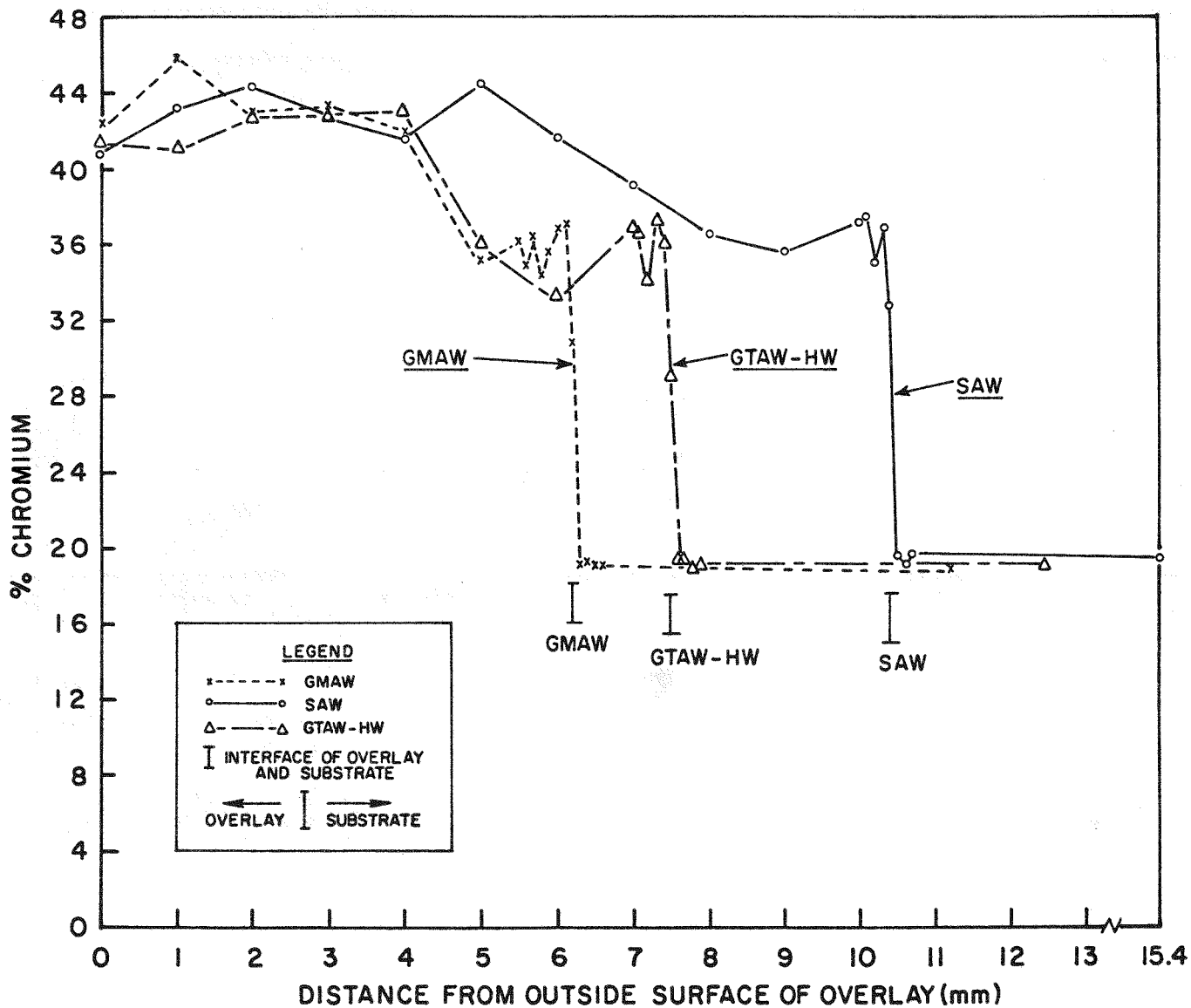


FIGURE 29 - CHROMIUM DISTRIBUTION IN INCONEL FILLER METAL 72-304 L WELDMENTS - AS WELDED - DOUBLE LAYER.

P.R. 4062.8

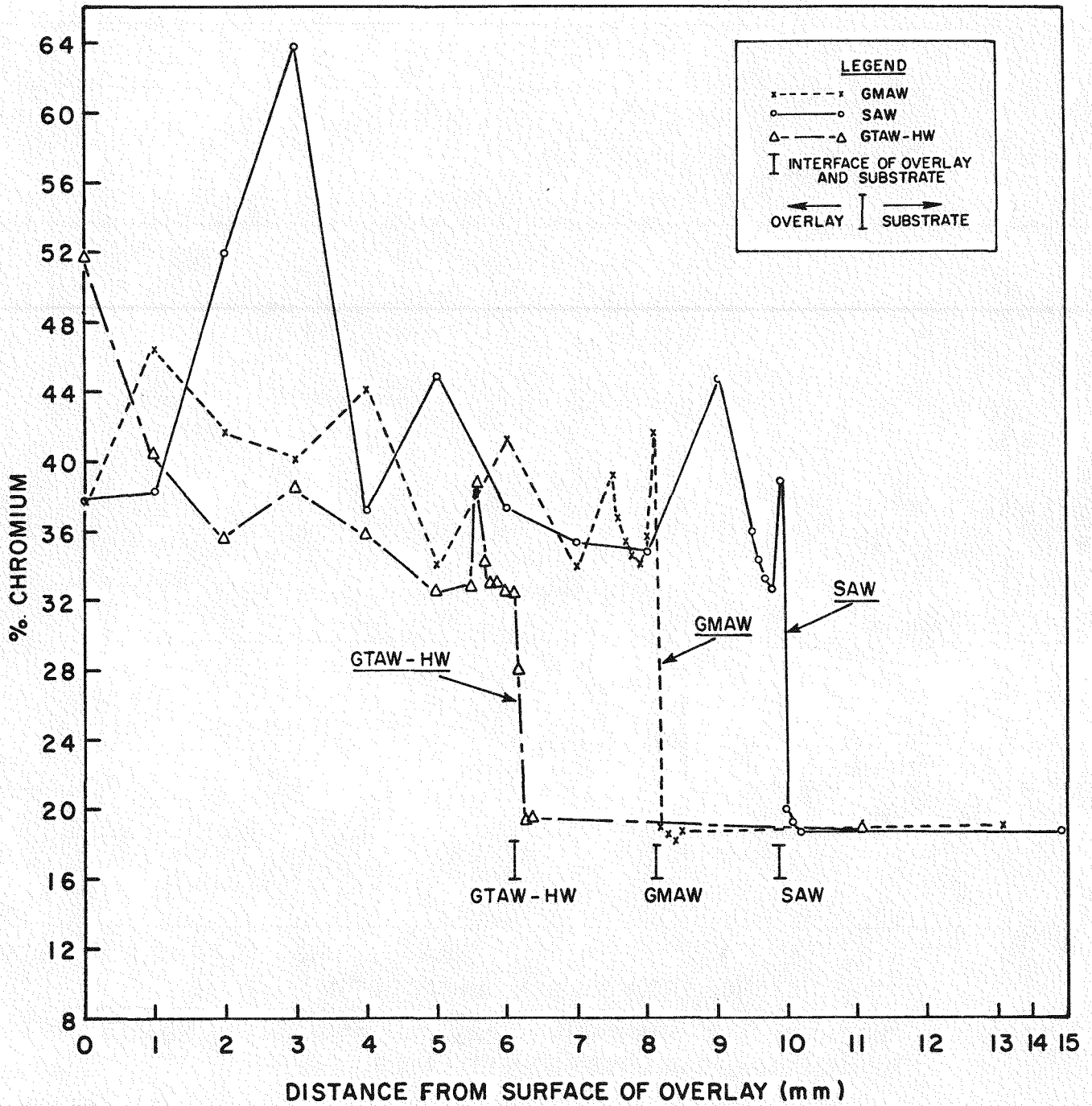


FIGURE 30-CHROMIUM DISTRIBUTION IN INCONEL FILLER METAL 72-304 L WELDMENTS AFTER EXPOSURE IN A CGA-DOUBLE LAYER.

P.R. 4062.8

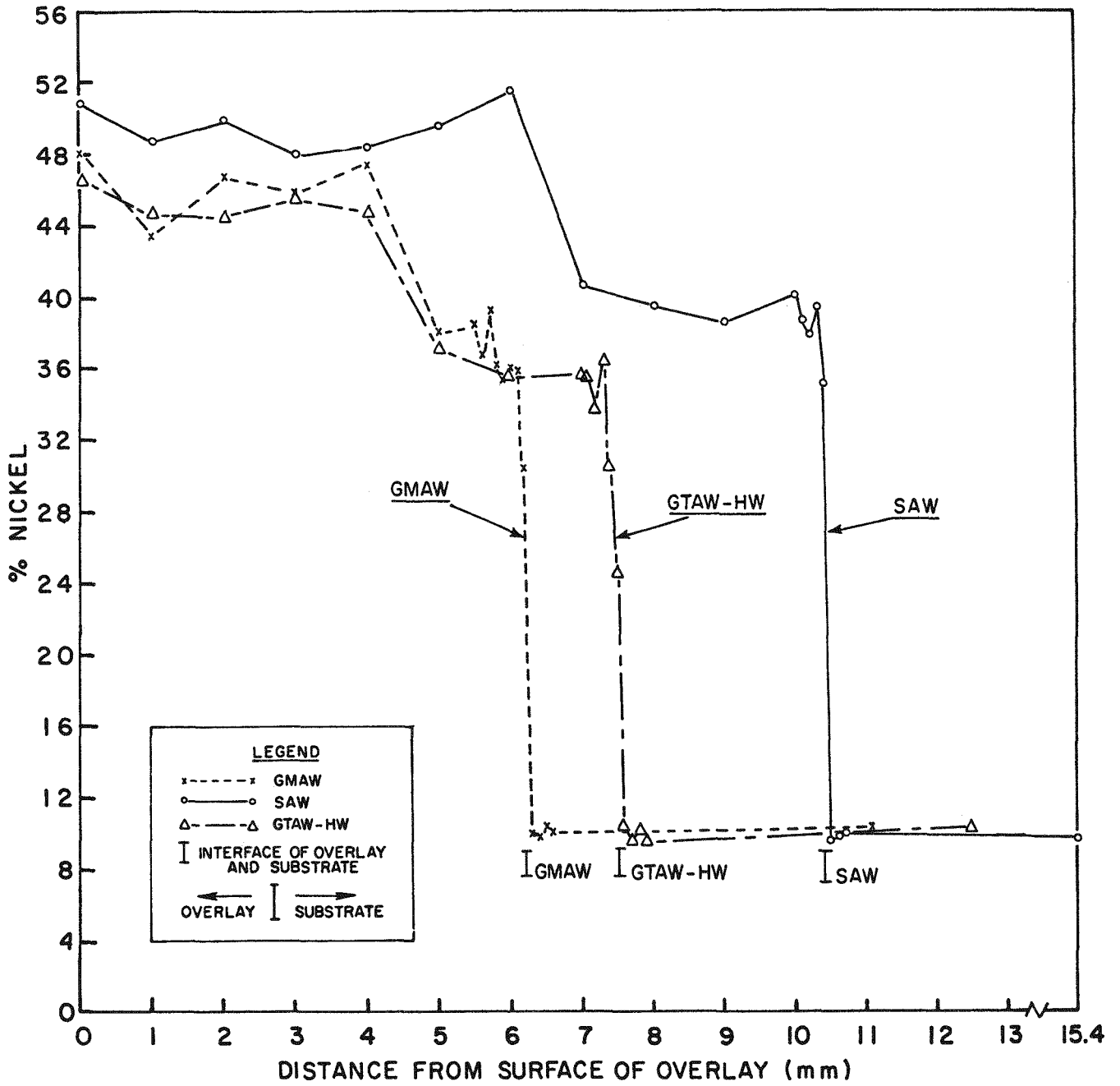


FIGURE 31 - NICKEL DISTRIBUTION IN INCONEL FILLER METAL 72-304 L WELDMENTS - AS WELDED - DOUBLE LAYER.

P.R. 4062.8

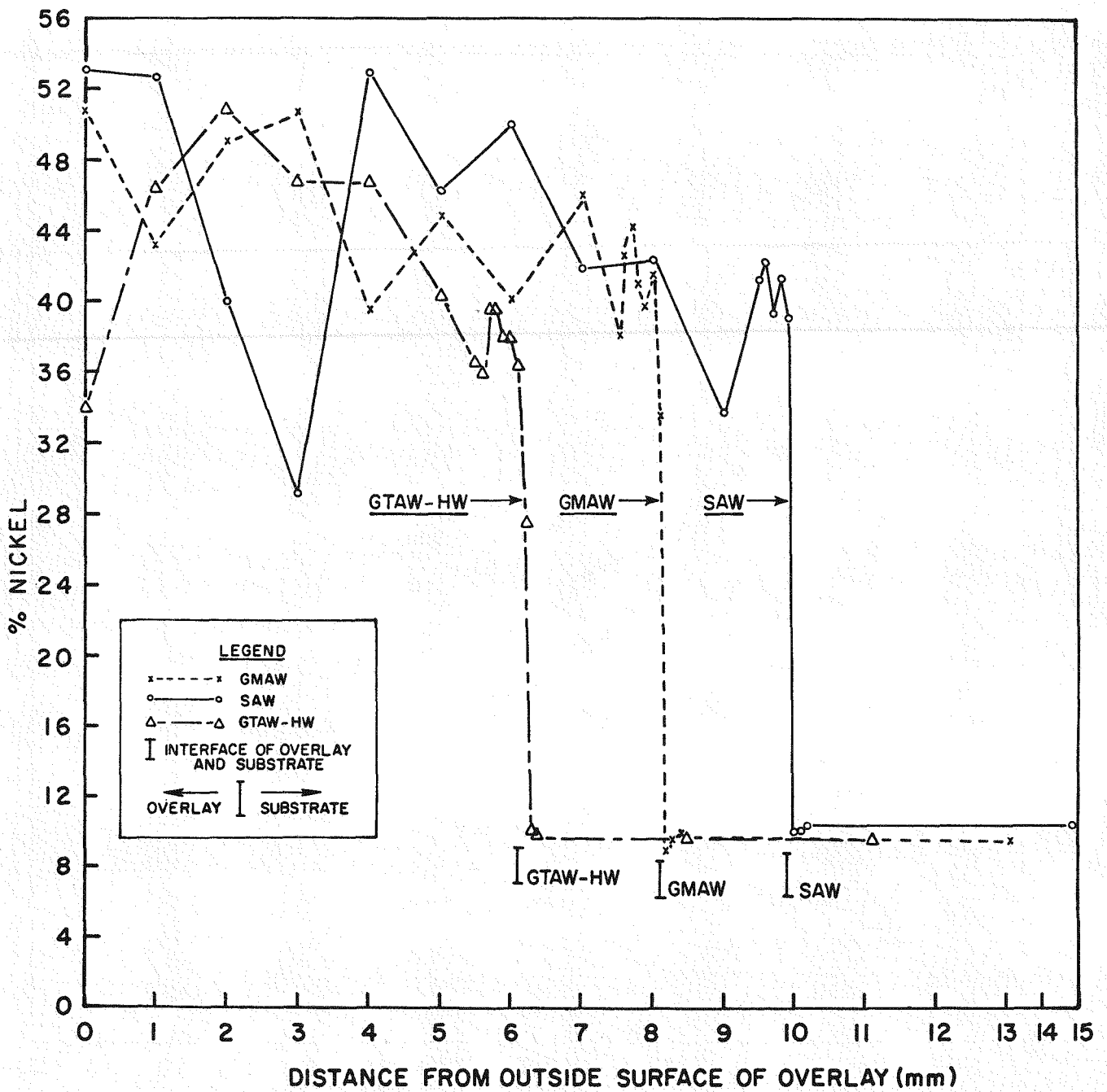


FIGURE 32-NICKEL DISTRIBUTION IN INCONEL FILLER METAL 72-304 L WELDMENTS AFTER EXPOSURE IN A CGA - DOUBLE LAYER.

P.R. 4062.8

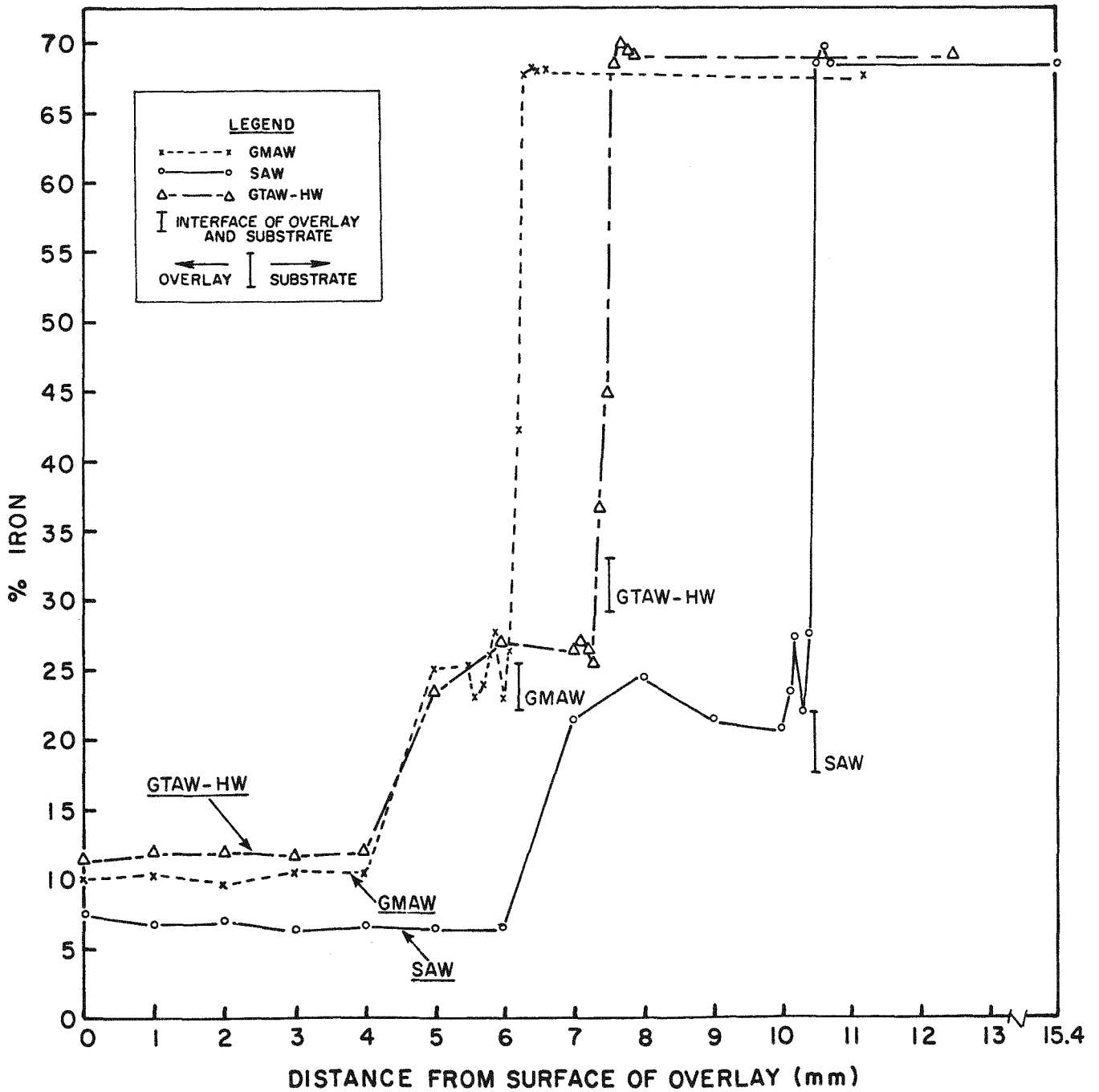


FIGURE 33- IRON DISTRIBUTION IN INCONEL FILLER METAL 72-304L WELDMENTS- AS WELDED - DOUBLE LAYER.

P.R. 4062.8

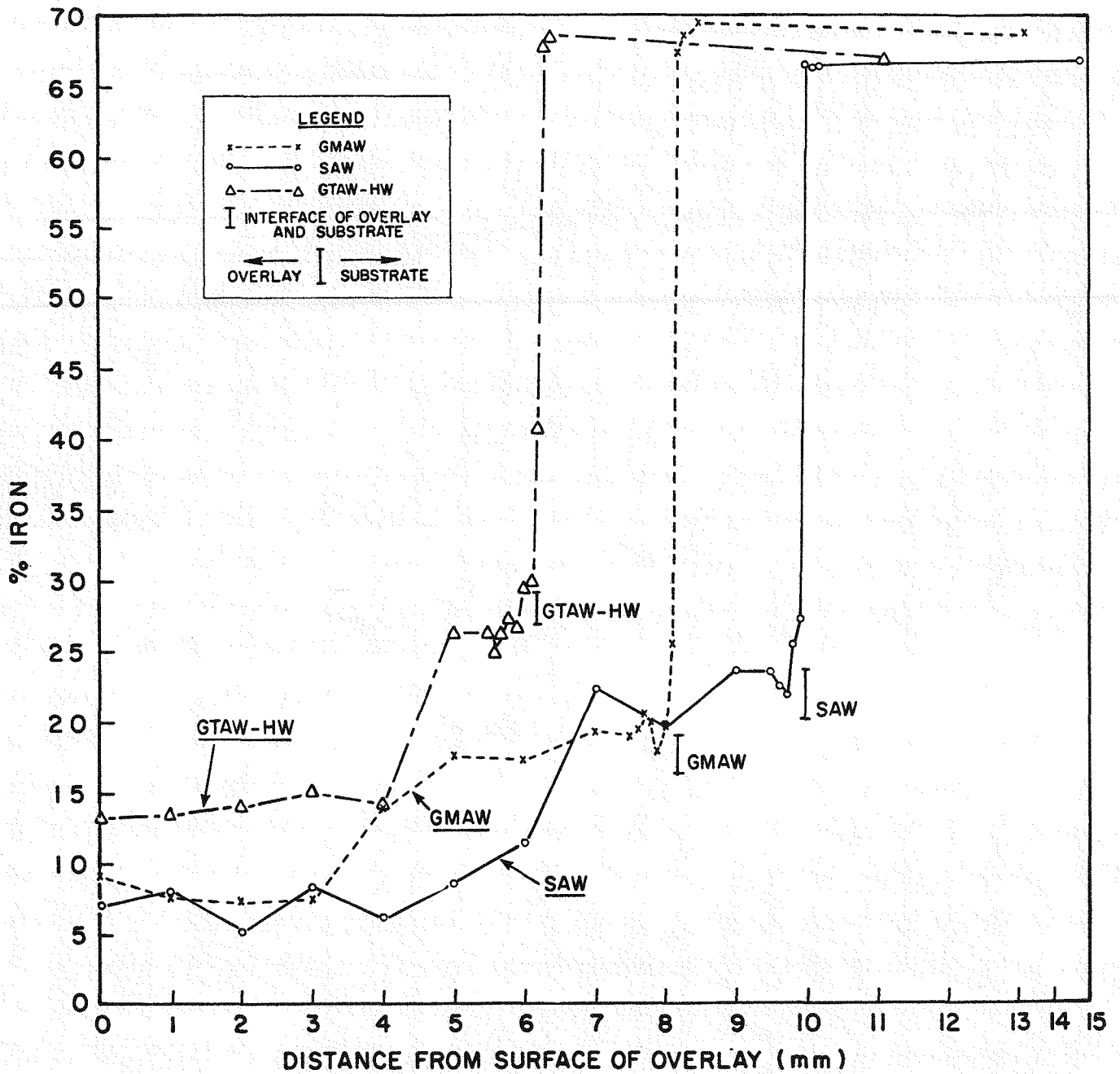


FIGURE 34 - IRON DISTRIBUTION IN INCONEL FILLER METAL 72-304 L WELDMENTS AFTER EXPOSURE - DOUBLE LAYER.

P.R. 4062.8

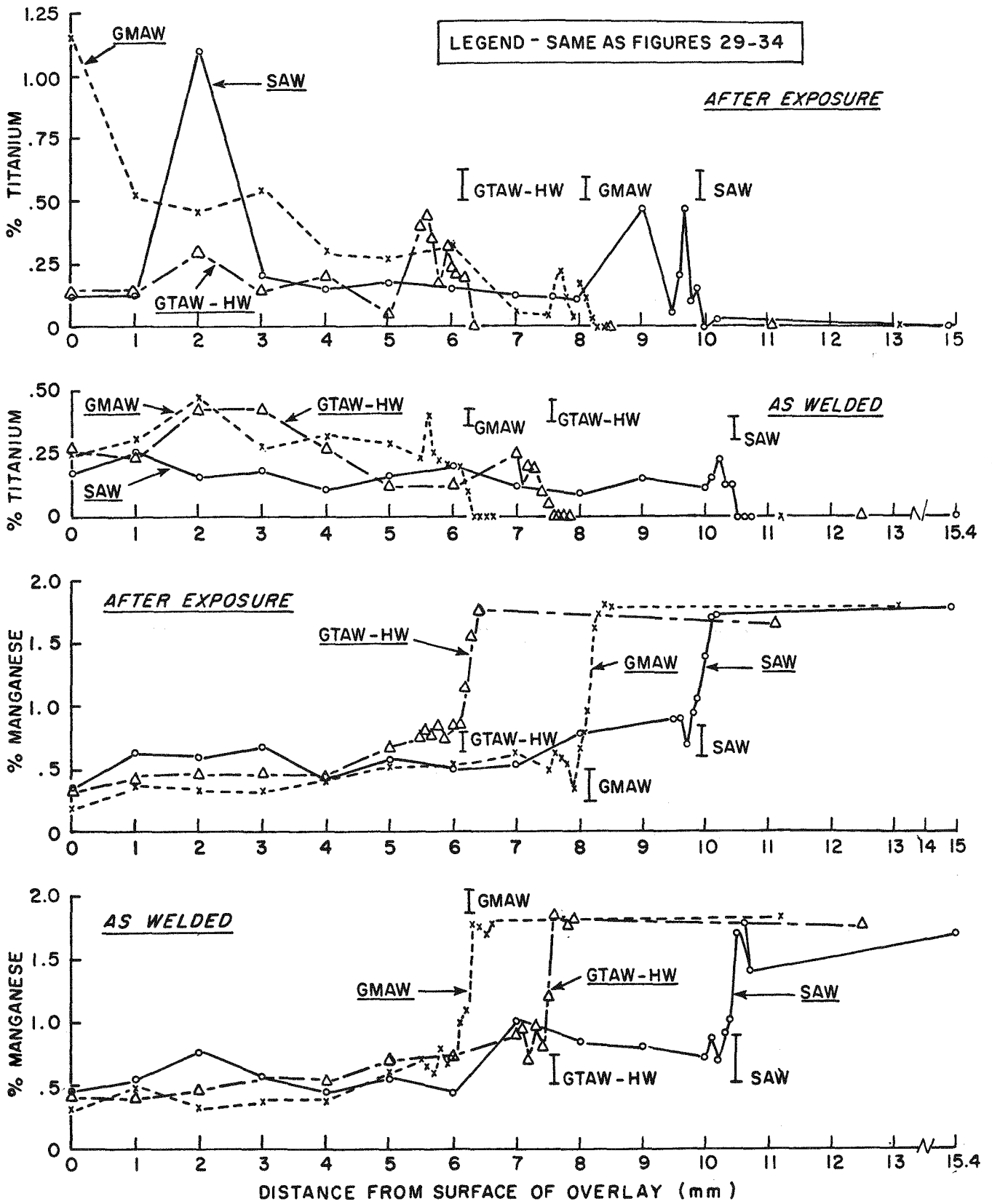


FIGURE 35-DISTRIBUTION OF MANGANESE AND TITANIUM IN INCONEL FILLER METAL 72-304 L. WELDMENTS, BEFORE AND AFTER EXPOSURE IN A CGA - DOUBLE LAYER.

P.R. 4062.8